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Soňa Benecká, Ludmila Fadejeva, and Martin Feldkircher *

Abstract

This paper investigates the international effects of a euro area monetary policy shock, focusing on countries from Central, Eastern, and Southeastern Europe (CESEE). To that end, we use a global vector autoregressive (GVAR) model and employ shadow rates as a proxy for the monetary policy stance during normal and zero-lower-bound periods. We propose a new way of modeling euro area countries in a multi-country framework, accounting for joint monetary policy, and a novel approach to simultaneously identifying shocks. Our results show that in most euro area and CESEE countries, prices adjust and output falls in response to a euro area monetary tightening, but with a substantial degree of heterogeneity.

Abstrakt

Tento článek zkoumá mezinárodní efekty měnověpolitických šoků z eurozóny, a to se zaměřením na ekonomiky střední, východní a jihovýchodní Evropy (CESEE). Pro tento účel využíváme globální vektor-autoregresivní model (GVAR) a stínové sazby jako proxy pro vývoj postoje měnové politiky v dobách normálních i v době omezení spodní (nulovou) hranicí sazeb. Nabízíme nový způsob modelování zemí eurozóny v rámci uskupení více zemí při současném modelování jednotné měnové politiky a nový přístup k současné identifikaci šoků. Naše výsledky ukazují, že ve většině zemí eurozóny a CESEE se v reakci na zpřísnění měnové politiky v eurozóně ceny přizpůsobí a výstup poklesne, ale se značným stupněm heterogenity.

JEL Codes: C32, E32, F44, O54.
Keywords: Euro area monetary policy, global vector autoregression, spillovers.

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Nontechnical Summary

This paper aims to assess both the domestic and international macroeconomic effects of euro area monetary policy on Central, Eastern, and Southeastern Europe (CESEE). For that purpose, we need a multi-country model that is able to take into account the economic links between the countries of interest and allow for spillovers. The model must also reflect two important factors. In the period under review, several central banks, including the ECB, implemented unconventional measures, such as the asset purchase program. Second, there is a degree of heterogeneity in the responses of euro area countries to monetary policy shocks, thus affecting the pattern for direct/indirect spillovers to CESEE.

Our paper contributes to the literature in at least three respects. First, we use a GVAR and shadow rates derived from term structure models to capture the overall effect of conventional and unconventional monetary policy in the euro area. These mirror actual policy rates during normal times but become negative during periods when the zero lower bound is binding, and are thus a more accurate indicator of the monetary policy stance for the sample period considered in this study. Since some economies in the CESEE region also reached the zero lower bound and/or implemented unconventional monetary policies, we also calculate shadow rates for these countries. This aspect is often neglected (for example in Chen et al., 2017; Hájek and Horváth, 2018; Horváth and Voslářová, 2016) and introduces an asymmetry into the model impeding correct assessment of the transmission of the euro area shock to CESEE countries.

Second, following Burriel and Galesi (2018), Georgiadis (2015), and Feldkircher et al. (2017), we explicitly account for the heterogeneity among euro area countries by disaggregating the euro area to account for both country-specific and region-specific information. In the classical versions of GVAR models (e.g., Pesaran et al., 2004; Dees et al., 2007a) and in later versions such as in Eickmeier and Ng (2015) and Chen et al. (2017) the euro area is introduced as one region due to the common short-term interest rate and exchange rate for the member states. Despite the modeling benefits of using aggregated euro area data, there are some important drawbacks. For example, aggregation of euro area time series reduces the volatility of euro area variables, which might imply higher impulse responses to euro area shocks for smaller countries with strong linkages to the euro area region. Also, aggregation reduces the effect of trade and financial linkage differentiation between euro area countries. This is important, since the effects within the euro area itself are rather heterogeneous (see for example, Burriel and Galesi, 2018; Georgiadis, 2015; Mandler et al., 2016).

Third, we study the effect of a structural monetary policy shock using sign restrictions, in line with the conventional approach used in the GVAR literature (Burriel and Galesi, 2018; Georgiadis, 2015; Feldkircher and Huber, 2016; Chen et al., 2017; Fadejeva et al., 2017). Unlike previous studies, however, we propose a way to identify the euro area-specific shock simultaneously both for individual variables and for aggregated variables through a step procedure. This ensures that we preserve the economic interpretation of the shock on the individual country level.

Our results show that in most euro area and CESEE countries, prices adjust and real GDP decreases when monetary policy is tightened in the euro area. Our results also show a substantial degree of cross-country heterogeneity. The transmission of the effects is very heterogeneous. For example, in the Baltic countries, spillovers transmitted through third countries account for half of the total effect on real GDP. By contrast, spillovers to other CESEE countries are transmitted directly through their economic links to the euro area.

1. Introduction

In the wake of the 2008/09 global financial crisis, major central banks cut their policy rates to stimulate economic growth and consumer price inflation. As a consequence, the room for conventional monetary policy was quickly eroded and nominal interest rates hit the zero lower bound. Against this background, other non-standard/unconventional forms of monetary policy were implemented. This makes it more complex to assess the overall monetary policy stance. Moreover, changes in the monetary policy stance do not only affect the domestic economy. There has been a discussion about the possible negative effects of the unconventional monetary policy of the ECB and the Fed on small open economies after the introduction of such measures. Monetary policy easing in the advanced economies may have stimulated significant capital inflows and exchange rate appreciation, thereby threatening external competitiveness. In addition, some of these flows could have fueled credit and asset price booms, amplifying financial fragilities. Cheap external funding also has an impact on exposures to foreign currency-denominated debt on domestic balance sheets.

For that purpose we need a multi-country model that is able to take into account the economic links between the countries of interest. As such, the GVAR model proposed by Hashem M. Pesaran and co-authors (Pesaran et al., 2004; Garrat et al., 2006) has been widely used in the literature. It provides a coherent way to model contemporaneously a set of countries taking into account their interactions through trade and financial linkages. Recent papers have applied the framework to the analysis of house price shocks (Cesa-Bianchi, 2013), credit supply shocks (Eickmeier and Ng, 2015), cost-push shocks (Galesi and Lombardi, 2013), financial stress shocks (Dovern and van Roye, 2014), monetary policy shocks (Feldkircher and Huber, 2016), and liquidity shocks during the Great Recession of 2007—2009 (Chudik and Fratzscher, 2011), for stress-testing of the financial sector (Castrén et al., 2010), and to the analysis of fiscal shocks (Belke and Osowski, 2016; Eller et al., 2017). For an excellent survey regarding covering a broad range of applications within the GVAR framework see Chudik and Pesaran (2016)[1].

A recent strand of the literature focuses solely on the quantification of the domestic effects of unconventional euro area monetary policy. These studies often use some sort of time series econometrics and differ in the way they capture unconventional monetary policy. Gambacorta et al. (2014) and Boeckx et al. (2017) look at an exogenous increase in the ECB's balance sheet. Gambacorta et al. (2014) estimate a structural panel VAR for eight advanced euro area countries and find that a positive shock to the ECB's balance sheet raises economic activity and – to a lesser degree – prices in the euro area. Boeckx et al. (2017) using a structural VAR framework find that an expansionary balance sheet shock stimulates bank lending, reduces interest rate spreads, leads to a depreciation of the euro, and more generally has a positive impact on economic activity and inflation.

A few papers look at spillovers from unconventional measures to emerging Europe.[2] Burriel and Galesi (2018) use a GVAR framework and a similar identification strategy as in Boeckx et al. (2017). In their analysis, an exogenous increase in the ECB's total assets triggers a significant rise in aggregate output and inflation and a depreciation of the effective exchange rate. They also demonstrate a high degree of cross-country variation of the effects and more generally that spillovers to countries with less fragile banks are largest. Feldkircher et al. (2017) specifically look at the effects of quantitative easing in the euro area measured as a flattening of the yield curve. They find that a decrease in the euro area term spread has persistent and positive effects on industrial production in

[1] Several authors have paid special attention to shock propagation to CESEE countries - see, for example, work by Feldkircher and Huber (2016), Hájek and Horváth (2016) and Fadejeva et al. (2017)

[2] For a recent assessment of spillovers from a conventional monetary policy shock to CESEE, see Potjagailo (2017).

the euro area itself and in neighboring economies and that the transmission works mainly through financial variables. They also report a considerable degree of heterogeneity in international output effects which can be explained by the degree of trade and financial openness. Bluwstein and Canova (2016) use a Bayesian mixed-frequency structural VAR model and find positive effects on prices and output. The effects tend to be larger in countries with more advanced financial systems and a larger share of domestic banks. Horváth and Voslářová (2016) use a panel vector autoregressive framework to examine the reaction of macroeconomic variables in CESEE economies to both a shock to the shadow rate as a measure of unconventional policy (Wu and Xia, 2016) and an exogenous increase in central banks' assets. They find strong effects on output, while spillovers to prices are rather weak. Last, Hájek and Horváth (2018) examine the spillovers of US and euro area monetary policy shocks. They find generally weaker spillovers to Southeastern EU economies compared to their peers from Central and Eastern Europe. Also, euro area monetary policy shocks turn out to cause stronger spillovers to CESEE relative to a US-based shock.

The paper is structured as follows: section 2 introduces the global VAR model, the data and the model specification; section 3 presents a set of sign restrictions that we employ to separate aggregate supply shocks from aggregate demand shocks and the shock of interest - a shadow rate/monetary policy shock; section 4 illustrates the results and section 5 concludes.

2. The GVAR Model

The empirical literature on GVAR models has been greatly influenced by the work of Hashem M. Pesaran and co-authors (Pesaran et al., 2004; Garrat et al., 2006). In a series of papers, these authors examine the effect of US macroeconomic impulses on selected foreign economies, employing agnostic, structural, and long-run macroeconomic relations to identify the shocks (Pesaran et al., 2004; Dees et al., 2007a,b). Since then, the literature on GVAR modeling has advanced in many directions – see Chudik and Pesaran (2016) for an excellent survey of recent applications within the GVAR framework.

The GVAR is a compact representation of the world economy designed to model multilateral dependencies among economies across the globe. In general, a GVAR model comprises *two layers* via which the model is able to capture cross-country spillovers. In the first layer, separate time series models – one per country – are estimated. In the second layer, the country models are stacked to yield a global model that is able to assess the spatial propagation of a shock as well as the dynamics of the associated responses.

In the classical representation of the GVAR model, the first layer is composed of country-specific local VAR models, enlarged by a set of weakly exogenous variables (VARX model). Assuming that our global economy consists of $N+1$ countries, we estimate a VARX of the following form for every country $i = 0,...,N$:[3]

$$x_{it} = a_{i0} + \Phi_i x_{i,t-1} + \Lambda_{i0} x^*_{it} + \Lambda_{i1} x^*_{i,t-1} + \varepsilon_{it}. \tag{1}$$

Here, a_{i0} is a vector of intercepts, x_{it} is a $k_i \times 1$ vector of endogenous variables in country i at time $t \in 1,...,T$, Φ_i denotes the $k_i \times k_i$ matrix of parameters associated with the lagged endogenous

[3] For simplicity, we use a first-order VARX model for the exposition. The generalization to longer lag structures is straightforward.

variables, and Λ_{ik} are the coefficient matrices of the k_i^* weakly exogenous variables, of dimension $k_i \times k_i^*$. Furthermore, $\varepsilon_{it} \sim N(0, \Sigma_i)$ is the standard vector error term.

