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SPILLOVERS FROM EURO AREA MONETARY POLICY: A FOCUS ON EMERGING EUROPE



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ABBREVIATIONS

bp – basis point
CB – central bank
CESEE – Central, Eastern, and Southeastern Europe
CNB – Česká Národní Banka
CPI – consumer price index
EA – euro area
ECB – European Central Bank
EU – European Union
Fed – Federal Reserve System
GDP – gross domestic product
GVAR – global vector autoregressive
IFS – international financial statistics
IMF – International Monetary Fund
ISO – International Organisation for Standardisation
nsa – seasonally non-adjusted series
NSO – national statistical office
OE – Oxford Economics
OECD – Organisation for Economic Co-operation and Development
PPP – purchasing power parity
sa – seasonally adjusted series
UK – United Kingdom
US – United States
VAR – vector autoregression
VARX – vector autoregression with exogenous variables

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 modelling 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.

Keywords: euro area monetary policy, global vector autoregression, spillovers

JEL codes: C32, F44, E32, O54

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NON-TECHNICAL 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. First, in the period under review, several CBs, including the ECB, implemented unconventional measures, such as the asset purchase programme. 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. They 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 (e.g. in Chen et al. (2017), Hájek and Horváth (2018), Horváth and Voslářová (2016)) and introduces 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 modelling 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, e.g. 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 2008–2009 global financial crisis, major CBs 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 fuelled 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 M. Hashem 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 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.

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

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 the euro area itself and in neighbouring 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 CBs' 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 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 M. Hashem 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; 2007b)). Since then, the literature on GVAR modelling 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

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

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 $i = 0, \dots, N$:³

$$x_{it} = a_{i0} + \Phi_i x_{i,t-1} + \Lambda_{i0} x_{it}^* + \Lambda_{i1} x_{i,t-1}^* + \varepsilon_{it} \quad (1)$$

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 $t \in 1, \dots, T$, Φ_i denotes the $k_i \times k_i$ matrix of parameters associated with the lagged endogenous 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,

$$x_{it}^* = \sum_{j \neq i}^N \omega_{ij} x_{jt} \quad (2)$$

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 modelled in a separate country (EA) and are included in the euro area country-specific VARX models contemporaneously and with lags. These (EA) 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

$$\kappa_{jt} = a_{j0} + D_j \kappa_{j,t-1} + F_{j0} \hat{x}_t + F_{j1} \hat{x}_{t-1} + \varepsilon_{jt} \quad (3)$$

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

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

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

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

$$l_t = \mu_0 + \Phi_1 l_{t-1} + \Lambda_{l1} \tilde{x}_{t-1} + \eta_t \quad (4)$$

where l is a dominant unit variable and \tilde{x} is a set of world feedback variables $\tilde{x}_t = \widehat{W}x_t$ constructed using the GDP–PPP 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 .

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

$$A_i z_{it} = a_{i0} + B_i z_{it-1} + \Psi_0 l_t + \Psi_1 l_{t-1} + \varepsilon_{it} \quad (5)$$

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 lead to the global equation, which is given by

$$x_t = G^{-1} a_0 + G^{-1} H x_{t-1} + G^{-1} \Psi_0 l_t + G^{-1} \Psi_1 l_{t-1} + G^{-1} \varepsilon_t \quad (6)$$

where $G = (A_0 W_0, \dots, A_N W_N)'$, $H = (B_0 W_0, \dots, B_N W_N)'$, 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 $y_t = (x_t', \kappa_t', l_t)'$, equations (6), (3), and (4) can be written as

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

where

$$H_0 = \begin{bmatrix} G_0 & -\Psi_0 \\ -F_0 \widehat{W} & I \\ 0 & I \end{bmatrix}, H_1 = \begin{bmatrix} G_1 & \Psi_1 \\ F_1 \widehat{W} & D_1 \\ \Lambda_{l1} \widehat{W} & \Phi_1 \end{bmatrix}, h_0 = \begin{bmatrix} a_{i0} \\ a_{j0} \\ \mu_0 \end{bmatrix}, \zeta_t = \begin{bmatrix} \varepsilon_{it} \\ \varepsilon_{jt} \\ \eta_t \end{bmatrix}$$

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).

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.

Table 1
Country coverage

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

Abbreviations refer to the two-digit ISO country code.

