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Keywords: Monetary policy, Euro area, Central and Eastern Europe, exchange rate regime, financial transmission, FAVAR

JEL classification: C33, E52, E58, F42.

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Spillover Effects from Euro Area Monetary Policy across the EU: A Factor-Augmented VAR Approach*

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March 11, 2016

Abstract

I analyze spillover effects from Euro area monetary policy shocks to thirteen EU countries outside the Euro area, i.e., ten countries from Central and Eastern Europe (CEE) and three Western EU members. The analysis is based on a FAVAR model with two blocks which exploits a large cross-country data set covering real activity variables, prices and financial variables. An expansionary Euro area monetary policy shock raises production in most non-Euro area countries. Somewhat larger and more instantaneous responses of production are observed in small open economies with fixed exchange rate regimes, where foreign demand effects are particularly strong. In addition, a Euro area monetary expansion leads to declines in interest rates and reductions in uncertainty in most non-Euro area countries. The spillovers on uncertainty are more pronounced in economies with flexible exchange rates, where the degree of financial market openness tends to be higher and where exchange rate appreciations further enhance risk taking by cushioning debt burdens from foreign currency loans. Finally, spillover effects on prices are heterogeneous across countries and behave asymmetrically in most CEE countries.

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1 Introduction

Strong integration in trade and financial markets within the European Union (EU) is likely to cause spillovers from domestic policies across member states. In particular, EU countries might be affected by the single monetary policy in the Euro area, even without being members of the monetary union. The small and open economies from Central and Eastern Europe (CEE), which joined the EU in 2004 and 2007 and have since deepened their economic and financial integration with the Euro area, are particularly exposed to spillover effects from Euro area monetary policy. Some of these countries pegged their currencies against the Euro and have recently joined the Euro area (Slovakia, Slovenia, Estonia, Latvia and Lithuania). In other CEE countries, monetary authorities maintain an exchange rate peg (Bulgaria) or limit exchange rate fluctuations against the euro due to high foreign currency lending exposures (Czech Republic, Hungary, Poland, Romania). But also Western EU members outside the monetary union such as Sweden, Denmark and the UK, are strongly financially integrated with the Euro area and have highly developed financial markets which might fuel monetary policy spillovers from the Euro area to these economies.

The direction and size of such spillovers is of high interest for policy makers and central banks in non-Euro area countries. In particular, they might need to react to spillovers from a highly expansionary monetary policy conducted by the European Central Bank (ECB) since the recent financial and Eurozone crises, as well as from a future exit from this policy. To the extent that these economies experience similar economic conditions as the Euro area, symmetric spillovers from a Euro area monetary expansion can be an important stimulus and can contribute to closing the output gap in these countries. If, however, non-Euro area economies are already at a point of the business cycle where no additional monetary stimulus is needed, symmetric spillovers could rather entail an overheating of the economy with lower levels of risk perceptions, capital inflows and rising asset prices. A thorough understanding of such spillover effects is thus crucial for the design of appropriate domestic monetary and macroprudential policies, which in the optimal case should allow to reap the benefits from strong economic and financial integration with the Euro area, while mitigating the associated risks.

In the present paper, I contribute to the understanding of monetary policy spillovers by analyzing the transmission of Euro area monetary policy shocks to macroeconomic aggregates of thirteen European countries which are outside the Euro area or have adopted the Euro only recently (referred to as "non-Euro area countries" in the following). The analysis uses a factor-augmented VAR (FAVAR) approach and is based on a large data set, including not only real activity variables and prices, but also financial variables such as interest rates, share prices and a measure of stock market volatility as proxy of uncertainty and risk perceptions (Bloom, 2009; Bruno and Shin, 2015a). Further, spillover effects from identified Euro area monetary policy shocks to real activity and financial variables are compared across different country groups, i.e., countries with different degrees of trade and financial openness, as well as countries with fixed and flexible exchange rate regimes.

The results from the empirical analysis suggest that symmetric spillovers on production via foreign demand effects and via the financial channel are sizable and that they outweigh expenditure switching effects from exchange rate movements. Whereas the trade channel dominates in the spillover effects to small open economies with fixed exchange rate regimes, the financial channel is relatively more pronounced in larger and more financially developed economies with flexible exchange rates.

From a theoretical point of view, the direction of spillover effects from Euro area shocks to non-Euro area economies can be ambiguous and can operate via various channels. Standard Mundell-Flemming-Dornbusch models focus on international spillover effects via trade (Dornbusch, 1980; Obstfeld and Rogoff, 1996, chapter 9). For countries that fix their exchange rate against the foreign currency, the trade channel suggests that domestic output should move in the same direction as foreign output via increased foreign demand. By contrast, in countries with flexible exchange rates, asymmetric movements driven by exchange rate adjustments counteract the demand channel and the direction of spillovers is a priori ambiguous. In addition, foreign monetary policy can transmit symmetrically to the domestic economy via the financial channel. If the foreign country is a large open economy, a drop in the foreign interest rate can lower domestic interest rates indirectly via a decline in world interest rates (Svensson and van Wijnbergen, 1989; Obstfeld and Rogoff, 1996, chapter 10). Moreover, in presence of highly integrated financial markets with globally operating banks and cross-border leverage, foreign monetary policy can transmit to the domestic economy via the banking sector (Cetorelli and Goldberg, 2012). On the one hand, this stimulates domestic investment and leads to symmetric international co-movements in output (Devereux and Yetman, 2010). On the other hand, persistently low costs of foreign funding can increase risk-taking and enhance credit booms or surges in capital flows (Bruno and Shin, 2015a; Rey, 2015).