The weakly exogenous or *foreign* variables, x_{it}^*, are constructed as a weighted average of their cross-country counterparts,

$$x_{it}^* := \sum_{j \neq i}^{N} \omega_{ij} x_{jt}, \tag{2}$$

where ω_{ij} denotes the weight corresponding to the pair of country i and country j. The weights ω_{ij} reflect economic and financial ties between economies, which are usually proxied using data on bilateral trade flows.[4] The assumption that the x_{it}^* variables are weakly exogenous at the individual level reflects the belief that most countries are small relative to the world economy.

There are different ways to introduce euro area country-specific and region-specific information within the GVAR framework. Georgiadis (2015) and Feldkircher et al. (2017), for example, use a mixed cross-section GVAR to account for the common monetary policy in the euro area. Burriel and Galesi (2018) introduce euro area monetary policy variables through common variables, that enter the euro area country-specific models in the GVAR. Importantly, in their framework, the common variable reacts contemporaneously to aggregated euro area variables such as output and prices.

We introduce euro area common variables in the spirit of the approach presented in Burriel and Galesi (2018). The euro area policy rate (or its shadow rate) and the exchange rate against the US dollar are modeled in a separate country (EA) and are included in the euro area country-specific VARX models contemporaneously and with lags. These (euro area) common variables are assumed to be driven by weighted euro area country-specific variables such as output, prices and long-term interest rates. Therefore, we modify the overall model (1) by extending the set of N countries to include an artificial country EA (j) that determines the two euro area common variables, namely, the shadow rate and the exchange rate.

The euro area common variables follow the process

$$\kappa_{jt} = a_{j0} + D_j \kappa_{jt-1} + F_{j0}\hat{x}_t + F_{j1}\hat{x}_{t-1} + \varepsilon_{jt} \tag{3}$$

where κ is a common euro area variable and $\hat{x}_t$ denote the aggregated euro area macroeconomic variables constructed using the euro area PPP-GDP weights $\hat{W}$: $\hat{x}_t = \hat{W} x_t$.

Following Chudik and Pesaran (2013) we further include oil prices as a dominant unit in our model

$$\iota_t = \mu_0 + \Phi_1 \iota_{t-1} + \Lambda_{\iota 1} \tilde{x}_{t-1} + \eta_t, \tag{4}$$

where ι is a dominant unit variable, and $\tilde{x}$ is a set of world feedback variables $\tilde{x}_t = \tilde{W} x_t$ constructed using the PPP-GDP weights of all countries. The difference between a dominant unit and a common variable is given by the assumption about the timing of the effect. The dominant unit – such as oil prices – is assumed not to react immediately to aggregate developments in the world variables $\tilde{x}_t$.

[4] See, for example, Eickmeier and Ng (2015) and Feldkircher and Huber (2016) for an application using a broad set of trade and financial weights.

The non-dominant VARX model (1) can be re-written as

$$A_i z_{it} = a_{i0} + B_i z_{it-1} + \Psi_0 \iota_t + \Psi_1 \iota_{t-1} + \varepsilon_{it}, \tag{5}$$

where $A_i := (I_{k_i},\ -\Lambda_{i0})$, $B_i := (\Phi_i,\ \Lambda_{i1})$, and $z_{it} = (x'_{it},\ x^{*'}_{it})'$. By defining a suitable link matrix W_i of dimension $(k_i + k_i^*) \times k$, where $k = \sum_{i=1}^{N} k_i$, we can rewrite z_{it} as $z_{it} = W_i x_t$. x_t denotes the vector that stacks all the endogenous variables of the countries in our sample. Note that this implies that the weakly exogenous variables are endogenous within the system of all equations. Substituting (5) in (1) and stacking the different local models leads to the global equation, which is given by

$$x_t \;=\; G^{-1}a_0 + G^{-1}Hx_{t-1} + G^{-1}\Psi_0 \iota_t + G^{-1}\Psi_1 \iota_{t-1} + G^{-1}\varepsilon_t, \tag{6}$$

where $G = (A_0W_0, \cdots, A_NW_W)'$, $H = (B_0W_0, \cdots, B_NW_W)'$, and a_0 contain the corresponding stacked vectors containing the parameter vectors of the country-specific specifications.

Assuming that the innovations ε_t and η_t are uncorrelated and defining vector $y_t = (x'_t, \kappa'_t, \iota'_t)$, equations (6), (3), and (4) can be written as

$$y_t \;=\; H_0^{-1}h_0 + H_0^{-1}H_1 y_{t-1} + H_0^{-1}\zeta_t = b_0 + \Gamma y_{t-1} + e_t \tag{7}$$

where

$$H_0 = \begin{bmatrix} G_0 & -\Psi_0 \\ -F_0\hat{W} & I \\ 0 & I \end{bmatrix}, H_1 = \begin{bmatrix} G_1 & \Psi_1 \\ F_1\hat{W} & D_1 \\ \Lambda_{\iota 1}\tilde{W} & \Phi_1 \end{bmatrix}, h_0 = \begin{bmatrix} a_{i0} \\ a_{j0} \\ \mu_0 \end{bmatrix}, \zeta_t = \begin{bmatrix} \varepsilon_{it} \\ \varepsilon_{jt} \\ \eta_t \end{bmatrix}$$

The eigenvalues of the matrix $\Gamma = H_0^{-1}H_1$, which is of prime interest for forecasting and impulse response analysis, have to lie within the unit circle in order to ensure stability of (7).

2.1 Data and Weights Specification

Our data set contains quarterly observations for 37 countries, including the 12 euro area countries that adopted the common currency prior to 2007 and 10 CESEE and Baltic countries. Together, we have 17 euro area member states. Table 1 presents the country coverage.

The sample features 64 quarterly observations and spans the period from 2001Q1 to 2016Q4. The *variables* used in our analysis comprise data on real activity, consumer prices, the real exchange rate, short-term interest rates and long-term government bond yields, and oil prices (Dees et al., 2007a,b; Pesaran et al., 2004, 2009, 2007). The variables used in the model are briefly described in Table 2 and Table 3. Most of the data are available with wide country coverage, with the exception

Table 1: Country Coverage

Advanced Economies [adv] (3):	US, UK, JP
Euro Area 12 [euro] (12):	AT, BE, DE, ES, FI, FR, GR, IE, IT, LU, NL, PT
CESEE and Baltics [cee] (10):	CZ, HU, PL, SK, SI, BG, RO, LT, LV, EE
Other Emerging [emer] (8):	RU, BR, MX, KR, IN, ID, CN, TR
Other Advanced [oadv] (7):	AU, CA, SE, DK

Notes: Abbreviations refer to the two-digit ISO country code.

Table 2: Data Description, 2001Q1-2016Q4

Variable	Description	Min.	Mean	Max.	Coverage
y	Real GDP, average of 2005=100. Seasonally adjusted, in logarithms.	4.19	4.66	5.54	100%
p	Consumer price. CPI seasonally adjusted, in logarithms.	3.63	4.70	5.54	100%
e	Nominal exchange rate vis-à-vis the US dollar, deflated by national price levels (CPI).	-5.57	-2.17	5.11	100%
i_S	Typically 3-month-market rates, rates per annum.	-0.02	0.01	0.16	100%
i_L	Typically government bond yields, rates per annum.	-0.00	0.01	0.06	65%
EA_{ls}	Shadow rate for the euro area	-0.018	0.002	0.011	-
US_{ls}	Shadow rate for the United States	-0.013	0.001	0.013	-
UK_{ls}	Shadow rate for the United Kingdom	-0.016	0.004	0.014	-
JP_{ls}	Shadow rate for Japan	-0.012	-0.004	0.001	-
CZ_{ls}	Shadow rate for the Czech Republic	-0.017	0.018	0.056	-
BG_{ls}	Shadow rate for Bulgaria	-0.023	0.016	0.054	-
poil	Price of oil, seasonally adjusted, in logarithms.	2.96	4.10	4.80	-
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.	-	-	-	-

Notes: Summary statistics pooled over countries and time. The coverage refers to the cross-country availability per country, in %.

of government bond yields. Since local capital markets in emerging economies (in particular in Eastern Europe) were still developing at the beginning of our sample period, data on long-term interest rates are hardly available for these countries.