Table 2
Data description (Q1 2001–Q4 2016)

Variable	Description	Min.	Mean	Max.	Coverage (%)
y	Real GDP, average of 2005 = 100. Seasonally adjusted, in logarithms.	4.19	0.66	5.54	100
p	Consumer price. CPI seasonally adjusted, in logarithms.	3.63	0.70	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_{i_S}	Shadow rate for the euro area.	-0.018	0.002	0.011	–
US_{i_S}	Shadow rate for the US.	-0.013	0.001	0.013	–
UK_{i_S}	Shadow rate for the UK.	-0.016	0.004	0.014	–
JP_{i_S}	Shadow rate for Japan.	-0.012	0.004	0.001	–
CZ_{i_S}	Shadow rate for the Czech Republic.	-0.017	0.018	0.056	–
BG_{i_S}	Shadow rate for Bulgaria.	-0.023	0.016	0.054	–
$poil$	Price of oil, seasonally adjusted, in logarithms.	2.96	0.10	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 (%).

The sample features 64 quarterly observations and spans the period from the first quarter of 2001 to the fourth quarter of 2016. The *variables* used in our analysis comprise data on real activity, consumer prices, the real exchange rate, short-term interest rates, long-term government bond yields, and oil prices (Dees et al. (2007a; 2007b), Pesaran et al. (2004; 2009; 2007)). The variables used in the model are briefly described in Tables 2 and 3. Most of the data are available with wide country coverage, with the exception of government bond yields. Since local capital markets in emerging economies (particularly 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	US	OE, sa	OECD, sa	IMF, IFS	IMF, IFS	
UK	UK	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, 3-month Treasury bills		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 CB provides an additional stimulus. This way, shadow rates allow for a continuous evaluation of the monetary policy

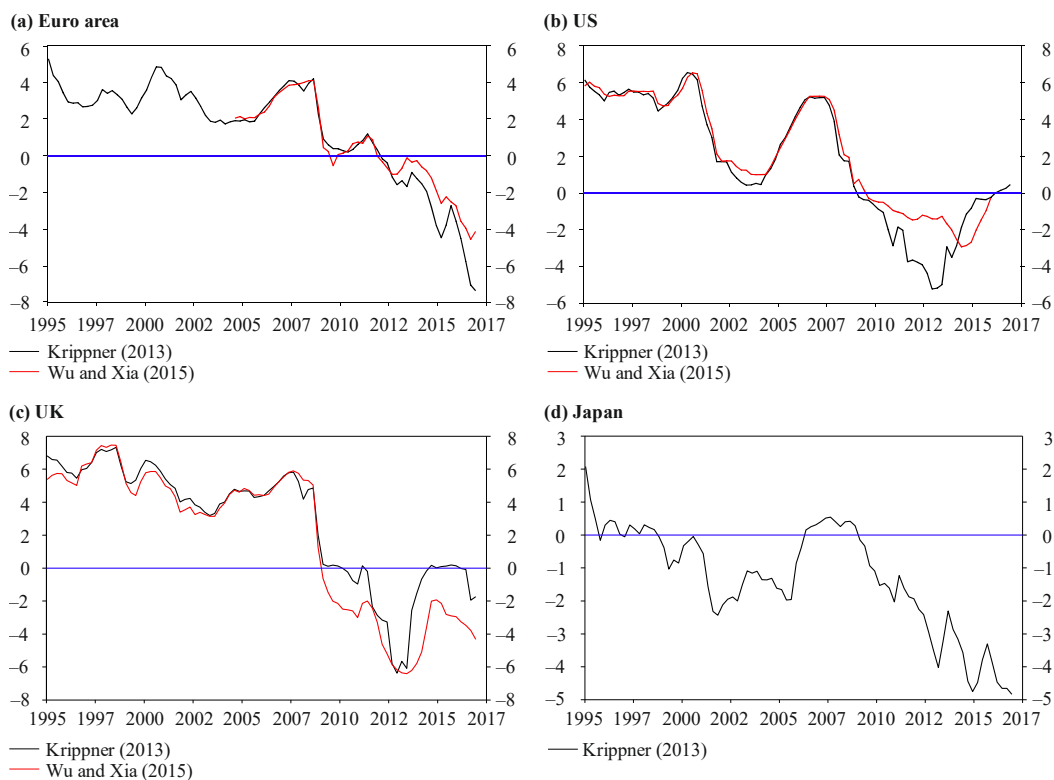
stance during periods of both conventional and unconventional monetary policy stimulus.