In view of these mixed theoretical predictions, it becomes an empirical question which of these channels dominate and whether spillover effects from foreign monetary policy vary with the exchange rate regime and with the level of trade and financial integration. Indeed, there exists a substantial empirical literature that analyzes the international transmission of monetary policy shocks, mostly applying structural VAR models or dynamic factor analysis. Early studies focus on the international effects of US shocks. Kim (2001) finds that expansionary US monetary policy stimulates output in G-6 countries, where the transmission operates via a decrease in world interest rates. Canova (2005) finds that US monetary policy shocks have strong effects on Latin American economies and that these spillovers mainly operate via the financial channel. In particular, a monetary policy contraction in the US leads to increases in domestic interest rates of Latin American countries and these effects are stronger in countries which fix their exchange rate against the dollar. Georgiadis (2015) estimates spillover effects from US monetary policy to a large set of countries using a GVAR approach. He finds that spillover effects on output are stronger in countries which are less financially developed, less open to trade and which have less flexible exchange rates and labor markets. Another set of papers examines the transmission of common Euro area monetary policy shocks across member states of the monetary union (Peersman, 2004; Boivin et al., 2008; Barigozzi et al., 2014). A common finding of these studies is that Euro area monetary policy transmits rather homogeneously to output in different member states, but that there remain asymmetries in the responses of prices and unemployment.

Monetary policy spillovers to European countries outside of the Euro area have also received attention in the literature. Mumtaz and Surico (2009) use a FAVAR approach to estimate the effects of an international monetary policy shock on the UK and find that, after a foreign monetary expansion, UK output increases despite an appreciation of the exchange rate. Using an SVAR approach, Jannsen and Klein (2011) find that Euro area monetary policy shocks induce significant proportional effects on interest rates and output in five Western non-Euro countries. Regarding countries from Central and Eastern Europe, Eickmeier and Breitung (2006) estimate a dynamic factor model for the Euro area and eight CEE countries. They find that in most CEE countries, output responds positively to an expansionary Euro area monetary policy shock, whereas the responses of inflation are mixed across CEE countries and insignificant in most cases. Jiménez-Rodríguez et al. (2010) receive comparable results when estimating a near-VAR model with structural breaks for ten CEE countries and a longer sample period. Benkovskis et al. (2011) estimate country-specific FAVAR models for Hungary, Poland and the Czech Republic and find that, after a contractionary Euro area monetary policy shock, exchange rates in the three countries depreciate and prices increase, whereas real activity variables decline being rather driven by reduced foreign demand. Finally, Feldkircher (2014) and Hájek and Horváth (2015) apply GVAR models to analyze the transmission of Euro area interest rate shocks to a large set of non-Euro area countries and find symmetric responses of output in most non-Euro area countries, with small economies reacting even stronger than the Euro area.

Overall, the existing empirical studies on spillover effects from Euro area monetary policy to non-Euro area countries, focus either on a small number of countries (Mumtaz and Surico, 2009; Benkovskis et al., 2011), do not account for potential spillover effects between non-Euro area countries (Jiménez-Rodríguez et al., 2010), or consider the responses of output and prices only (Eickmeier and Breitung, 2006; Feldkircher, 2014; Hájek and Horváth, 2015). Also, these studies focus on spillover effects via the trade channel, whereas the financial channel has only been accounted for in the analysis of spillovers from equity price and output shocks (Galesi and Sgherri, 2013; Backé et al., 2013), or in the analysis of spillovers from unconventional monetary policy measures (Bluwstein and Canova, 2015; Halova and Horváth, 2015).

I contribute to this literature by analyzing spillover effects of Euro area monetary policy to thirteen EU countries outside the Euro area, including countries from Central and Eastern Europe and Western economies, simultaneously within a cross-country factor model. I jointly consider the reactions of real activity and financial variables in order to account for both the trade and the financial channels of monetary policy transmission. In addition, I compare impulse responses across country groups in order to investigate the role of the exchange rate regime and of a country's openness towards trade and finance for the size of spillover effects.

In particular, I estimate a FAVAR model with two blocks of factors. The first block describes the joint dynamics of the Euro area and is assumed to be block-exogenous with respect to non-Euro area variables. The second block summarizes the joint dynamics behind non-Euro area variables that are not driven by the Euro area business cycle. The dynamics of the estimated factors are then modeled, together with the Euro area short-term interest rate as policy variable, within a VAR in the vein of Bernanke et al. (2005). Euro area monetary shocks are identified by assuming that the Euro area interest rate does not react contemporaneously to a rotation of Euro area factors which captures the dynamics of slow-moving Euro area variables. The analysis is based on a large data set covering monthly time series for the period from 1999 and 2013. The data set includes the main macroeconomic and financial aggregates from the aggregate Euro area, as well as from individual Euro area member states, ten CEE countries and three Western European countries (Sweden, Denmark, UK).