Table 3: Data Sources

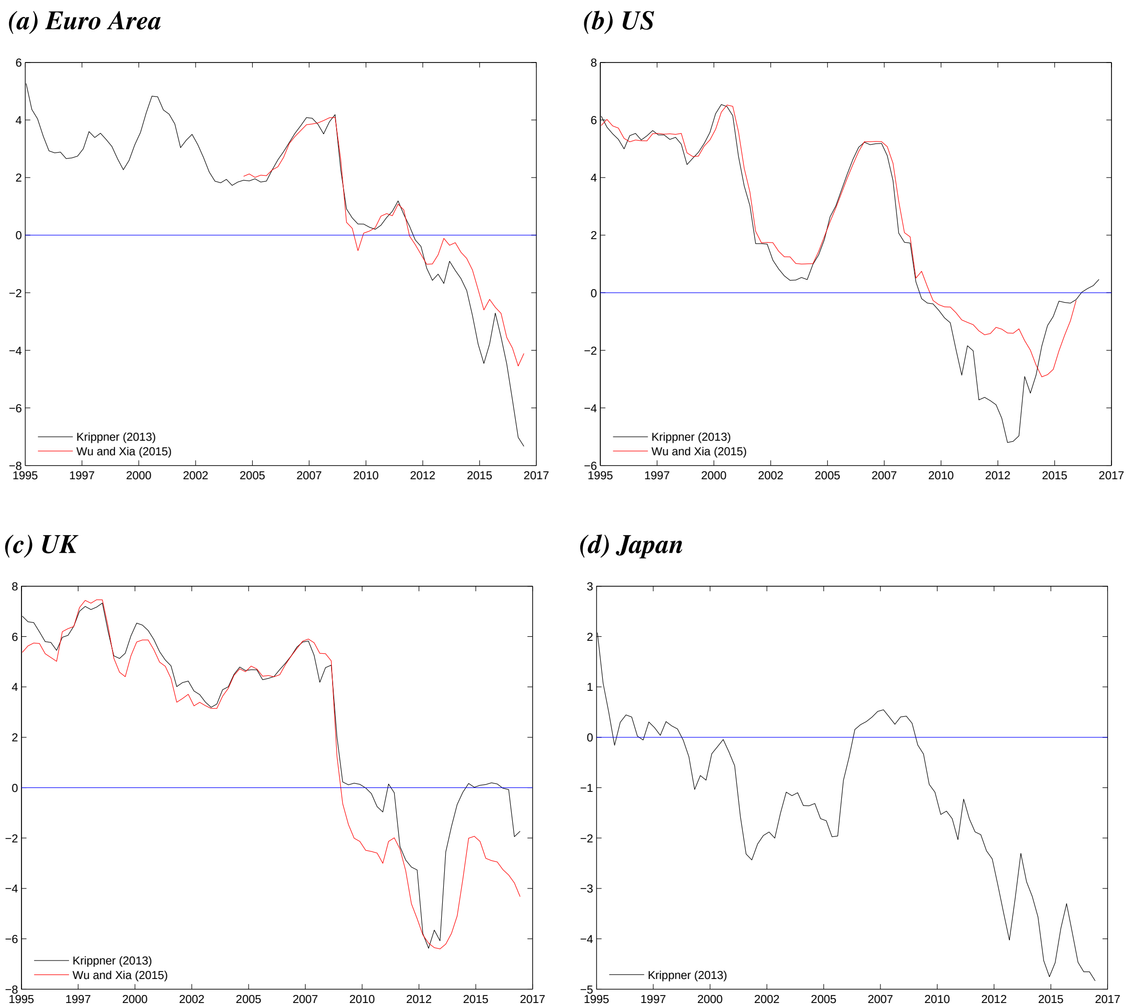
Code	Country	GDP	CPI	Short rate	Long rate	Exchange rate
EA	Euro area		OECD, sa	IMF, IFS	IMF, IFS	Thomson Reuters
US	USA	OE, sa	OECD, sa	IMF, IFS	IMF, IFS	
UK	United Kingdom	OE, sa	OECD, sa	IMF, IFS	IMF, IFS	Thomson Reuters
JP	Japan	OE, sa	OECD, sa	IMF, IFS	IMF, IFS	Thomson Reuters
CN	China	OE, sa	OECD, sa	CB	IMF, IFS	Thomson Reuters
CZ	Czech Republic	OE, sa	OECD, sa	IMF, IFS		Thomson Reuters
HU	Hungary	OE, sa	OECD, sa	CB		Thomson Reuters
PL	Poland	OE, sa	OECD, sa	IMF, IFS		Thomson Reuters
SI	Slovenia	NSO, sa	IMF, nsa	IMF, IFS		Thomson Reuters
SK	Slovakia	OE, sa	OECD, sa	CB		Thomson Reuters
BG	Bulgaria	OE, sa	IMF, nsa	IMF, IFS	IMF, IFS	Thomson Reuters
RO	Romania	OE, sa	IMF, nsa	IMF, IFS		Thomson Reuters
EE	Estonia	NSO, sa	IMF, nsa	IMF, IFS	IMF, IFS	Thomson Reuters
LT	Lithuania	NSO, sa	IMF, nsa	IMF, IFS		Thomson Reuters
LV	Latvia	OECD, sa	IMF, nsa	IMF, IFS		Thomson Reuters
RU	Russia	OE, sa	IMF, nsa	IMF, IFS		Thomson Reuters
BR	Brazil	OE, sa	OECD, sa	IMF, IFS		Thomson Reuters
MX	Mexico	OE, sa	OECD, sa	IMF, IFS	IMF, IFS	Thomson Reuters
KR	South Korea	OE, sa	OECD, sa	IMF, IFS	IMF, IFS	Thomson Reuters
IN	India	OE, sa	OECD, sa	CB, 3m Tbill		Thomson Reuters
ID	Indonesia	OE, sa	IMF, nsa	IMF, IFS		Thomson Reuters
AU	Australia	OE, sa	OECD, sa	IMF, IFS	IMF, IFS	Thomson Reuters
TR	Turkey	OE, sa	IMF, nsa	CB		Thomson Reuters
CA	Canada	OE, sa	OECD, sa	IMF, IFS	IMF, IFS	Thomson Reuters
SE	Sweden	OE, sa	OECD, sa	CB	IMF, IFS	Thomson Reuters
DK	Denmark	OE, sa	OECD, sa	IMF, IFS	IMF, IFS	Thomson Reuters
AT	Austria	OE, sa	OECD, sa		IMF, IFS	
BE	Belgium	OE, sa	OECD, sa		IMF, IFS	
DE	Germany	OE, sa	OECD, sa		IMF, IFS	
ES	Spain	OE, sa	OECD, sa		IMF, IFS	
FI	Finland	OE, sa	OECD, sa		IMF, IFS	
FR	France	OE, sa	OECD, sa		IMF, IFS	
GR	Greece	OE, sa	OECD, sa		IMF, IFS	
IE	Ireland	OE, sa	OECD, sa		IMF, IFS	
IT	Italy	OE, sa	OECD, sa		IMF, IFS	
LU	Luxembourg	OECD, sa	OECD, sa		IMF, IFS	
NL	Netherlands	OE, sa	OECD, sa		IMF, IFS	
PT	Portugal	OE, sa	OECD, sa		IMF, IFS	

Moreover, in the case of four advanced economies we employ a *shadow interest rate*, i.e., a measure of the overall monetary policy stance. According to the original Scholes idea, a shadow rate stands for the hypothetical rate that would occur if the zero lower bound was not binding. In normal times, the shadow rate is very close to the actual policy rate, while it can become negative if the central bank provides an additional stimulus. This way, shadow rates allow for a continuous evaluation of the monetary policy stance during periods of both conventional and unconventional monetary policy stimulus.

There exist several versions of shadow interest rates depending on the econometric technique used to estimate them (see Comunale and Striaukas, 2017, for an excellent overview of further measures of unconventional monetary policy). The most widely used ones are from Krippner (2013) and Wu and Xia (2016). Other versions of euro area shadow interest rates are developed by Ajevskis (2016) in the Latvijas Banka and Babecka Kucharcukova et al. (2016) in the Česka Národní Banka.

Several methods based on yield curve modeling or factor analysis have been developed to estimate shadow short-term rates in a zero lower bound environment, giving slightly different paths (see Figure 1).

Figure 1: Shadow Rate Estimates for the Euro Area, the US, the UK and Japan

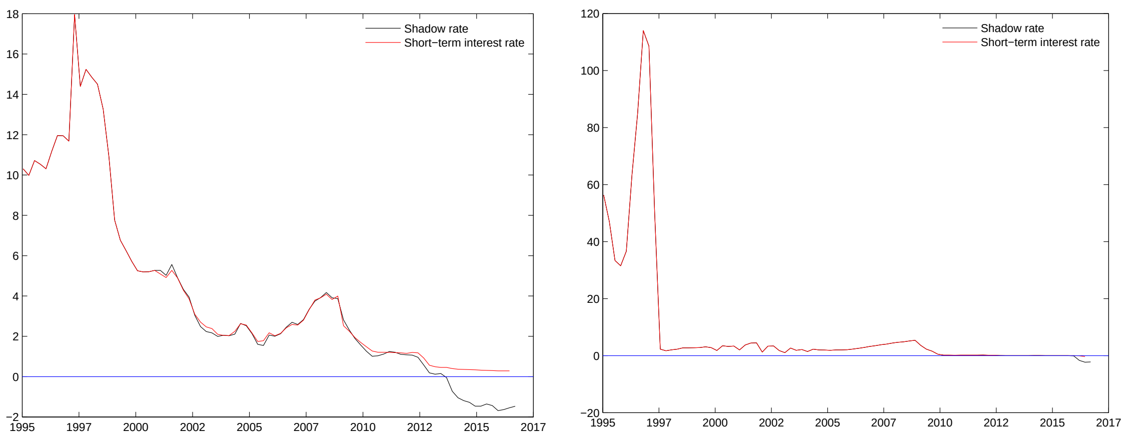


In this paper, we use the shadow rate of Krippner (2013) for the euro area, the United States, the United Kingdom, and Japan. As a robustness check, we compare the results employing shadow rates from Wu and Xia (2016). Several CESEE and Baltic countries introduced the euro towards the middle or end of the period analyzed in this paper (SK – 2007, SI – 2009, EE – 2011, LV –

2014, LT – 2015). In order to account for euro area monetary policy effects on these countries, we adjust their short-term rates time series with the dynamics of the euro area interest shadow rate with the introduction of the euro. In 2015–2016, some CESEE countries, such as the Czech Republic and Bulgaria, also implemented unconventional monetary policies, mirrored in negative values of yield curves and deposit facility rates. To account for this, we also calculate shadow rates for these economies applying the method described in Ajevskis (2016). The shadow rates are provided in Figure 2. Including shadow rates for the CESEE economies where applicable ensures a proper assessment of the transmission of the euro area monetary policy shock to the region.

Figure 2: Shadow Rate Estimates for the Czech Republic and Bulgaria

(a) the Czech Republic ***(b) Bulgaria***



Notes: Estimated using the method presented in Ajevskis (2016).

Next, we have to specify *weights* that link the single country models. These should proxy the (economic) connectivity between the countries. In the early literature on GVARs, weakly exogenous variables were constructed exclusively based on bilateral trade flows (Pesaran et al., 2004, 2009; Dees et al., 2007b). More recent GVAR 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 and total credit). An alternative strand of the literature focuses on statistical as opposed to observed measures of connectivity. As such, Diebold and Yilmaz (2009) and Diebold and Yilmaz (2014) propose using forecast error variance decompositions for a VAR model to gauge the connectivity between the variables of interest. Most recent applications span analyses of the connectivity between (the returns of) international asset classes, banking networks and firm networks (see Chan-Lau, 2017).[5] We follow the GVAR literature though and choose time-varying weights based on bilateral trade flows to calculate y^*, p^* and financial weights based on bilateral banking sector exposure[6] to construct i_s^* and i_l^*. This approach is in line with Eickmeier and Ng (2015).

In order to include euro area aggregated variables (output, prices, and long-term interest rates) in the euro area VARX model, the weights should be set to zero for all countries except single euro area member states (see Table 4). The euro area VARX model then includes the aggregated long-term rate of non-EA countries as a foreign variable and we consequently leave these weights unrestricted.

[5] A recent paper Elhorst et al. (2018) presents an interesting bridge between GVAR and spatial econometrics, introducing a measure of spillovers using cross-section connectivity (weight) matrices and impulse responses.
[6] For more details on how to construct the financial weights, see Backé et al. (2013).

Since the euro area exchange rate is defined in the euro area model, we include it in the euro area single country models as a foreign variable with a weight equal to one.

We check for weak exogeneity of foreign variables and present the results in Table 5. Only some of the foreign variables in the euro area country models do not satisfy the weak exogeneity assumption. For example, in the German model foreign output and interest rates and in the Netherlands model the foreign exchange rate do not satisfy the assumption. Also, foreign output and interest rates in the VARX for China do not pass the weak exogeneity test. This reflects the country's dominant role in the world economy.

We also tested each variable for the presence of a unit root by means of an augmented Dickey-Fuller test. Output, prices and interest rates are mostly integrated of order 1 (see Tables 6 and 7), which ensures the appropriateness of the econometric framework pursued in this study.

Table 4: Weights Used to Construct Foreign Variables

y , p (trade weights)	EA	US	..	AT	..	PT
EA	0	0	0	0	0	0
US	0	0	x	x	x	x
..	0	x	0	x	x	x
AT (euro area countries)	x	x	x	0	x	x
..	x	x	x	x	0	x
PT	x	x	x	x	x	0
Σ	1	1	1	1	1	1

i_l (financial weights)	EA	US	..	AT	..	PT
EA	0	0	0	0	0	0
US	0	0	x	x	x	x
..	0	x	0	x	x	x
AT (euro area countries)	x	x	x	0	x	x
..	x	x	x	x	0	x
PT	x	x	x	x	x	0
Σ	1	1	1	1	1	1

i_s (financial weights)	EA	US	..	AT	..	PT
EA	0	x	x	x	x	x
US	x	0	x	x	x	x
..	x	x	0	x	x	x
AT (euro area countries)	0	0	0	0	0	0
..	0	0	0	0	0	0
PT	0	0	0	0	0	0
Σ	1	1	1	1	1	1

e (trade weights)	EA	US	..	AT	..	PT
EA	0	x	x	1	1	1
US	x	0	x	0	0	0
..	x	x	0	0	0	0
AT (euro area countries)	0	0	0	0	0	0
..	0	0	0	0	0	0
PT	0	0	0	0	0	0
Σ	1	1	1	1	1	1

Notes: x – values between zero and one.