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) at Latvijas Banka and Babecká Kucharčuková et al. (2016) at Česká Národní Banka.

Several methods based on yield curve modelling 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

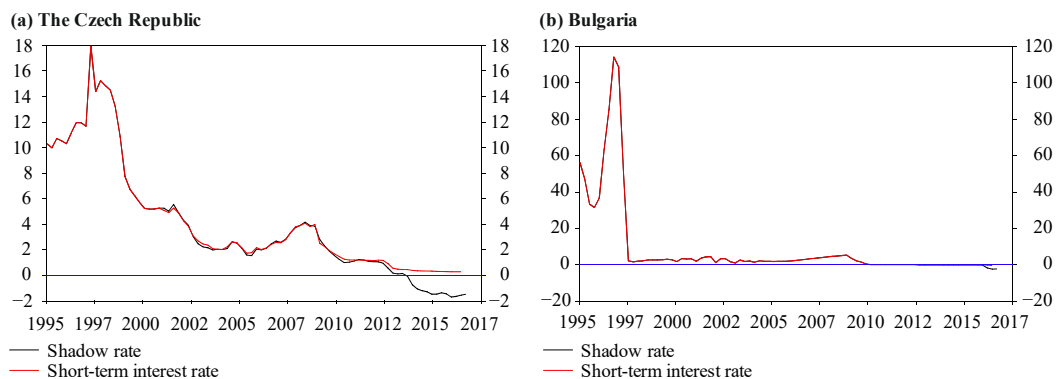


In this paper, we use the shadow rate of Krippner (2013) for the euro area, the US, the UK, and Japan. As a robustness check, we compare the results employing shadow rates from Wu and Xia (2016). Several CESEE and Baltic countries introduced the euro towards the middle or end of the period analysed in this paper (SK – in 2007, SI – in 2009, EE – in 2011, LV – in 2014, LT – in 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. The inclusion of 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



Note. 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 based exclusively 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 exposure⁶ 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-euro area countries as a foreign variable and we consequently leave these weights unrestricted. 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.

⁵ A recent paper by 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).

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
UK–DK	0	x	0	x	x	x
AT	x	x	x	0	x	x
BE–NL	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
UK–DK	0	x	0	x	x	x
AT	x	x	x	0	x	x
BE–NL	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
UK–DK	x	x	0	x	x	x
AT	0	0	0	0	0	0
BE–NL	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
UK–DK	x	x	0	0	0	0
AT	0	0	0	0	0	0
BE–NL	0	0	0	0	0	0
PT	0	0	0	0	0	0
Σ	1	1	1	1	1	1

Note. x – values between zero and 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, foreign output and interest rates in the German model and the foreign exchange rate in the Netherlands model 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.

Table 5

Test for weak exogeneity at the 5% significance level – baseline

Country	F test	Compliance (%)	ys	cpis	stirs	ltirs	rers	poil
Euro area	F(1,49)	100	0.51	0.49		0.35		0.06
US	F(1,49)	100	0.65				0.14	0.59
UK	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
Slovakia	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

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 6

Unit root tests for the domestic variables at the 5% significance level

Country	Dy	Dy	Dcpi	Dcpi	Dstir	Dstir	Dltir	Dltir	Drer	Drer
	ADF	WS	ADF	WS	ADF	WS	ADF	WS	ADF	WS
Compliance (%)	92	100	59	78	96	88	100	100	80	88
Euro area					-5.38	-5.60			-2.98	-2.66
US	-3.82	-3.98	-5.43	-5.67	-2.99	-2.47	-7.02	-7.28		
UK	-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
Slovakia	-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*	Dy*	Dcpi*	Dcpi*	Dstir*	Dstir*	Dltir*	Dltir*	Drer*	Drer*
	ADF	WS	ADF	WS	ADF	WS	ADF	WS	ADF	WS
Compliance (%)	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
US	-4.04	-4.06	-4.92	-5.08	-4.66	-4.82	-6.57	-6.76	-5.33	-5.55
UK	-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
Slovakia	-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 $i = 0$:

$$x_{0,t} = \psi_{01}x_{0,t-1} + \Lambda_{00}x_{0,t}^* + \Lambda_{01}x_{0,t-1}^* + \varepsilon_{0,t} \quad (8).$$