The findings of the analysis are as follows. An expansionary Euro area monetary policy shock raises production in most EU countries that are outside the Euro area. These effects are on average comparable to the response of industrial production in the aggregate Euro area. In addition, interest-rate declines and reductions of uncertainty are observed in most non-Euro area countries after a Euro area monetary expansion, whereas prices react heterogeneously across countries. Regarding differences in spillover effects across countries, somewhat larger and more instantaneous responses of production are observed in small open economies with fixed exchange rate regimes, where foreign demand effects are particularly strong. Nonetheless, spillovers to real activity in countries with flexible exchange rates are also sizable and result as a combination of positive foreign demand effects, negative expenditure switching effects and stimulating financial spillovers. In particular, the spillover effects on uncertainty after a Euro area monetary expansion are more pronounced in countries with flexible exchange rate regimes, where the degree of financial market openness tends to be higher and where exchange rate appreciations further enhance risk taking by cushioning debt burdens from foreign currency loans. Finally, consumer and producer prices tend to increase in the three Western economies, but behave asymmetrically in most transition economies from Central and Eastern Europe. In the latter country group, price dynamics seem to rather be driven by domestic factors such as price regulations in the service sector and productivity increases in the course of the CEE countries' accession to the European Union.

These results survive a number of robustness checks. In particular, results remain qualitatively similar when the FAVAR model is estimated over two sub-samples, before and after the financial crisis which started in 2007. Results are also robust when using a shadow rate measure as Euro area policy variable to account for the use of unconventional monetary policies and the zero lower bound on nominal interest rates. Further, results are highly robust to alternative specifications of the FAVAR model and to alternative numbers of estimated factors.

The remainder of this paper is organized as follows. Section 2 describes the empirical methodology and presents the data set as well as the preferred specification of the model. Section 3 presents and discusses the main results and then investigates the role of trade and financial openness for cross-country differences in the size of spillover effects. Section 4 shows the results from a number of robustness checks. Section 5 concludes.

2 Empirical Methodology

The empirical analysis is based on a factor-augmented vector-autoregressive model (FAVAR) with two blocks of factors. For this purpose, a small number of factors is extracted from large sets of Euro area and non-Euro area time series, respectively. A VAR model including the two factor groups and the Euro area short-term interest rate is then estimated. Finally, a Euro area monetary policy shock is identified by imposing an ordering on the factors and the Euro area short-term interest rate. Impulse responses to the monetary policy shock can then be calculated for each time series of interest from the large data set. In the following, I present each step of the estimation in detail and I describe the data used for the analysis.

2.1 The FAVAR model with two blocks

The general FAVAR model was developed by Bernanke et al. (2005) and can be considered as a version of a structural dynamic factor model (Stock and Watson, 2005; Forni et al., 2009). It describes the dynamics of a a small set of estimated factors, which summarize the common components of a large set of time series, together with an observed policy variable within a vector-autoregressive (VAR) model. The number of estimated factors included in the VAR remains relatively small, but the model is less likely to suffer from omitted variable bias compared to standard SVAR models because the factors summarize information from a large data set. Numerous studies have extended the FAVAR model to a cross-country framework, mostly following two approaches. The first set of papers analyzes international spillover effects from domestic shocks using FAVAR models with two blocks—a block of foreign factors summarizing joint dynamics in the data of a foreign economy or region and a second block describing the dynamics of a domestic economy (see among others Mumtaz and Surico, 2009; Benkovskis et al., 2011; Charnavoki and Dolado, 2014). Other studies rather consider the transmission of common shocks across a group of economies. They extract factors from a cross-country data set and thus model the joint dynamics of various countries with a set of common factors (Eickmeier and Breitung, 2006; Boivin et al., 2008; Barigozzi et al., 2014; Belke and Rees, 2014).[1]

In the present paper, I combine features of both approaches. As my interest lies in the analysis of spillovers of monetary policy shocks from the Euro area to non-Euro area countries, I adopt a model with two blocks of factors. At the same time, the aim is to compare these spillovers across various non-Euro area countries that are also likely to be interconnected among each other. For this purpose, each block represents a group of countries instead of a single economy only. In addition, such an approach allows to address weak data availability for CEE countries: the overall large number of variables in the non-Euro area data set increases the estimation precision for non-Euro area factors, while for each country only a few macroeconomic series of interest have to be included.

Specifically, the first block describes the joint dynamics of Euro area countries. It consists of a $(K+1) \times 1$ vector $Z_t^{EA} = [F_t^{EA} \; R_t^{EA}]'$, where F_t^{EA} is a $K \times 1$ vector of unobserved factors that summarize information from a large set of Euro area variables and R_t^{EA} is the Euro area short-term interest rate as observed variable. The second block summarizes the joint business cycle of of non-Euro area countries and consists of a $M \times 1$ vector of unobserved factors, F_t^{nonEA},

[1] An alternative approach for modeling cross-country spillovers in a single framework is the GVAR model developed by Pesaran et al. (2004). The advantage of the GVAR approach lies in the direct modeling of country interconnections via trade shares and in its focus on both short-run and long-run dynamics which makes the model easier to interpret from a theoretical point of view. However, in the case of CEE countries time series are available for relatively short time periods only, which leads to a low estimation precision of the individual country models in the first layer of the GVAR. Also, identification of structural monetary policy shocks within a GVAR is rather difficult and generalized impulse responses that have no structural interpretation are typically reported (Feldkircher, 2014; Hájek and Horváth, 2015).

that summarize information from a large set of non-Euro area variables. Following Charnavoki and Dolado (2014) and Dahlhaus et al. (2014), I rotate the non Euro area factors such that they are orthogonal to the Euro area factors and thus capture joint dynamics of the non-Euro area countries that are not driven by Euro area spillovers (see Section 2.5).