Table 5: Test for Weak Exogeneity at the 5% Significance Level – Baseline

Country	F test	Compliance (in %)	ys	cpis	stirs	ltirs	rers	poil
Euro Area	F(1,49)	100%	0.51	0.49		0.35		0.06
United States	F(1,49)	100%	0.65				0.14	0.59
United Kingdom	F(1,46)	100%	0.37	0.02	0.00	0.51		0.03
Japan	F(1,46)	100%	3.23	0.03	0.00	0.64		0.63
China	F(1,46)	60%	6.48	0.02	6.86	1.44		0.20
Czech Republic	F(1,47)	100%	0.00	0.16	0.45	0.92		0.01
Hungary	F(1,47)	100%	0.83	0.13	1.07	1.10		2.00
Poland	F(1,47)	100%	0.00	1.03	0.00	0.63		0.01
Slovenia	F(1,47)	80%	4.47	0.03	0.03	0.01		0.35
Slovak Republic	F(1,47)	100%	3.87	0.94	0.33	0.07		0.17
Bulgaria	F(1,47)	100%	0.26	1.38	0.08	1.18		0.05
Romania	F(1,47)	80%	1.72	1.72	0.12	0.11		4.79
Estonia	F(1,47)	100%	0.78	1.19	0.06	0.40		0.19
Lithuania	F(1,47)	100%	0.73	0.01	0.21	0.03		0.67
Latvia	F(1,47)	100%	1.34	0.00	0.36	0.74		0.13
Russia	F(1,47)	100%	1.61	0.25	0.27	3.06		3.04
Brazil	F(1,47)	100%	2.69	0.01	0.00	0.11		0.15
Mexico	F(1,46)	100%	1.16	2.73	3.92	1.24		0.70
Korea	F(1,46)	100%	0.03	0.01	0.49	0.18		0.06
India	F(1,47)	100%	0.07	2.22	0.19	2.27		0.01
Indonesia	F(1,47)	80%	1.88	8.25	0.08	0.09		0.02
Australia	F(1,46)	100%	0.11	1.35	0.75	1.17		0.70
Turkey	F(1,47)	100%	0.61	0.00	0.30	0.22		0.61
Canada	F(1,46)	100%	0.00	0.46	1.02	0.73		1.12
Sweden	F(1,46)	100%	0.85	0.17	0.17	0.19		0.00
Denmark	F(1,46)	100%	0.36	1.47	0.27	0.03		0.81
Austria	F(1,48)	100%	0.00	0.65	3.51	0.20	0.03	1.28
Belgium	F(1,48)	100%	0.16	1.17	0.36	0.23	0.16	0.27
Germany	F(1,48)	67%	4.19	0.27	4.02	4.19	0.25	0.90
Spain	F(1,48)	100%	0.29	0.04	0.07	2.44	0.00	0.14
Finland	F(1,48)	100%	1.04	1.41	0.02	0.66	0.22	0.05
France	F(1,48)	100%	0.51	0.81	0.53	0.02	1.16	1.04
Greece	F(1,48)	100%	0.96	0.96	0.29	0.17	0.02	0.09
Ireland	F(1,48)	100%	3.16	0.18	0.03	0.11	0.03	0.08
Italy	F(1,48)	100%	0.22	0.25	1.39	1.63	0.11	0.53
Luxembourg	F(1,48)	100%	0.02	3.96	0.55	2.03	1.16	2.46
Netherlands	F(1,48)	83%	0.00	2.36	0.02	0.08	6.25	2.48
Portugal	F(1,48)	100%	2.30	1.81	0.12	0.32	1.02	0.36

Table 6: Unit Root Tests for the Domestic Variables at the 5% Significance Level

Country	Dy ADF	Dy WS	Dcpi ADF	Dcpi WS	Dstir ADF	Dstir WS	Dltir ADF	Dltir WS	Drer ADF	Drer WS
Compliance (in %)	92%	100%	59%	78%	96%	88%	100%	100%	80%	88%
Euro Area					-5.38	-5.60			-2.98	-2.66
United States	-3.82	-3.98	-5.43	-5.67	-2.99	-2.47	-7.02	-7.28		
United Kingdom	-3.92	-4.19	-2.65	-2.87	-4.62	-4.84	-6.21	-6.38	-6.54	-6.78
Japan	-4.86	-4.98	-4.35	-4.42	-5.51	-4.94	-5.98	-6.22	-2.95	-3.09
China	-3.44	-3.53	-4.95	-4.96	-5.17	-5.40	-4.05	-4.28	-2.76	-2.92
Czech Republic	-3.04	-3.28	-3.99	-4.10	-3.58	-3.73			-6.14	-6.38
Hungary	-3.68	-3.88	-3.44	-3.40	-4.79	-5.02			-6.12	-6.35
Poland	-3.13	-2.91	-2.87	-2.62	-4.60	-1.99			-6.37	-6.62
Slovenia	-3.25	-3.49	-2.79	-1.47	-5.61	-5.84			-2.82	-2.53
Slovak Republic	-2.98	-3.30	-2.88	-2.61	-5.43	-5.62			-4.64	-4.87
Bulgaria	-2.29	-2.61	-2.87	-2.93	-2.23	-2.45			-2.74	-2.42
Romania	-4.29	-4.48	-2.71	0.59	-3.62	-3.61			-5.69	-5.93
Estonia	-2.75	-2.99	-3.68	-3.95	-5.05	-5.27			-2.87	-2.61
Lithuania	-3.70	-3.93	-2.33	-2.55	-5.58	-5.44			-2.09	-2.31
Latvia	-2.15	-2.38	-2.36	-2.61	-6.40	-6.60			-5.44	-5.68
Russia	-3.38	-3.63	-3.68	-2.98	-4.87	-4.56			-5.56	-5.75
Brazil	-4.38	-4.41	-2.94	-3.20	-6.86	-6.83			-5.91	-5.83
Mexico	-4.77	-4.93	-2.63	-2.86	-6.23	-3.10	-6.50	-3.76	-5.92	-6.01
Korea	-4.71	-4.85	-2.42	-2.70	-5.02	-5.17	-4.67	-4.78	-5.11	-5.34
India	-6.09	-6.33	-1.34	-1.58	-4.46	-4.37			-4.89	-5.20
Indonesia	-6.33	-5.98	-3.31	-2.69	-5.04	-5.27			-3.68	-3.86
Australia	-4.94	-5.07	-5.59	-5.81	-4.79	-4.23	-5.85	-5.93	-5.50	-5.72
Turkey	-3.78	-4.01	-6.35	2.36	-4.22	-2.96			-4.04	-4.39
Canada	-4.95	-5.12	-3.31	-3.58	-4.03	-3.18	-6.04	-6.16	-4.80	-5.03
Sweden	-4.04	-4.35	-3.92	-3.73	-3.73	-4.01	-6.11	-6.17	-5.47	-5.61
Denmark	-3.85	-3.99	-3.70	-3.85	-4.23	-4.39	-6.03	-6.22	-3.03	-2.73
Austria	-3.73	-3.78	-4.18	-4.36			-4.04	-4.24		
Belgium	-4.22	-4.29	-4.50	-4.71			-4.98	-5.18		
Germany	-3.93	-4.13	-3.16	-3.25			-4.59	-4.72		
Spain	-1.69	-1.94	-2.89	-3.12			-3.07	-3.35		
Finland	-4.08	-4.31	-3.24	-3.26			-6.10	-6.28		
France	-3.25	-3.49	-3.64	-3.67			-6.38	-6.59		
Greece	-1.75	-1.99	-2.17	-2.17			-4.51	-4.74		
Ireland	-2.65	-2.92	-2.41	-1.88			-4.02	-4.24		
Italy	-3.85	-4.04	-2.24	-2.46			-3.30	-3.58		
Luxembourg	-4.16	-4.14	-4.27	-4.49			-3.11	-3.36		
Netherlands	-3.70	-3.93	-3.06	-2.05			-6.27	-6.46		
Portugal	-3.25	-3.13	-2.92	-3.01			-3.63	-3.86		

Table 7: Unit Root Tests for the Foreign Variables at the 5% Significance Level

Country	Dy* ADF	Dy* WS	Dcpi* ADF	Dcpi* WS	Dstir* ADF	Dstir* WS	Dltir* ADF	Dltir* WS	Drer* ADF	Drer* WS
Compliance (in %)	100%	100%	97%	97%	100%	100%	100%	100%	55%	68%
Euro Area	-3.64	-3.86	-3.17	-3.20	-4.43	-4.57	-5.38	-5.58	-5.92	-6.13
United States	-4.04	-4.06	-4.92	-5.08	-4.66	-4.82	-6.57	-6.76	-5.33	-5.55
United Kingdom	-3.84	-4.01	-4.01	-4.05	-3.76	-3.49	-6.85	-7.08	-2.85	-2.57
Japan	-4.24	-4.28	-4.39	-4.61	-3.45	-3.28	-7.08	-7.32	-5.53	-5.74
China	-4.61	-4.77	-5.24	-5.47	-4.84	-4.96	-6.67	-6.87	-2.74	-2.30
Czech Republic	-3.91	-4.11	-3.65	-3.62	-5.27	-5.49	-6.37	-6.57	-2.66	-2.54
Hungary	-4.10	-4.29	-3.51	-3.49	-5.26	-5.47	-6.31	-6.51	-2.74	-2.54
Poland	-4.03	-4.25	-3.79	-3.72	-5.24	-5.45	-6.23	-6.42	-2.73	-2.55
Slovenia	-4.02	-4.20	-3.33	-3.30	-5.34	-5.56	-4.17	-4.34	-2.74	-2.57
Slovak Republic	-3.96	-4.18	-3.48	-3.32	-5.28	-5.50	-6.26	-6.46	-2.61	-2.52
Bulgaria	-4.15	-4.37	-3.75	-2.83	-5.27	-5.49	-5.18	-5.39	-5.22	-5.38
Romania	-3.99	-4.19	-2.88	-2.16	-5.29	-5.50	-5.49	-5.70	-5.37	-5.54
Estonia	-3.58	-3.89	-4.10	-3.95	-3.52	-3.83	-6.25	-6.36	-2.66	-2.53
Lithuania	-3.26	-3.50	-3.54	-3.38	-3.47	-3.77	-6.33	-6.46	-5.57	-5.79
Latvia	-3.91	-4.14	-4.32	-4.34	-4.92	-5.15	-6.37	-6.51	-2.63	-2.60
Russia	-3.85	-4.01	-3.59	-2.92	-5.04	-5.25	-6.60	-6.79	-5.52	-5.70
Brazil	-4.24	-4.19	-4.48	-4.69	-3.45	-3.15	-7.36	-7.61	-2.76	-2.51
Mexico	-4.05	-4.16	-5.28	-5.51	-3.11	-2.67	-7.32	-7.58	-5.23	-5.42
Korea	-4.52	-4.42	-4.22	-4.44	-4.70	-4.71	-6.90	-7.14	-2.58	-2.14
India	-4.51	-4.60	-4.27	-4.43	-3.27	-3.00	-7.13	-7.37	-2.80	-2.47
Indonesia	-4.14	-4.09	-4.20	-4.38	-3.55	-3.13	-6.98	-7.22	-2.77	-2.13
Australia	-4.08	-4.09	-4.29	-4.51	-4.51	-4.65	-6.84	-7.06	-2.98	-2.19
Turkey	-4.21	-4.43	-4.53	-4.70	-4.80	-4.96	-7.00	-7.22	-2.72	-2.58
Canada	-4.12	-4.24	-5.26	-5.49	-3.16	-2.79	-7.11	-7.37	-2.59	-2.31
Sweden	-3.93	-4.15	-3.79	-3.84	-4.59	-4.75	-6.61	-6.81	-2.81	-2.55
Denmark	-3.73	-3.93	-3.81	-3.80	-4.91	-5.13	-6.46	-6.63	-2.75	-2.50
Austria	-3.97	-4.17	-3.46	-3.42	-4.73	-4.80	-6.60	-6.80	-2.98	-2.66
Belgium	-3.71	-3.92	-3.79	-3.75	-5.00	-5.20	-6.42	-6.62	-2.98	-2.66
Germany	-3.94	-4.23	-3.80	-3.69	-4.87	-5.05	-6.45	-6.66	-2.98	-2.66
Spain	-4.05	-4.25	-3.81	-3.83	-4.92	-5.10	-6.49	-6.71	-2.98	-2.66
Finland	-4.10	-4.33	-3.99	-4.05	-4.56	-4.75	-6.57	-6.75	-2.98	-2.66
France	-4.06	-4.26	-3.67	-3.72	-4.88	-5.05	-6.59	-6.79	-2.98	-2.66
Greece	-4.14	-4.34	-4.47	-4.57	-4.76	-4.93	-6.39	-6.59	-2.98	-2.66
Ireland	-3.74	-3.96	-4.35	-4.53	-4.83	-5.02	-6.81	-7.01	-2.98	-2.66
Italy	-4.29	-4.59	-4.16	-4.07	-5.06	-5.27	-6.41	-6.61	-2.98	-2.66
Luxembourg	-4.11	-4.27	-3.67	-3.78	-5.15	-5.34	-6.60	-6.80	-2.98	-2.66
Netherlands	-4.16	-4.35	-4.16	-4.32	-4.80	-4.98	-6.56	-6.76	-2.98	-2.66
Portugal	-3.40	-3.63	-3.38	-3.49	-5.13	-5.35	-6.00	-6.19	-2.98	-2.66