The structural form of the model is given by

$$Q_0x_{0,t} = \tilde{\psi}_{01}x_{0,t-1} + \tilde{\Lambda}_{00}x_{0,t}^* + \tilde{\Lambda}_{01}x_{0,t-1}^* + \tilde{\varepsilon}_{0,t} \quad (9)$$

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 $Q_0^{-1} = P_0R_0$ 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 $\Sigma_{\varepsilon,0} = P_0^{-1}R_0R_0'P_0^{-1'}$. 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, i.e. 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

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

⁷ Orthogonality implies that R_0 satisfies $R_0R_0' = I_{k_0}$.

The corresponding structural form of the global model is:

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

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 12 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 summarises 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	$i_s(\text{shadow})$	i_l	e
Monetary policy	↓	<u>↓</u>	↑	–	–
Aggregate supply	↓	↑	↑	–	↑
Aggregate demand	↓	↓	↓	–	–

Notes. The restrictions are imposed as \geq/\leq on the growth rates of the variables in the table. They are imposed on impact in the first quarter. 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, i.e. 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.

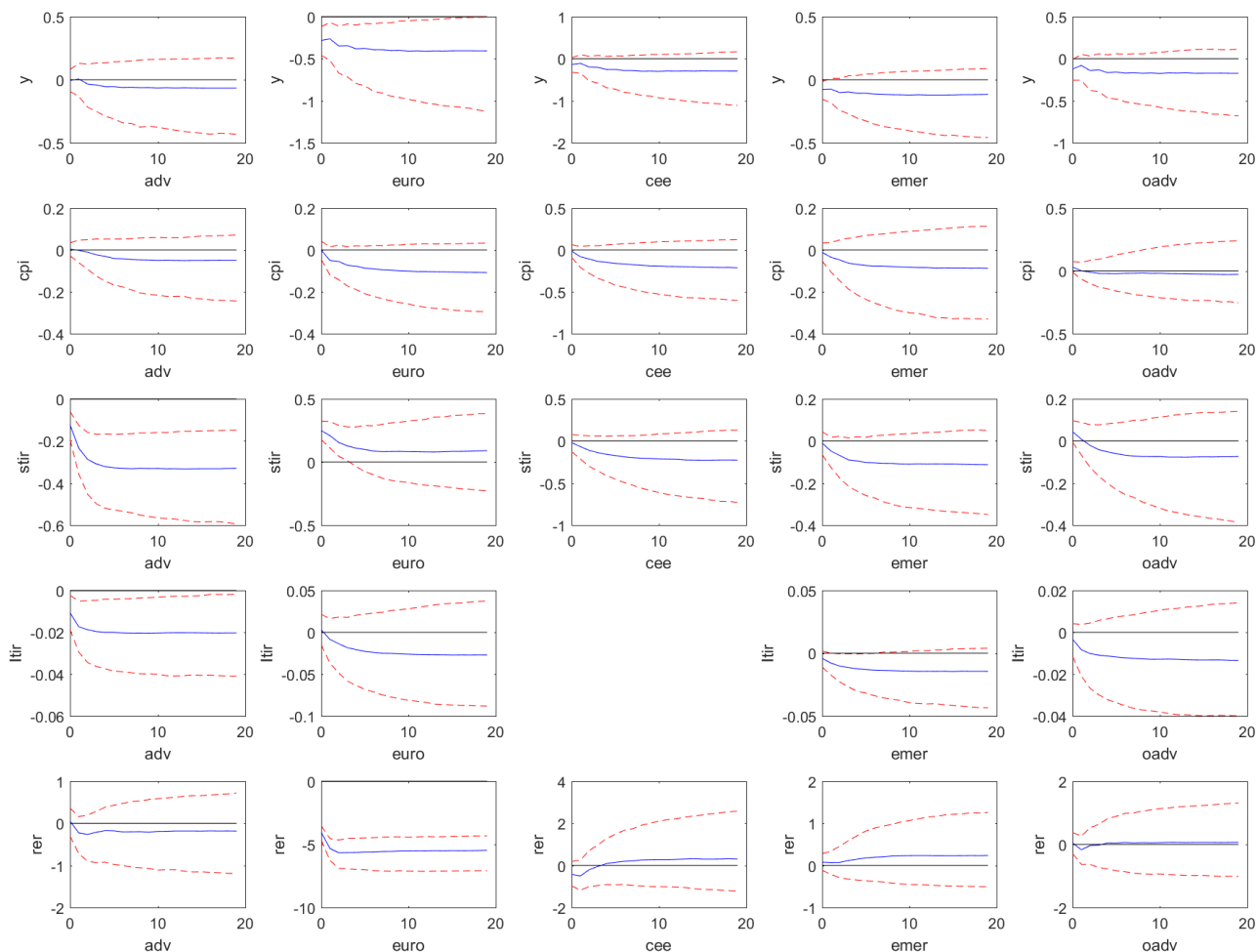
In choosing the identification of the monetary policy shock, we followed the widely used assumption that monetary policy tightening will on aggregate reduce price growth, although not necessarily immediately (Georgiadis (2015), Feldkircher and Huber (2016), Chen et al. (2017), Uhlig (2005)). The effect 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 bootstrap 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 (normalised to a 25 bp increase in the euro area shadow rate)