The reduced-form FAVAR model can then be described as follows.

$$\begin{bmatrix} Z_t^{EA} \\ F_t^{nonEA} \end{bmatrix} = \begin{bmatrix} \Phi_{1,1}(L) & \Phi_{1,2}(L) \\ \Phi_{2,1}(L) & \Phi_{2,2}(L) \end{bmatrix} \begin{bmatrix} Z_{t-1}^{EA} \\ F_{t-1}^{nonEA} \end{bmatrix} + \nu_t, \tag{1}$$

where ν_t is a vector of residuals assumed to be i.i.d. with mean zero and a constant covariance matrix Σ_ν. The coefficients $\Phi_{i,j}(L)$ are lag polynomials of finite order p. The Euro area and non-Euro area panel data sets, X_t^{EA} and X_t^{nonEA} relate to the unobserved factors according to the following equation.

$$\begin{bmatrix} X_t^{EA} \\ X_t^{nonEA} \end{bmatrix} = \begin{bmatrix} \Lambda_{1,1} & \Lambda_{1,2} \\ \Lambda_{2,1} & \Lambda_{2,2} \end{bmatrix} \begin{bmatrix} Z_t^{EA} \\ F_t^{nonEA} \end{bmatrix} + e_t, \tag{2}$$

where $\Lambda_{i,j}$ are loading matrices corresponding to the common factors. The measurement errors $e_t = [e_t^{EA} \; e_t^{nonEA}]'$ are assumed to be zero-mean i.i.d. They represent the idiosyncratic component of the variables in the data set and are assumed to be uncorrelated with the common factors. The latent factors F_t^{EA} and F_t^{nonEA} are unobservable, but the space spanned by the factors can be consistently estimated from the data by principal component analysis for large N (Stock and Watson, 2005, 2011).

Even though the FAVAR model exploits information from large data sets while keeping the number of variables in the VAR relatively low, the number of parameters to be estimated grows rapidly when increasing the number of factors. Given the relatively short time series available for most CEE countries, estimation can easily become imprecise and unstable. In order to economize degrees of freedom, I impose block-exogeneity restrictions and I assume that Euro area dynamics are not affected by non-Euro area variables. This implies setting the parameters $\Phi_{1,2}(L)$ and $\Lambda_{1,2}$ in the above equations to zero such that neither Euro area factors nor individual Euro area variables can react to non-Euro area factors.[2] An unrestricted model without block-exogeneity restrictions is estimated as a robustness check and results remain very similar (see Section 4.4).

2.2 Data

The data set is a balanced panel of 206 monthly time series. To capture Euro area dynamics, the data set comprises around 30 Euro area aggregate time series and five to eight macroeconomic variables for eleven old Euro area member states.[3] Further, eight variables are included for each of the CEE economies (Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania,

[2]The block-exogeneity assumption is frequently applied in the literature that considers spillover effects from large to small economies (Cushman and Zha, 1997; Benkovskis et al., 2011; Charnavoki and Dolado, 2014). In the present context, the block-exogeneity assumption is more restrictive as the domestic block consists of a group of thirteen economies which, despite of being small individually, might have a joint impact on the Euro area. However, F-tests indicate that the hypotheses of zero coefficients in the VAR model are not rejected at the five percent confidence level for each but the first equation, where it is not rejected at the one percent confidence level.

[3]These are Austria, Belgium, Finland, France, Germany, Greece, Italy, Ireland, Netherlands, Portugal, Spain.

Poland, Slovakia, Slovenia, Romania), as well as Denmark, Sweden and the UK, respectively. The main time series are measures of industrial production, unemployment rates, consumer and producer prices and real effective exchange rates, as well as short-term interest rates, share prices and a measure of realized stock market volatility as a proxy for uncertainty and risk perceptions (Bloom, 2009; Bruno and Shin, 2015a). For the aggregate Euro area a commodity price measure, two monetary aggregates, the nominal exchange rate against the dollar and indicators of consumer and business sentiment are included in addition. Also, oil prices and a few main macroeconomic variables for the US and Japan are added to capture world developments. The main data sources are Eurostat, OECD Main Economic Indicators, IMF Financial Statistics and in some cases national sources. The measure of stock market volatility is calculated as average realized volatilities of daily stock returns over each month (see Cesa-Bianchi et al., 2014). Stock returns are computed as day-to-day log changes in each country's major stock index which are obtained from Thomson Financial Datastream and HSBC. The full list of variables, countries and data sources can be found in Table A1 in the appendix.

Monthly data from 1999M1 to 2013M12 are used. The choice of the sample period is restricted by the relatively short time series available for most CEE countries which is a common problem when analyzing formerly socialist countries empirically. The sample period thus excludes data from the 1990s—a period of institutional transformation and large volatility in the CEE economies. Moreover, the sample begins with the creation of the Euro area and hence structural breaks in the time series due to the change in the European monetary policy framework are avoided. In order to account for a possible structural break due to the financial crisis which began in 2007, the analysis will also be carried out for the sub-samples 1999-2006 and 2007-2013 as a robustness check. Thereby, the use of monthly data increases the time series length and makes estimation feasible for rather short sub-samples.