3. Identification of Structural Shocks in the Euro Area

The classical way to identify a shock is presented in Dees et al. (2007a) and identifies a shock locally (for applications, see Eickmeier and Ng, 2015; Chen et al., 2017; Feldkircher and Huber, 2016; Fadejeva et al., 2017, among others.) Recently, Feldkircher et al. (2017) have proposed a mixture of zero and sign restrictions to identify a structural shock using the global representation of the GVAR. Burriel and Galesi (2018) use a combination of zero and sign restrictions to identify conventional and unconventional monetary policy shocks via restrictions on the average responses across 19 euro area economies. In this paper we offer a different solution. We propose a way to identify shocks simultaneously for both individual and aggregated variables in a group of countries with common variables through a two-step procedure, which allows us to preserve the economic interpretation of the shock on the individual country level.

First, consider the case of identification in an individual country model. Suppose that the euro area model uses aggregated data and is indexed by $i = 0$:

$$x_{0,t} = \psi_{01} x_{0,t-1} + \Lambda_{00} x^*_{0,t} + \Lambda_{01} x^*_{0,t-1} + \varepsilon_{0,t}. \tag{8}$$

The structural form of the model is given by

$$Q_0 x_{0,t} = \tilde{\psi}_{01} x_{0,t-1} + \tilde{\Lambda}_{00} x^*_{0,t} + \tilde{\Lambda}_{01} x^*_{0,t-1} + \tilde{\varepsilon}_{0,t}, \tag{9}$$

where $\tilde{\varepsilon}_{0,t} \sim \mathcal{N}(0, I_{k_0})$ and $\tilde{\psi}_{01}, \tilde{\Lambda}_{00}$ and $\tilde{\Lambda}_{01}$ denote the structural parameters to be estimated. The relationship between the reduced form in (8) and the structural form in (9) can be seen by noting that $\psi_{01} = Q_0^{-1}\tilde{\psi}_{01}, \Lambda_{00} = Q_0^{-1}\tilde{\Lambda}_{00}, \Lambda_{01} = Q_0^{-1}\tilde{\Lambda}_{01}$ and $\varepsilon_{0,t} = Q_0^{-1}\tilde{\varepsilon}_{0,t}$. Finding the structural form of the model thus boils down to finding Q_0.

In what follows we can set $Q_0^{-1} = P_0 R_0$ where P_0 is the lower Cholesky factor of $\Sigma_{\varepsilon,0}$ and R_0 is an orthogonal $k_0 \times k_0$ matrix chosen by the researcher.[7] The variance-covariance structure of $\varepsilon_{0,t}$ is given by $\Sigma_{\varepsilon,0} = P_0^{-1} R_0 R_0' P_0^{-1'}$. This implies that, conditional on using a suitable rotation matrix R_0, we can back out the structural shocks.

In the present application we find R_0 by relying on sign restrictions. That is, we search for an orthogonal rotation matrix until we find an R_0 that fulfills a given set of restrictions on the impulse response functions. To obtain a candidate rotation matrix we draw R_0 using the algorithm outlined in Rubio-Ramírez et al. (2010). Since there is a multitude of R_0 that satisfies the restrictions, Fry and Pagan (2011) suggest to base the inference on the rotation matrix that gives the impulse responses closest to the median impulse responses obtained from the whole set of R.

After choosing R_0, we proceed by constructing a $k \times k$ matrix Q, where the first k_0 rows and columns correspond to Q_0.

Formally, Q looks like

$$Q = \begin{pmatrix} Q_0 & 0 & \cdots & 0 \\ 0 & I_{k_1} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & I_{k_N} \end{pmatrix}. \tag{10}$$

[7] Orthogonality implies that R_0 satisfies $R_0 R_0' = I_{k_0}$.

The corresponding structural form of the global model is:

$$QGx_t = \tilde{F}x_{t-1} + \tilde{\varepsilon}_t, \tag{11}$$

with $\Sigma_{\tilde{\varepsilon}} = G^{-1}\Sigma_{\varepsilon}G^{-1'}$ and assuming a block diagonal structure on Σ_{ε} as proposed in Eickmeier and Ng (2015).

The example above explains how to obtain structural impulse responses assuming country specific (local) shocks. Our case is more complicated, since we would like to specify economically meaningful shocks to variables in the group of euro area countries and two euro area common variables simultaneously. This triggers a set of additional challenges. First, taking into account the number of variable-country pairs and the potential number of sign restrictions, it would make the orthogonal rotation matrix huge and the overall procedure computationally costly. Second, we want to have the same economic interpretation of the shocks for all countries in the region so that the individual euro area country shocks can be combined into a euro area regional shock. This implies that rotation matrix coefficients for the same variables in different countries should be of the same sign and of the same relative size.

We propose to approach the multi-country structural shock identification in several steps: first, collect the orthogonal impulse responses of the euro area countries (i.e., based on the Cholesky decomposition); second, draw an orthogonal rotation matrix with dimensions equal to the number of unique variables in the euro area countries/region (the matrix dimensions are [variables x shocks]); third, expand the rotation matrix obtained along the variable dimension using country weights, which preserves the economic interpretation of shocks across countries. Fourth, apply the rotation matrix obtained to the orthogonal impulse responses and collect country impulse responses to shocks; fifth, aggregate the collected impulse responses with weights (e.g., GDP-PPP) and check if the sign restrictions (regional or country-specific) are satisfied. A simplified example of rotation matrix expansion is presented in Table 8. Importantly, the expanded rotation matrix $\tilde{R}$ obtained is a pseudo inverse matrix $\tilde{R}\tilde{R}^{+} = I$, thus the orthogonality condition of the rotation matrix is preserved.

Table 8: Orthogonal Rotation Matrix for the Euro Area Country Group

Rotation Matrix Expanded (Example)

	AD shock	MP shock	AS shock		AD shock	MP shock	AS shock
Shadow r	r11	r12	r13	Shadow r	r11	r12	r13
EUR/USD	r21	r22	r23	EUR/USD	r21	r22	r23
EA* y	r31	r32	r33	AT y	r31/W(AT)	r32/W(AT)	r33/W(AT)
EA* dp	r41	r42	r43	BE y	r31/W(BE)	r32/W(BE)	r33/W(BE)
EA* ltir	r51	r42	r53		...	...	...
				AT dp	r41/W(AT)	r42/W(AT)	r43/W(AT)
				BE dp	r41/W(BE)	r42/W(BE)	r43/W(BE)
					...	...	...
				AT ltir	r51/W(AT)	r52/W(AT)	r53/W(AT)
				BE ltir	r51/W(BE)	r52/W(BE)	r53/W(BE)
					...	...	...
				PT ltir	r51/W(PT)	r52/W(PT)	r53/W(PT)

We propose the following constraints to separate monetary policy disturbances from the other macroeconomic shocks. Table 9 summarizes the sign restrictions for identifying three main types of shocks – monetary policy, aggregate demand, and aggregate supply. Separating two additional shocks as opposed to leaving them as a residual in the analysis, should help pin down the monetary policy shock more clearly, as increasing the number of restrictions enhances the identification of the shock of interest (Paustian, 2007).

Table 9: Sign Restrictions

Shock	y	p	$i_s(shadow)$	i_l	e
Monetary Policy	↓	$\underline{\downarrow}$	↑	-	-
Aggregate Supply	↓	↑	↑	-	↑
Aggregate Demand	↓	↓	↓	-	-

Notes: The restrictions are imposed as $\geq$ / $\leq$ and on the growth rates of the variables in the table. They are imposed on impact and in the first quarters. The underlined arrow indicates an exception to this in the sense that the restriction is imposed in the second and third quarters.

The sign restrictions are defined for two blocks of variables: first, for euro area common variables – i.e., the shadow rate and the exchange rate – and second, for *aggregates* of the euro area country-specific variables – output, prices, and the long-term interest rate. In this way, we allow for heterogeneity in the aggregate effect of the euro area countries as a whole. Sign restrictions are imposed on impact and in the following quarter for all variables with the exception of the price reaction to the monetary policy shock. Allowing for price rigidities, we restrict the response of prices to the monetary policy shock to be negative in the second and third quarters only.