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

Analysing 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 increase in the price level of 0.15%. The effect is particularly pronounced in Greece and Ireland where it reaches on average 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 countries compared to euro area countries.

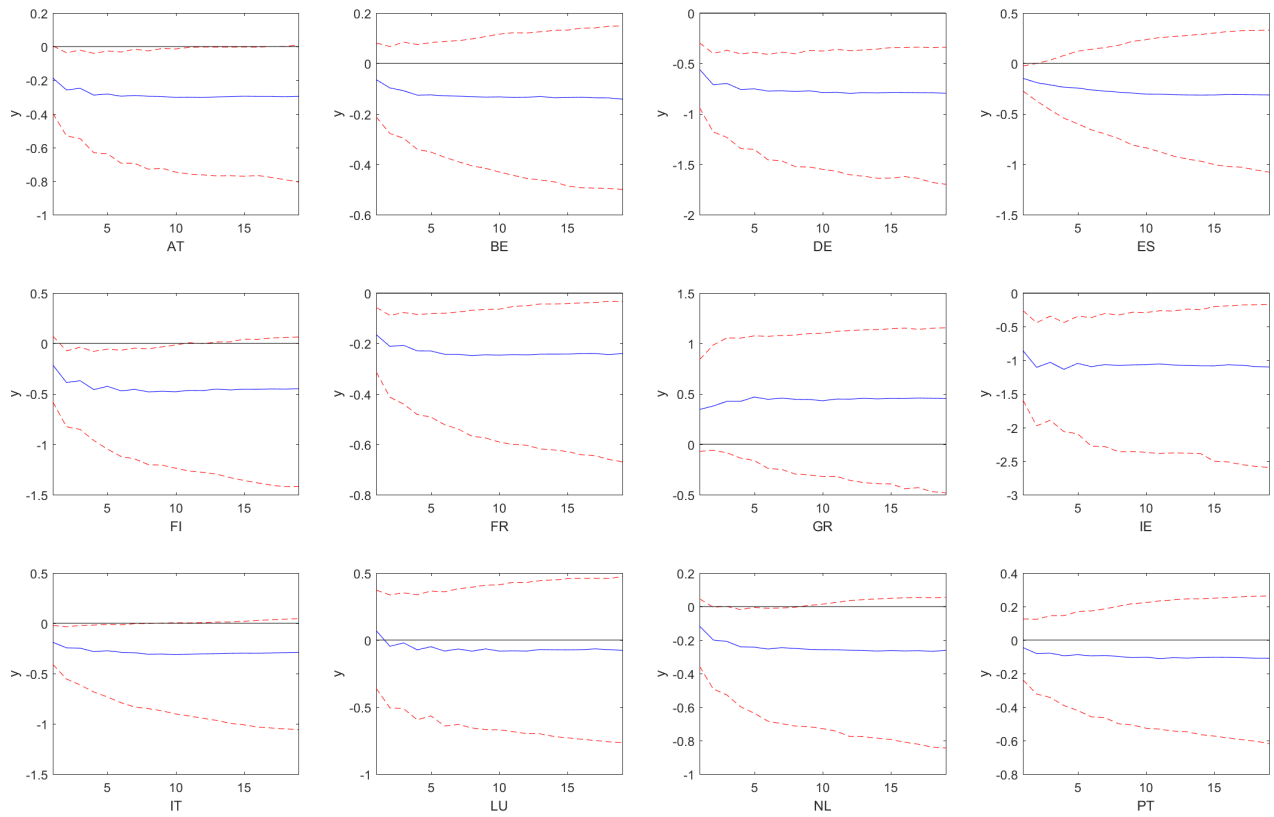
The effect on prices is statistically significant for the Czech Republic and Hungary (around 0.2%). In Bulgaria and Estonia, the effect is statistically significant in the long run.