Data are transformed prior to factor analysis. Logs are taken of all variables except for interest rates and unemployment rates. Data on price indices and monetary aggregates for all countries, as well as industrial production for Latvia, Lithuania and Romania are not available in a seasonally adjusted form and are seasonally adjusted with a stable seasonal filter.[4] First differences of all variables except interest rates are taken, which removes most unit roots according to augmented Dickey-Fuller tests. The use of month-to-month differences significantly reduces autocorrelation in the time series, as compared to data in levels or to data in year-to-year or quarter-to-quarter growth rates.[5] Finally, data are standardized prior to factor analysis.

2.3 Number of estimated factors

To fully specify the model, the number of latent Euro area and non-Euro area factors to be included in the FAVAR (i.e. parameters K and M) needs to be defined. For this purpose, the upper panel of Table 1 shows the information criterion IC 2 of Bai and Ng (2002). The

[4]Specifically, the data series are first detrended using a 5-term moving average filter. A centered estimate of the seasonal component is then calculated by using seasonal dummies and averaging the detrended data over each quarter. Finally, the estimated seasonal component is subtracted from the original data.

[5]Uhlig (2008) points out that autocorrelation should be removed prior to applying factor analysis because it can be misinterpreted as comovement of the data. Results for autocorrelation levels in the differenced series are available upon request

criterion indicates that the number of latent factors in the Euro area data is six and the number of latent factors in the non-Euro area data is three. On the basis of this result, the preferred FAVAR specification includes six estimated Euro area factors, the Euro area policy rate and three non-Euro area factors. As it is shown in Section 4.3, results are strongly robust across different specifications that include two to eight Euro area factors and one to five non-Euro area factors.

Table 1: Number of factors selection

Number of factors	1	2	3	4	5	6	7	8	9	10
Bai and Ng criterion (IC 2)										
Euro area	-0.16	-0.24	-0.31	-0.35	-0.37	**-0.40**	-0.39	-0.37	-0.35	-0.34
Non-Euro countries	-0.07	-0.12	**-0.14**	-0.14	-0.13	-0.12	-0.10	-0.07	-0.05	-0.02
Explained Variance										
Euro area	0.20	0.31	0.40	0.46	0.51	**0.55**	0.58	0.60	0.62	0.64
Non-Euro countries	0.19	0.37	**0.43**	0.49	0.54	0.58	0.60	0.63	0.65	0.66

Notes: The upper panel shows the Bai and Ng criterion IC 2 for different numbers of factors extracted by principal component analysis from the Euro area and non-Euro area data sets, respectively. The lower panel shows the shares of variance in the Euro area and non-Euro area data sets explained by different numbers of factors.

Six Euro area and three non-Euro area factors explain a considerable share of fluctuations in the data, as can be seen in the lower panel of Table 1. Starting with the Euro area data set, the first six principal components explain 55 percent of variance in the data. Increasing the number of principal components further provides only small gains in explained variance. In the non-Euro area data set, the first three principal components explain over 40 percent of variance.[6] Figure A1 in the appendix shows the estimated factors, i.e. the first six principal components extracted from the Euro area data set (first two rows) and the first three principal components extracted from the non-Euro area data set (last row). All estimated principal components have zero mean and a variance below one which is implied by the fact that they are extracted from stationary and standardized data.

2.4 Identification of monetary policy shocks

As in small-scale SVAR models, identification of structural monetary policy shocks needs to be achieved in the FAVAR by imposing additional restrictions on some VAR parameters. I follow Bernanke et al. (2005), Blaes (2009) and Benkovskis et al. (2011) and I identify the Euro area monetary policy shock by using a Cholesky decomposition and by imposing contemporaneous restrictions on the dynamics of the estimated factors and the Euro area short term interest-rate. Specifically, I order the Euro area unobserved factors before the Euro area short-term interest rate and I order non-Euro area factors last. Such an ordering imposes the identifying assumption that the joint dynamics behind Euro area variables do not react contemporaneously to shocks in the interest rate. In addition, both Euro area latent dynamics and the Euro area short term

[6]Previous literature also finds that, for Euro area or European data sets, shares of variance explained by common factors lie in the range of 40 to 60 percent. See for instance Eickmeier and Breitung (2006), Altissimo et al. (2010), Barigozzi et al. (2014).

interest rate are assumed not to respond to non-Euro factors on impact which is in line with the more general block-exogeneity assumption discussed in section 2.1. I experiment with changing the order of the Euro area factors and with ordering the short-term interest rate last, i.e., after the non-Euro area factors and results remain robust.

The contemporaneous zero restriction on Euro area latent factors does not necessarily involve the same restrictions on individual Euro area variables. While the common component of each variable is restricted, the idiosyncratic part can a priori respond to interest rate shocks on impact. In line with Bernanke et al. (2005), I distinguish between two groups of variables in the Euro area data set, "slow-moving" variables and "fast-moving" variables. The former group comprises variables such as industrial production or price indices that are expected to respond sluggishly to monetary policy shocks from a theoretical point of view and whose contemporaneous reactions are thus restricted to zero. The latter group covers financial variables such as exchange rates or stock market volatilities that are allowed to react to the shock instantaneously.[7] The identification of the monetary policy shock is then achieved by a rotation of the Euro area factors which separates the common component behind the slow-moving variables from the influence of the short-term interest rate.