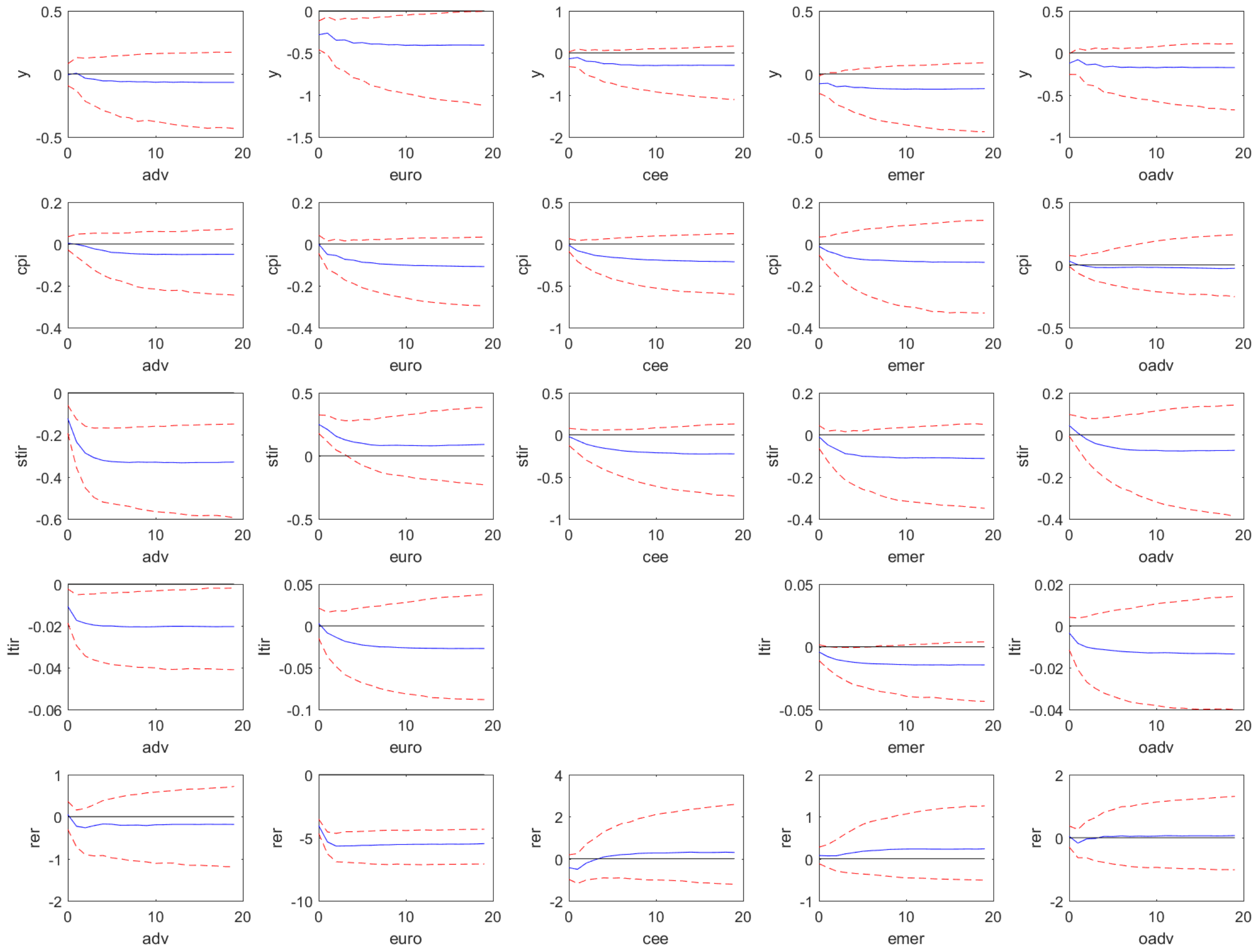
In choosing the identification of the monetary policy shock we followed the widely used assumption, that a monetary policy tightening will on aggregate reduce price growth, although not necessarily immediately (Georgiadis, 2015; Feldkircher and Huber, 2016; Chen et al., 2017; Uhlig, 2005). The effect on real GDP, however, is more ambiguous. Uhlig (2005) has shown that it can be either slightly positive or negative. We restrict the overall effect of euro area real GDP to be negative, while allowing for heterogeneity in the aggregate effect of the euro area countries by not restricting country-specific effects.

4. Empirical Results

In this section we present the responses to a +25 bp increase in the euro area's shadow rate.

We first show the regional impulse responses aggregated using GDP-PPP weights. Figure 3 plots the impulse responses, with the solid line representing median effects and the red dotted lines the 16th and 84th percentiles of 400 bootstrapped replications. A euro area shadow rate increase leads to a significant negative effect on aggregate output and the price level in the euro area – the latter, though, being less statistically significant. Real GDP and prices converge to a new equilibrium level after two years, with the peak decline occurring during the first year. The responses of CESEE countries are of similar and in some cases even higher magnitude. This can be explained by the high trade and financial connectivity of the region to euro area countries. The aggregate effects on output and prices in other regions are of smaller size and on average not statistically significant (in line with the results of Chen et al. (2017).

Figure 3: Impulse Responses to the Euro Area Monetary Policy Shock (Normalized to a 25 bp EA Shadow Rate Increase)



Notes: The figure displays the median impulse responses (solid blue lines) and the 68% confidence bands (red dotted lines) based on 400 bootstrap replications.

Analyzing the transmission of the euro area monetary policy shock in more detail, we present the impulse responses of real GDP and prices in euro area and CESEE countries. Our results are qualitatively in line with the findings of Ciccarelli et al. (2012), Mandler et al. (2016), and Bluwstein and Canova (2016). The country responses are very heterogeneous.

The effects on real GDP are strongest in Germany, Spain, and Ireland. They are weaker, but also statistically significant in Italy, France and Austria (see Figure 4). On average, a 25 bp increase in the euro area shadow rate reduces output in euro area countries by 0.4%. The relative strength and the size of the overall effect are very similar to the estimates provided in Boeckx et al. (2017) and Burriel and Galesi (2018), who assess monetary policy using an exogenous increase in the ECB's balance sheet.

The effects on the price level are statistically significant in Belgium, Germany, Spain, France, and Ireland (see Figure 5). On average, a 25 bp increase in the shadow rate leads to an decrease in the price level of 0.15%. The effect is particularly pronounced in Greece and Ireland, where on average it reaches 0.3–0.4%.

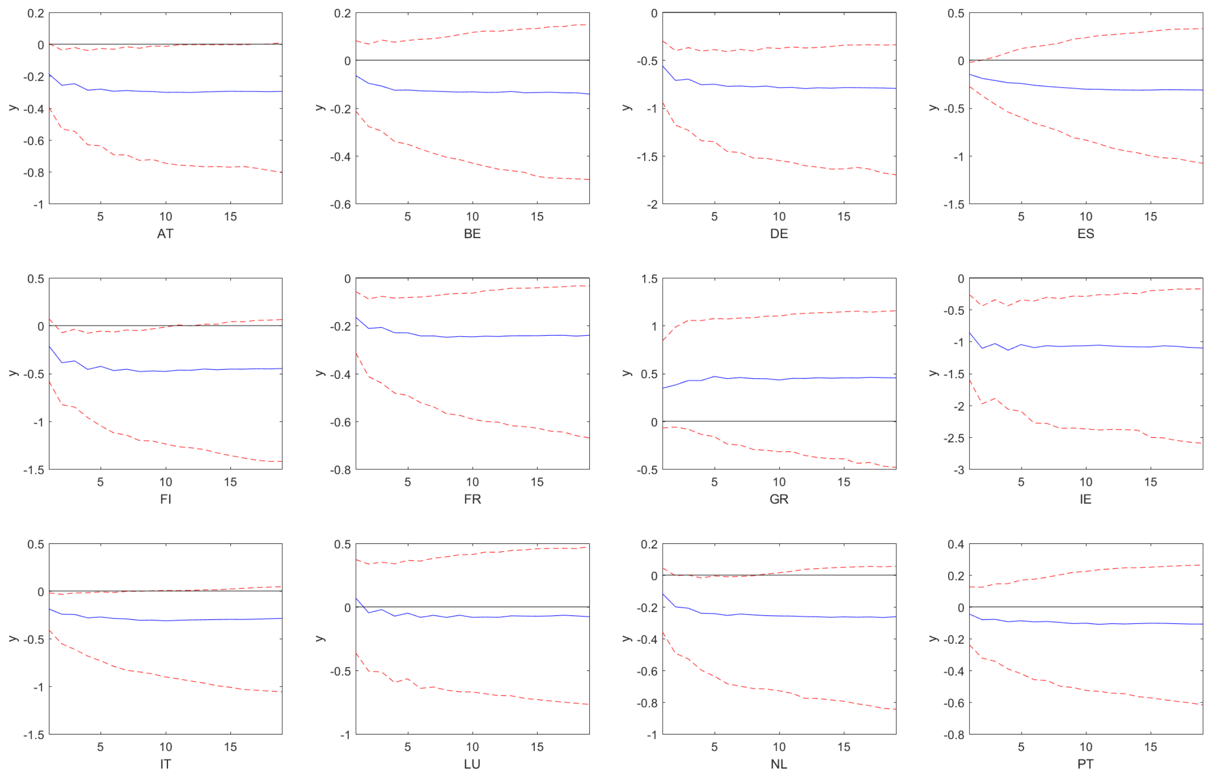
The effects of the euro area shock for CESEE countries are presented in Figures 6 and 7. On average the median output effect is strongest in the Baltic countries (0.5%) and weakest in Poland and Hungary (0.15%) (however insignificant). The effect is statistically significant at the longer horizon (in the Baltic countries, the Czech Republic, Poland, and Slovenia), indicating slower transmission of the shock to CESEE compared to euro area countries.

The effect on prices is statistically significant for the Czech Republic and Hungary (around 0.2%). In Bulgaria and Estonia, the effect is statistically significant in the long-run.

To check the overall validity of our results we examine spillovers from a euro area monetary policy shock using a modification of the euro area model. In this specification, euro area common variables are introduced as variables in the dominant unit block (see (4)). Dominant unit endogenous variables enter the euro area country equations only. Aggregated foreign variables in the dominant unit model are formed from euro area real GDP, prices, and long-term rates, while spillovers are allowed from the shadow rates in advanced countries (the US, the UK, and Japan). The exchange rate, in addition to the above-mentioned variables, assumes the feedback effect from the other exchange rates worldwide. The price of oil remains a global variable, but is now endogenously modeled inside the US country model. This exercise results in a slightly stronger reaction of both real GDP and prices in CESEE countries.

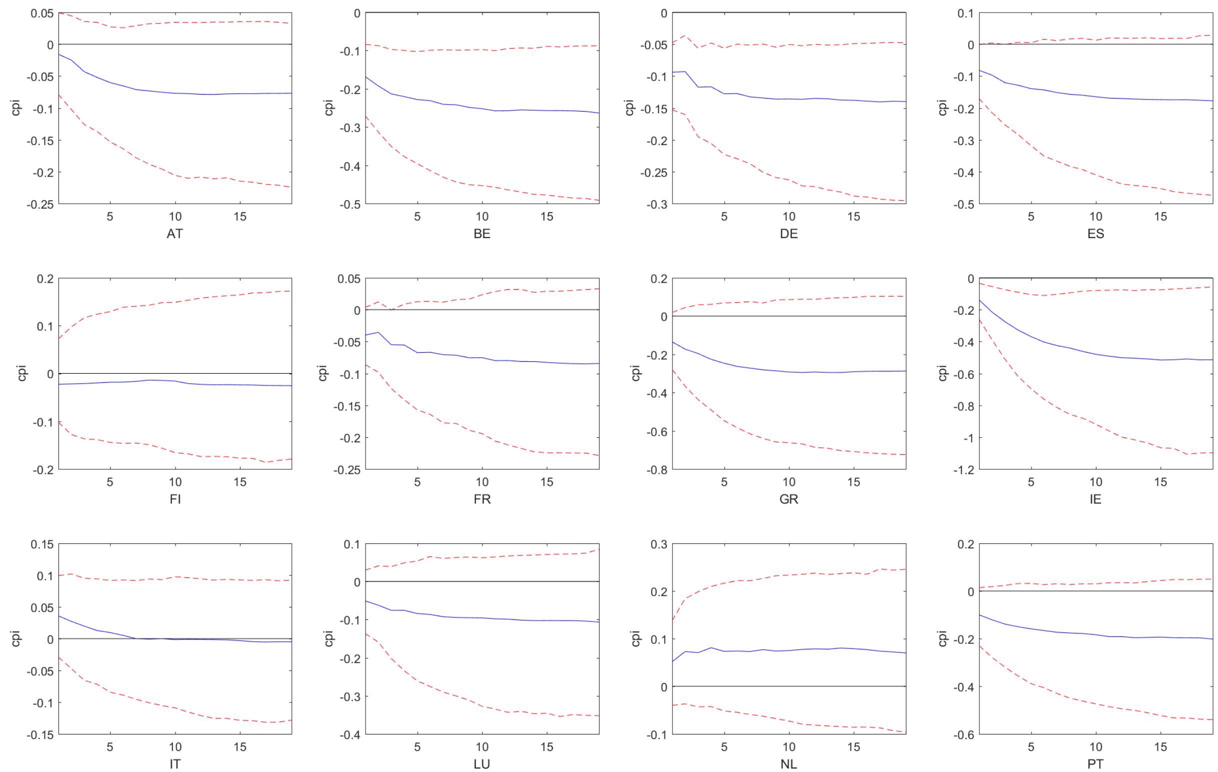
As another robustness check we try an alternative specification of the shadow rate, namely, that proposed by Wu and Xia (2016). As shown in Figure 1 their estimates of shadow rates for the euro area are quite similar to the ones provided by Krippner (2013). Not surprisingly then, our overall results are qualitatively unchanged when using the shadow rates of Wu and Xia (2016).