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 equation (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 modelled 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, the one 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

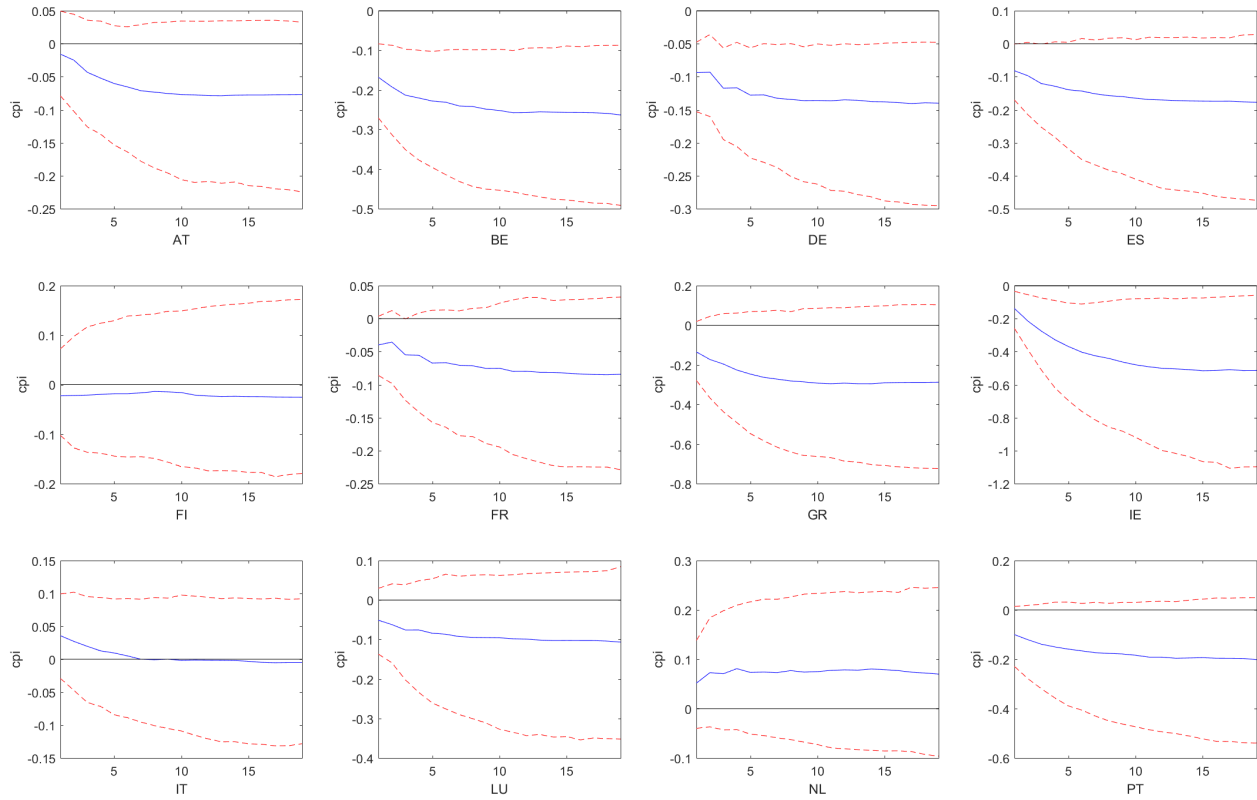
Impulse responses of GDP in euro area countries to the euro area monetary policy shock (normalised to a 25 bp increase in the euro area shadow rate)