2.5 Estimation

Estimation is carried out in two steps. The first step consists in estimating the latent Euro area and non-Euro area factors by principal component analysis. Initial estimates of the K unobserved Euro area factors, $\hat{F}_t^{EA}(0)$, are obtained as the first K principal components of the Euro area data set.[8] To subtract the influence of the Euro area short-term interest rate from the estimated factors, a second set of K Euro area factors, $\hat{F}_t^{EAslow}$, is extracted from the sub-set of slow-moving variables, following Bernanke et al. (2005). This group of variables is by assumption not correlated with the short-term interest rate contemporaneously. Thus, the influence of the short-term interest rate on the initial factors, $\hat{F}_t^{EA}(0)$, can be identified via the following regression

$$\hat{F}_t^{EA}(0) = b_1 \hat{F}_t^{EAslow} + b_2 R_t + e_t. \tag{3}$$

The final estimate of Euro area factors is then obtained as a rotation of the initial factors by subtracting the estimated impact of the short-term interest rate

$$\hat{F}_t^{EA} = \hat{F}_t^{EA}(0) - \hat{b}_2 R_t. \tag{4}$$

Initial estimates of the M unobserved non-Euro area factors, $\hat{F}_t^{nonEA}(0)$, are obtained as the first M principal components of the non-Euro area data set. Following the iterative procedure of Charnavoki and Dolado (2014), the non-Euro area factors are then rotated in order to make them orthogonal to the Euro area factors. In this, it is assured that the estimated non-Euro

[7] This categorization is in line with identifying restrictions typically imposed in the SVAR literature (Christiano et al., 1999). See Table A1 in the appendix for a full classification of the time series in the data into slow-moving and fast-moving variables.

[8] This implies setting the factor loadings of Euro area variables equal to the scaled eigenvectors corresponding to the K largest eigenvalues of the sample covariance matrix of the Euro area data $\hat{\Sigma}_{XX}^{EA}$.

area factors capture joint dynamics other than the Euro area factors.[9]

In the second step of the estimation, the VAR model in (1) is estimated on the extracted principal components and the short-term Euro area interest rate with OLS. One lag is included in the VAR, as suggested by the Akaike and Schwarz criteria.[10] Using the estimated parameters from equation (1), impulse responses of the estimated factors to the monetary policy shock can be calculated. However, it is difficult to assign an economic interpretation to the responses of the factors and the main interest of the analysis lies in the impulse responses of some of the individual time series in the data. The latter can be obtained by multiplying the responses of the factors by the estimated factor loadings from equation (2).

Confidence bands around the impulse responses are calculated with a bootstrap-in-bootstrap procedure developed in Kilian (1998).[11] This bootstrap method accounts for the fact that estimation is conducted in two steps and that the factors estimated in the first step are subject to uncertainty.

3 Results

This section presents the main results of the empirical analysis. In section 3.1, I first describe the main findings on monetary policy transmission within the Euro area, before I turn in more detail to the results for spillover effects from Euro monetary policy to non-Euro area countries. In section 3.2, I link my empirical findings to the existing theoretical predictions on international monetary policy transmission and, in section 3.3, I investigate the role of trade and financial openness for the size of monetary policy spillovers.

3.1 Main results

Figure 1 shows the reactions of the main Euro aggregate variables to an unexpected one percent decrease in the Euro area short-term interest rate. Solid lines represent the impulse responses of the selected variables to an unexpected one percentage point decrease in the Euro area short-term interest rate and shaded areas represent 68 percent confidence bands. The responses are in line with theoretical predictions. Euro area industrial production growth increases by up to 0.26 percent during the first year, before the effect slows down and dies out after three years. Consumer price inflation increases significantly after after one year, albeit the effect stays rather

[9] Applying the approach of Charnavoki and Dolado (2014) results in the following steps: (1) Non-Euro area data X_t^{nonEA} are regressed on the initial estimate $\hat{F}_t^{nonEA(0)}$ and on the estimated Euro area factors $\hat{Z}_t^{EA} = [\hat{F}_t^{EA} \; R_t^{EA}]'$. The estimated parameter corresponding to $\hat{Z}_t^{EA}$ is $\hat{\lambda}_{EA}^{(0)}$. (2) $\hat{X}_t^{nonEA(0)} = X_t^{nonEA} - \hat{\lambda}_{EA}^{(0)'} \hat{Z}_t^{EA}$ is computed. (3) A new estimate of non-Euro area factors, $\hat{F}_t^{nonEA(1)}$, is obtained by extracting the first KM principal components from $\hat{X}_t^{nonEA(0)}$. (4) Steps (1)-(3) are repeated various times. While results remain very similar when not orthogonalizing non-Euro area factors, the share of explained variance in the non-Euro area data set is increased considerably through orthogonalization.

[10] Results are similar when estimated with two or three lags, but impulse responses become quite volatile during the first periods because of the larger number of estimated parameters and the relatively short sample period.

[11] First, the residuals from equation 2 are bootstrapped and a new data set $\tilde{X}_t$ is generated on the basis of the generated shocks, the estimated factors and factor loadings. New common factors are extracted from $\tilde{X}_t$ and the estimation is carried out on the basis of these bootstrapped factors, giving us bias-adjusted estimated coefficients. A second bootstrap procedure is then applied to the VAR estimation to generate bootstrapped impulse responses.

small.[12] Producer price inflation does not show any price puzzle and exhibits a stronger increase than in it is the case for consumer prices, reaching a maximum response after one year. The change in the unemployment rate becomes significantly negative after six months. The real effective exchange rate depreciates during the first two years after the shock, although the effect is only marginally significant. On the financial side, stock prices strongly increase on impact, whereas stock market volatility declines. The negative response of the long-term rate is about half as large as the decline in the short-term interest rate and both rates return to zero about two years after the shock.