Figure 4: Impulse Responses of GDP in Euro Area Countries to the Euro Area Monetary Policy Shock (Normalized to a 25 bp EA Shadow Rate Increase)



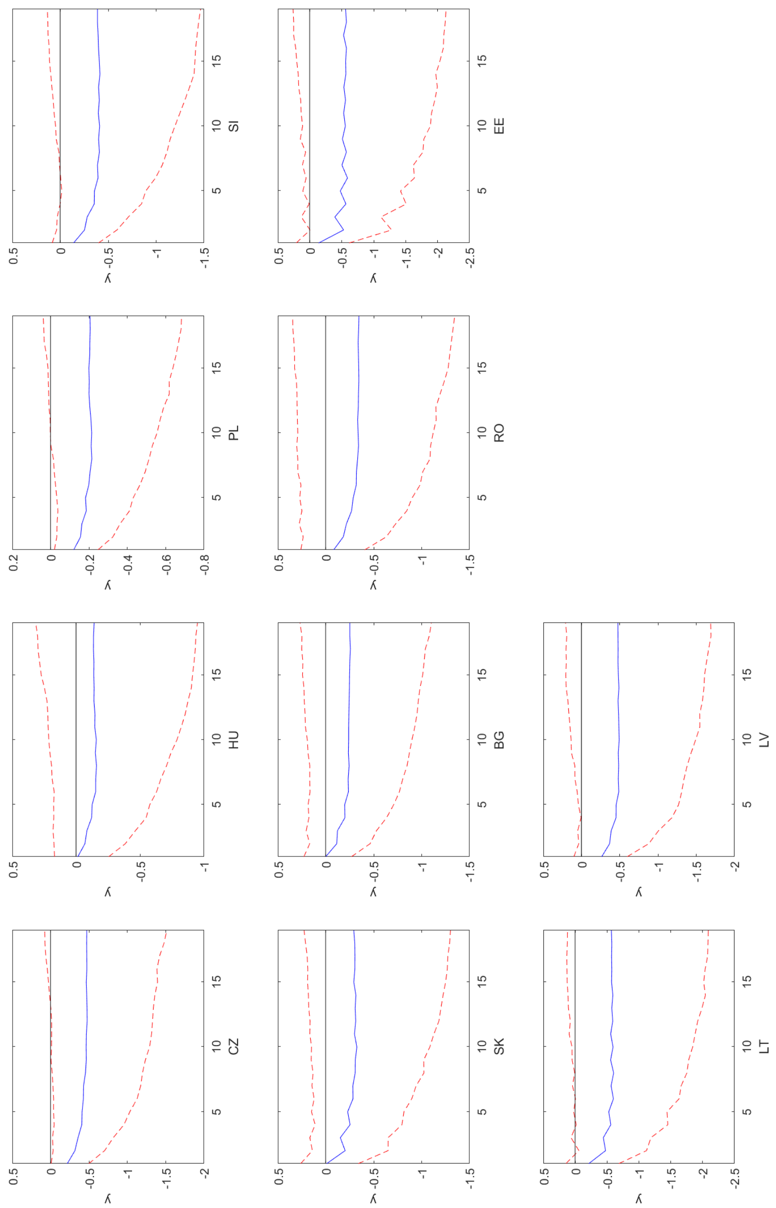
Notes: The figure displays the median impulse responses (solid blue lines) and the 68% confidence bands (red dotted lines) based on 400 bootstrap replications.

Figure 5: Impulse Responses of CPI in Euro Area Countries to the Euro Area Monetary Policy Shock (Normalized to a 25 bp EA Shadow Rate Increase)



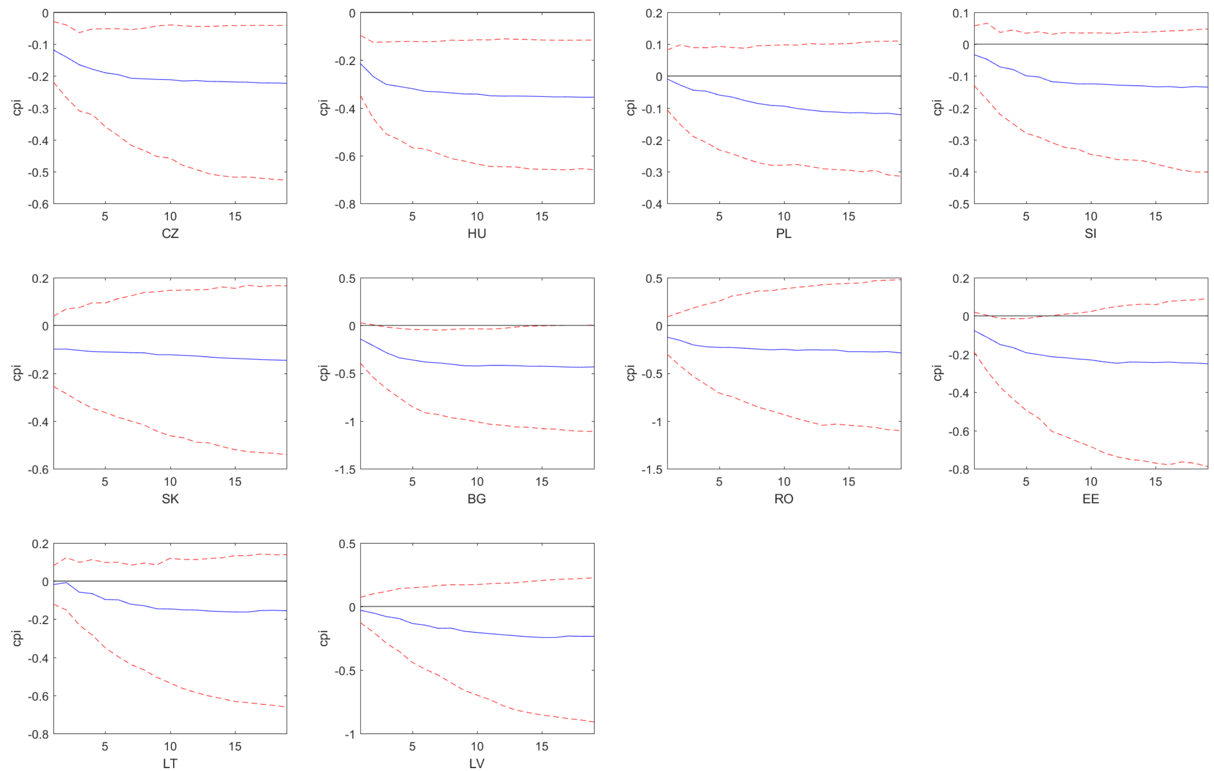
Notes: The figure displays the median impulse responses (solid blue lines) and the 68% confidence bands (red dotted lines) based on 400 bootstrap replications.

Figure 6: Impulse Responses of GDP in CESEE Countries to the Euro Area Monetary Policy Shock (Normalized to a 25 bp EA Shadow Rate Increase)



Notes: The figure displays the median impulse responses (solid blue lines) and the 68% confidence bands (red dotted lines) based on 400 bootstrap replications.

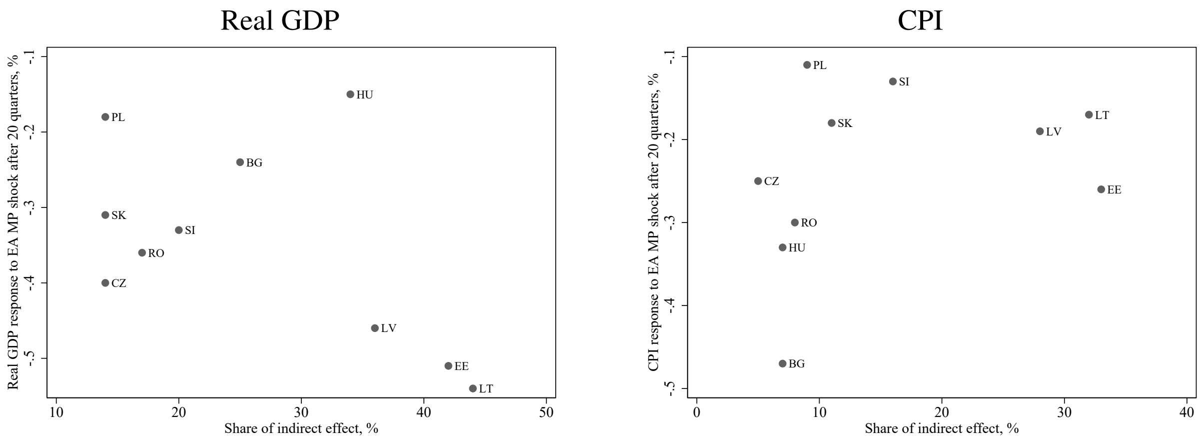
Figure 7: Impulse Responses of CPI in CESEE Countries to the Euro Area Monetary Policy Shock (Normalized to a 25 bp EA Shadow Rate Increase)



Notes: The figure displays the median impulse responses (solid blue lines) and the 68% confidence bands (red dotted lines) based on 400 bootstrap replications.

We also examine what proportion of a spillover effect can be traced back to the direct economic and financial linkages between the receiving country and the shock-originating country compared to indirect "knock-on" effects via third countries. For that purpose, we follow Cesa-Bianchi (2013) and manipulate the weight matrix in the second step of the GVAR layer. That is, we set the bilateral weights of CESEE and euro area countries to zero[8], "shutting off" the direct transmission of spillover effects from the euro area. The resulting responses can be interpreted as the proportion of the spillover that is caused by indirect effects through other economies besides the euro area countries. Figure 8 shows the ratio of the indirect effect to the total effect (on the x-axis) versus the total effect (on the y-axis) after 20 quarters. For the Baltic countries, in line with results presented by Burriel and Galesi (2018), knock-on effects through third countries account for most of the total effect on their real GDP (and less so in the case of prices). The Czech Republic, Poland and Slovakia, on the other hand, receive the highest share of the monetary policy effects directly from links to the euro area.

Figure 8: Ratio of the Indirect to the Total Effect of the Euro Area Monetary Policy Shock (Normalized to a 25 bp EA Shadow Rate Increase) after 20 Quarters



Notes: The scatter plots show the ratio of the indirect to total effect for real GDP and CPI on the x-axis and the total effect on the y-axis. The indirect effect is calculated using a CESEE-EA weight matrix that sets the weights to zero. Ratios close to zero indicate the importance of direct links from the euro area (EA12) countries, while large values show that knock-on effects via third countries account for most of the total effect on real GDP and CPI.