Note. 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

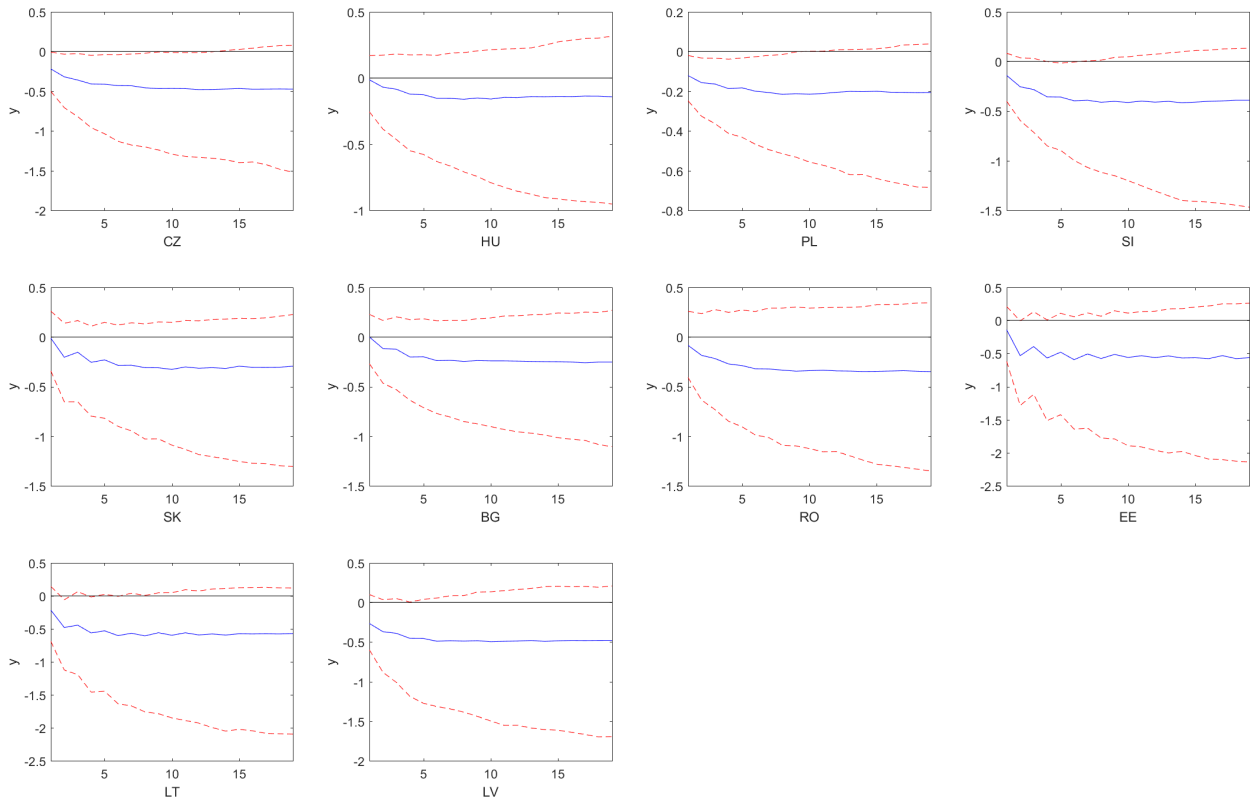
Impulse responses of CPI in euro area countries to the euro area monetary policy shock (normalised to a 25 bp increase in the euro area shadow rate)