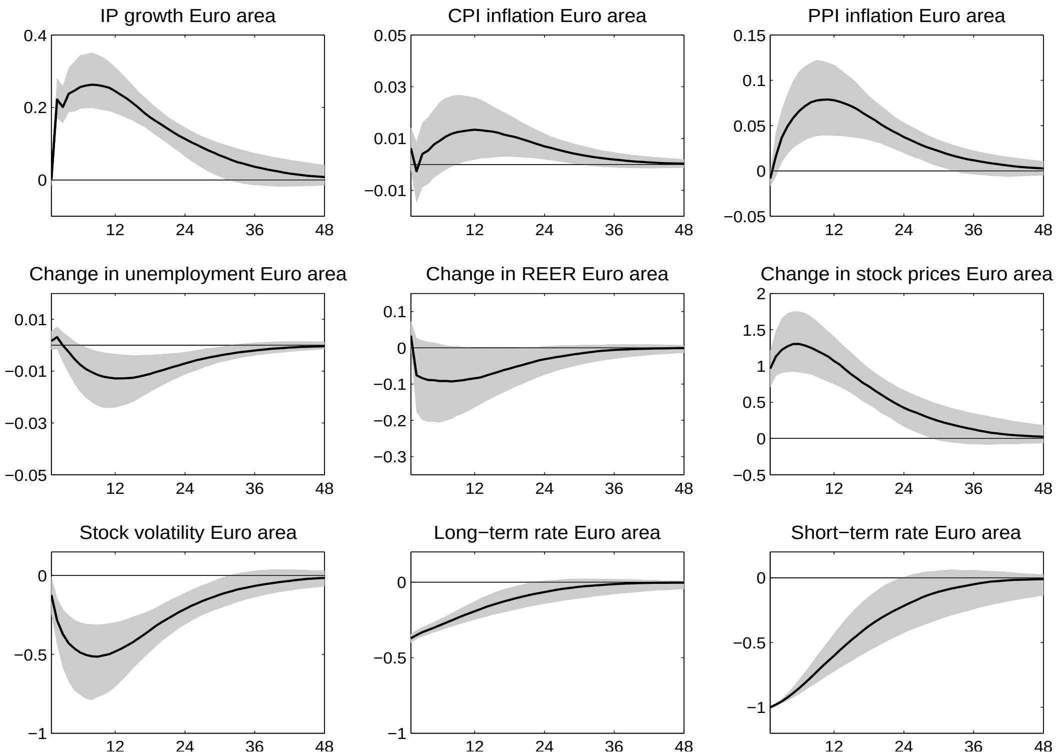


Figure 1: Monetary policy transmission within the Euro area
Notes: Impulse responses of Euro area aggregate variables to a negative 100bp EA monetary policy shock from the baseline FAVAR specification. Solid lines represent median impulse responses in percent. Shaded areas represent 68 percent confidence bands.

Turning to the spillover effects from a expansionary Euro area monetary policy shock to non-Euro area countries, Figures 2 to 6 show the responses of a the main variables of interest for all non-Euro area countries in the sample, together with the responses of the respective Euro area aggregates which are shown again for comparison. Figure 2 shows the impulse responses of industrial production growth in twelve non-Euro area countries.[13] All non-Euro area countries experience symmetric spillovers on their industrial production growth, i.e., industrial production growth increases during the first two years after the Euro area monetary policy expansion. The effects are strongly significant in the majority of countries with the exception of Latvia,

[12] The sub-sample analysis conducted in Section 4.1 reveals that the response of Euro area CPI inflation becomes stronger and more significant in the second sub-sample beginning in 2007.

[13] Results for Bulgaria are missing because data for Bulgarian industrial production were not available for the full sample and thus were not included in the estimation. Similarly, stock market volatilities for Bulgaria and Latvia were not included in the analysis due to lack of data (see Figure 6).

Romania and Denmark, where the effects are only marginally significant, and Lithuania, where the response is insignificant. On average, the response of non-Euro area production growth is comparable in size to the reaction of the Euro area aggregate.