5. Conclusions

In this paper, we evaluate the effect of euro area monetary policy on output and prices, with a special focus on individual euro area and CESEE countries. As an overall measure of the monetary policy stance, we rely on shadow rates for the euro area, other advanced economies, and CESEE countries in which the policy rate hit the zero lower bound.

We propose a new way of treating the euro area in a GVAR framework, namely, by modeling the euro area as individual countries while treating euro area common variables, such as the interest rate and the exchange rate, jointly. The common variables enter the individual country models as foreign variables, and the aggregated euro area variables (real GDP, prices, and long-term rates) enter the equations for common variables with contemporaneous and lagged effects. We also propose a novel

[8] We do not re-distribute the weights that are set to zero to other economies yielding a weight matrix with row sums smaller than unity. This modification should not have any effect on the overall stability of the model (as opposed to having row sums of the weight matrix exceeding unity).

way of defining orthogonal shocks to a set of countries rather than a country by using an adjusted orthogonal rotation matrix, which preserves the economic interpretation of the shocks identified.

We find that in the majority of euro area and CESEE countries, the effect of a euro area shadow rate increase on real GDP and prices is negative but sometimes not precisely estimated. For euro area countries, our results emphasize the stabilizing role of euro area monetary policy. Looking at the effects in more detail, a shadow rate increase of 25 bp results in an average decline in real output of 0.4% and prices of 0.15% in euro area countries. The effect on real GDP in CESEE countries is especially pronounced in the Baltic countries and the Czech Republic (-0.5%). The price effects are stronger on average (at -0.2%) in CESEE than in the euro area and are significant for the Czech Republic, Bulgaria, and Hungary.

The effects of a euro area monetary policy shock on the Baltic countries can be accounted for to a large degree by second-round effects through other non-euro area countries. The Czech Republic and Poland, on the other hand, tend to be affected directly through their high degree of integration with the euro area.

References

AJEVSKIS, V. (2016): "A Term Structure of Interest Rates Model with Zero Lower Bound and the European Central Bank's Non-standard Monetary Policy Measures." Working Papers 2016/02, Latvijas Banka

BABECKA KUCHARCUKOVA, O., P. CLAEYS, AND B. VASICEK (2016): "Spillover of the ECB's Monetary Policy outside the Euro Area: How Different is Conventional from Unconventional Policy?" *Journal of Policy Modeling,* 38(2):199–225.

BACKÉ, P., M. FELDKIRCHER, AND T. SLAČÍK (2013): "Economic Spillovers from the Euro Area to the CESEE Region via the Financial Channel: A GVAR Approach." *Focus on European Economic Integration,* (4):50–64.

BELKE, A. AND T. OSOWSKI (2016): "Measuring Fiscal Spillovers in EMU and Beyond: A Global VAR approach." CEPS Papers 12109, Centre for European Policy Studies

BLUWSTEIN, K. AND F. CANOVA (2016): "Beggar-Thy-Neighbor? The International Effects of ECB Unconventional Monetary Policy Measures." *International Journal of Central Banking,* 12(3):69–120.

BOECKX, J., M. DOSSCHE, AND G. PEERSMAN (2017): "Effectiveness and Transmission of the ECB's Balance Sheet Policies." *International Journal of Central Banking,* 13(1):297–333.

BURRIEL, P. AND A. GALESI (2018): "Uncovering the Heterogeneous Effects of ECB Unconventional Monetary Policies across Euro Area Countries." *European Economic Review,* 101: 201–229.

CASTRÉN, O., S. DÉES, AND F. ZAHER (2010): "Stress-testing Euro Area Corporate Default Probabilities Using a Global Macroeconomic Model." *Journal of Financial Stability,* 6(2): 64 – 78.

CESA-BIANCHI, A. (2013): "Housing Cycles and Macroeconomic Fluctuations: A Global Perspective." *Journal of International Money and Finance,* 37(C):215–238.

CHAN-LAU, J. (2017): "Variance Decomposition Networks: Potential Pitfalls and a Simple Solution." Working Paper WP/17/107, International Monetary Fund

CHEN, Q., M. LOMBARDI, A. ROSS, AND F. ZHU (2017): "Global Impact of US and Euro Area Unconventional Monetary Policies: a Comparison." Working Papers 610, Bank of International Settlements; Working Papers

CHUDIK, A. AND M. FRATZSCHER (2011): "Identifying the Global Transmission of the 2007-2009 Financial Crisis in a GVAR Model." *European Economic Review,* 55(3):325–339.

CHUDIK, A. AND H. M. PESARAN (2016): "Theory and Practice of GVAR Modeling." *Journal of Economic Surveys,* 30:165–197.

CHUDIK, A. AND M. H. PESARAN (2013): "Econometric Analysis of High Dimensional VARs Featuring a Dominant Unit." *Econometric Reviews,* 32(5-6):592–649.

CICCARELLI, M., E. ORTEGA, AND M. T. VALDERRAMA (2012): "Heterogeneity and Cross-Country Spillovers in Macroeconomic-Financial Linkages." Working Paper Series 1498, European Central Bank

COMUNALE, M. AND J. STRIAUKAS (2017): "Unconventional Monetary Policy: Interest Rates and Low Inflation. A Review of Literature and Methods." DP 2017/26, Center for Operations Research and Econometrics, Université catholique de Louvain

DEES, S., F. DI MAURO, H. M. PESARAN, AND L. V. SMITH (2007): "Exploring the International Linkages of the Euro Area: a Global VAR Analysis." *Journal of Applied Econometrics,* 22 (1).

DEES, S., S. HOLLY, H. M. PESARAN, AND V. L. SMITH (2007): "Long Run Macroeconomic Relations in the Global Economy." *Economics - The Open-Access, Open-Assessment E-Journal,* 1(3):1–20.

DIEBOLD, F. X. AND K. YILMAZ (2009): "Measuring Financial Asset Return and Volatility Spillovers, with Application to Global Equity Markets." *The Economic Journal,* 119.

DIEBOLD, F. X. AND K. YILMAZ (2014): "On the Network Topology of Variance Decompositions: Measuring the Connectedness of Financial Firms." *Journal of Econometrics,* 182.

DOVERN, J. AND B. VAN ROYE (2014): "International Transmission and Business-Cycle Effects of Financial Stress." *Journal of Financial Stability,* 13(0):1 – 17.

EICKMEIER, S. AND T. NG (2015): "How Do Credit Supply Shocks Propagate Internationally? A GVAR Approach." *European Economic Review,* 74:128–145. Issue C

ELHORST, J. P., M. GROSS, E. TEREANU, ET AL. (2018): "Spillovers in Space and Time: Where spatial Econometrics and Global VAR Models Meet." Technical report

ELLER, M., M. FELDKIRCHER, AND F. HUBER (2017): "How Would a Fiscal Shock in Germany Affect Other European Countries? Evidence from a Bayesian GVAR Model with Sign Restrictions." *Focus on European Economic Integration,* (1):54–77.

FADEJEVA, L., M. FELDKIRCHER, AND T. REININGER (2017): "International Spillovers from Euro Area and US Credit and Demand Shocks: A Focus on Emerging Europe." *Journal of International Money and Finance,* 70:1–25.

FELDKIRCHER, M. AND F. HUBER (2016): "The International Transmission of US Shocks – Evidence from Bayesian global vector autoregressions." *European Economic Review,* 81 (C):167–188.

FELDKIRCHER, M., T. GRUBER, AND F. HUBER (2017): "Spreading the Word or Reducing the Term Spread? Assessing Spillovers from Euro Area Monetary Policy." Department of Economics Working Paper Series 5554, WU Vienna University of Economics and Business

FRY, R. AND A. PAGAN (2011): "Sign Restrictions in Structural Vector Autoregressions: A Critical Review." *Journal of Economic Literature,* 49(4):938–960.

GALESI, A. AND M. J. LOMBARDI (2013): *The GVAR Handbook: Structure and Applications of a Macro Model of the Global Economy for Policy Analysis,* chapter External shocks and international inflation linkages, pages 255–270. Oxford University Press.

GAMBACORTA, L., B. HOFMANN, AND G. PEERSMAN (2014): "The Effectiveness of Unconventional Monetary Policy at the Zero Lower Bound: A Cross-Country Analysis." *Journal of Money, Credit and Banking,* 46(4):615–642.

GARRAT, A., K. LEE, M. H. PESARAN, AND Y. SHIN (2006): *Global and National Macroeconometric Modelling: A Long-Run Structural Approach.* Oxford University Press.

GEORGIADIS, G. (2015): "Examining Asymmetries in the Transmission of Monetary Policy in the Euro Area: Evidence from a Mixed Cross-Section Global VAR Model." *European Economic Review,* 75(C):195–215.

HÁJEK, J. AND R. HORVÁTH (2018): "International Spillovers of (Un)Conventional Monetary Policy: The Effect of the ECB and US Fed on Non-Euro EU Countries." *Economic Systems,* forthcoming.

HÁJEK, J. AND R. HORVÁTH (2016): "The Spillover Effect of Euro Area on Central and Southeastern European Economies: A Global VAR Approach." *Open Economies Review,* 27(2): 359–385.

HORVÁTH, R. AND K. VOSLÁŘOVÁ (2016): "International Spillovers of ECB's Unconventional Monetary Policy: the Effect on Central Europe." *Applied Economics,* 0:1–13.

KRIPPNER, L. (2013): "Measuring the Stance of Monetary Policy in Zero Lower Bound Environments." *Economics Letters,* 118(1):135–138.

MANDLER, M., M. SCHARNAGL, AND U. VOLZ (2016): "Heterogeneity in Euro Area Monetary Policy Transmission: Results from a Large Multi-Country BVAR Model." Discussion Papers 03/2016, Deutsche Bundesbank, Research Centre

PAUSTIAN, M. (2007): "Assessing Sign Restrictions." *The B.E. Journal of Macroeconomics,* 7(1): 1–33.

PESARAN, M. H., T. SCHUERMANN, AND S. M. WEINER (2004): "Modeling Regional Interdependencies Using a Global Error-Correcting Macroeconometric Model." *Journal of Business and Economic Statistics, American Statistical Association,* 22:129–162.

PESARAN, M. H., T. SCHUERMANN, AND L. V. SMITH (2007): "What if the UK or Sweden Had Joined the Euro in 1999? An Empirical Evaluation Using a Global VAR." *International Journal of Finance and Economics,* 12(1):55–87.

PESARAN, M. H., T. SCHUERMANN, AND L. V. SMITH (2009): "Forecasting Economic and Financial Variables with Global VARs." *International Journal of Forecasting,* 25(4):642–675.

POTJAGAILO, G. (2017): "Spillover Effects from Euro Area Monetary Policy Across Europe: A Factor-Augmented VAR Approach." *Journal of International Money and Finance,* 72(C): 127–147.

RUBIO-RAMÍREZ, J. F., D. F. WAGGONER, AND T. ZHA (2010): "Structural Vector Autoregressions: Theory of Identification and Algorithms for Inference." *Review of Economic Studies,* 77(2):665–696.

UHLIG, H. (2005): "What are the Effects of Monetary Policy on Output? Results from an Agnostic Identification Procedure." *Journal of Monetary Economics,* 52(2):381–419.

WU, J. C. AND F. D. XIA (2016): "Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound." *Journal of Money, Credit and Banking,* 48(2-3):253–291.

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