Note. 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

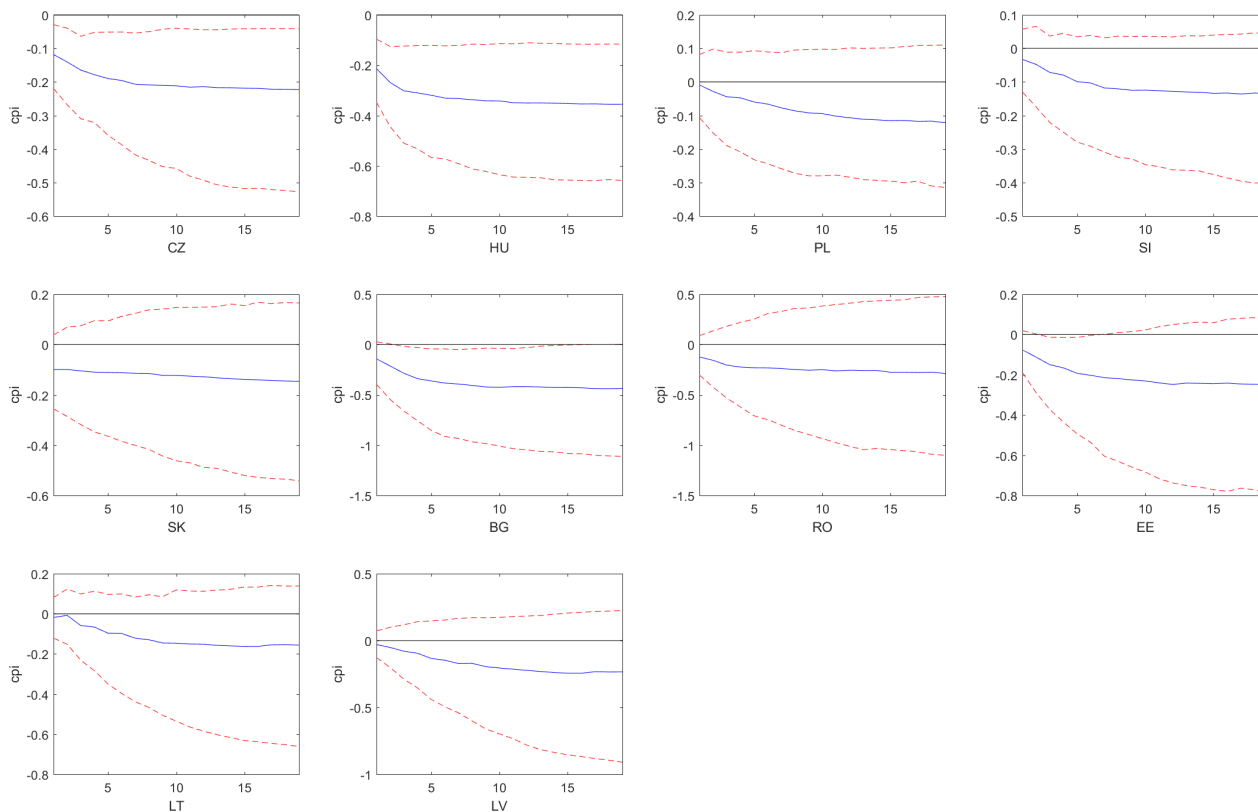
Impulse responses of GDP in CESEE countries to the euro area monetary policy shock (normalised to a 25 bp increase in the euro area shadow rate)



Note. 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 (normalised to a 25 bp increase in the euro area shadow rate)



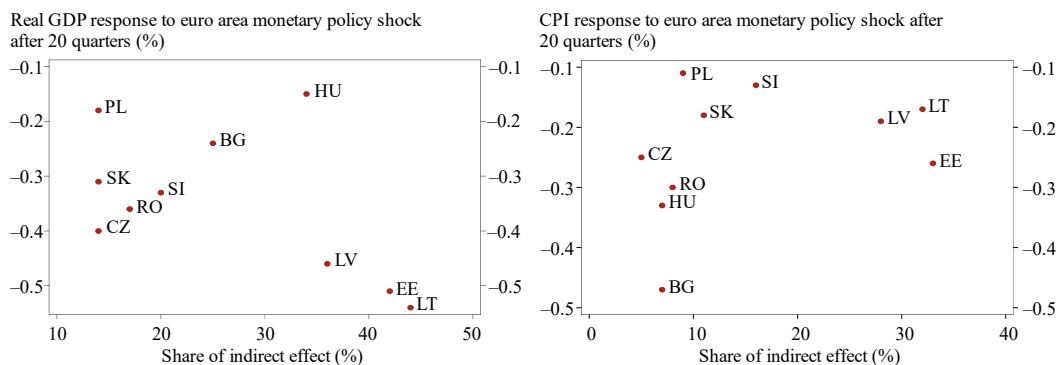
Note. The figure displays the median impulse responses (solid blue lines) and the 68% confidence bands (red dotted lines) based on 400 bootstrap replications.

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, i.e. 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 caused by indirect effects through other economies besides 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 the 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.

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).

Figure 8

Ratio of the indirect to the total effect of the euro area monetary policy shock (normalised a 25 bp increase in the euro area shadow rate) 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 12 euro area 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 modelling 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 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 emphasise the stabilising 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 countries than in the euro area countries 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.

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