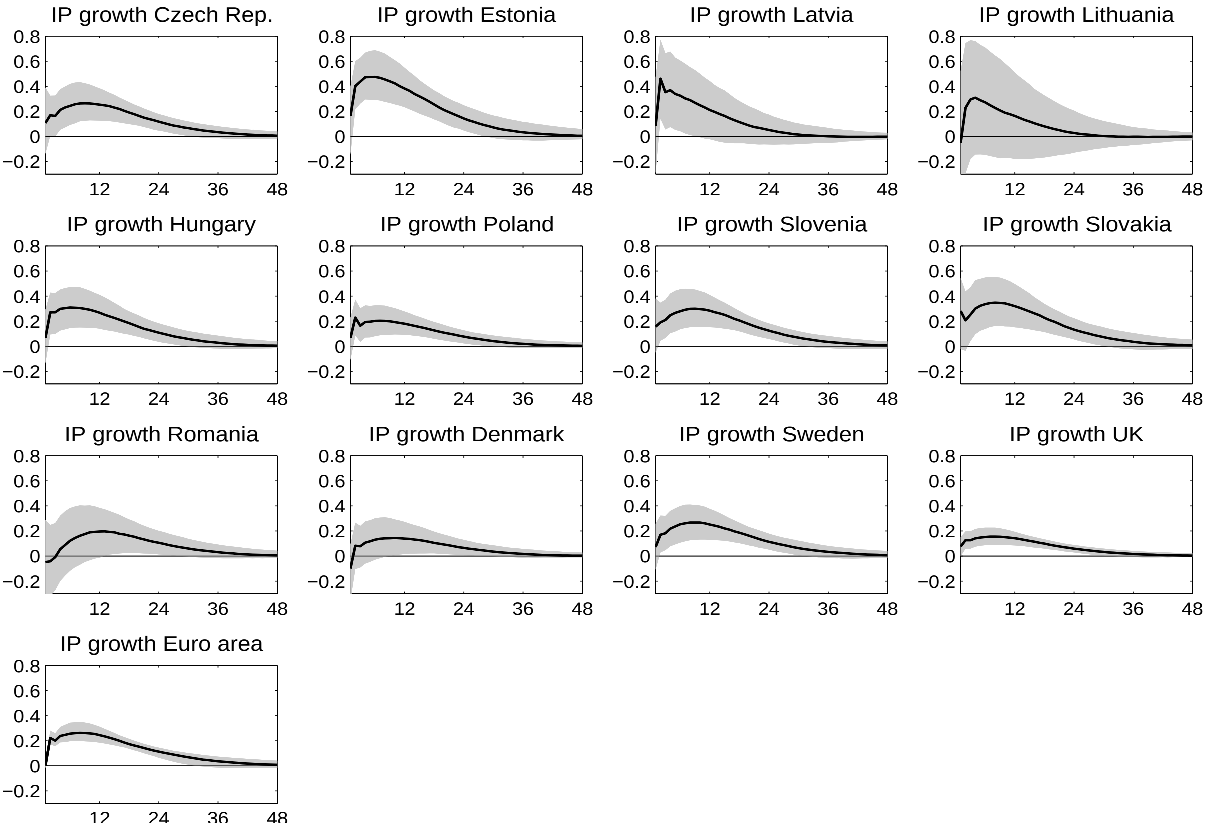


Figure 2: Monetary policy spillovers to non-Euro area industrial production growth
Notes: Impulse responses of non-Euro area countries' industrial production growth to a negative 100bp EA monetary policy shock from the baseline FAVAR specification. Solid lines represent median impulse responses in percent. Shaded areas represent 68 percent confidence bands.

The largest and most instantaneous responses in industrial production are observed in countries which fix their exchange rate against the euro or which have joined the euro area towards the end of the sample (Estonia, Latvia, Lithuania, Slovenia, Slovakia). In all of these countries, reactions of industrial production are even stronger than in the Euro area, albeit not always significant. However, also some of the countries with flexible exchange rates do experience relatively large spillovers on production: in Czech Republic, Hungary and Sweden the effects are comparable in size to the response of the Euro area aggregate. Somewhat smaller, but compared to the Euro area still sizable, reactions are observed in Poland, Romania, Denmark and the UK. Thus, spillover effects to production remain rather homogeneous across countries, even though small differences in the size of the effects are observed.[14] Section 3.3 will examine the driving

[14]These results are in line with previous findings from the literature, where rather homogeneous spillover effects from Euro area monetary policy to real activity is a typical finding. To the extent that heterogeneous effects are observed, relatively weak spillover effects to real activity in Poland are frequently observed (see Jiménez-Rodríguez et al., 2010; Benkovskis et al., 2011; Feldkircher, 2014; Hájek and Horváth, 2015). In addition, Hájek and Horváth (2015) find relatively weak effects of a Euro area interest rate shock on real activity in Romania and the UK and relatively strong effects in Czech Republic, Hungary and Sweden. Feldkircher (2014) finds strong spillovers to Slovakia and Slovenia, but contrary to the present and other findings he also finds a strong effect in Romania.

forces behind these quantitative differences in more detail, focusing on the role of the countries' trade and financial openness.

Figure 3 shows the impulse responses of consumer price inflation to the Euro area monetary policy shock in all thirteen non-Euro area economies together with the response in the Euro area. In the UK and in Sweden, consumer price inflation increases after an initial decline. Whereas the symmetric price response is strong and significant in the UK, it is weaker and insignificant in Sweden. Consumer price inflation in Denmark, stays mostly unaffected by the Euro area monetary policy shock. By contrast, consumer prices behave asymmetrically to Euro area monetary policy in all countries from Central and Eastern Europe. In Bulgaria, Czech Republic, Estonia, Latvia and Lithuania, CPI inflation declines on impact after the Euro area monetary expansion and then returns to zero after about one year. In Hungary, Poland, Slovenia, Slovakia and Romania, the asymmetric response sets in later and is more persistent, albeit only marginally significant. The finding of a detachment of consumer prices in Central and Eastern Europe from Euro are monetary policy is in line with the results of Eickmeier and Breitung (2006) and Jiménez-Rodríguez et al. (2010), and can be the result of regulated prices in the service sector and price dynamics of non-tradable goods during the catching-up process of transition economies (see Section 3.2).

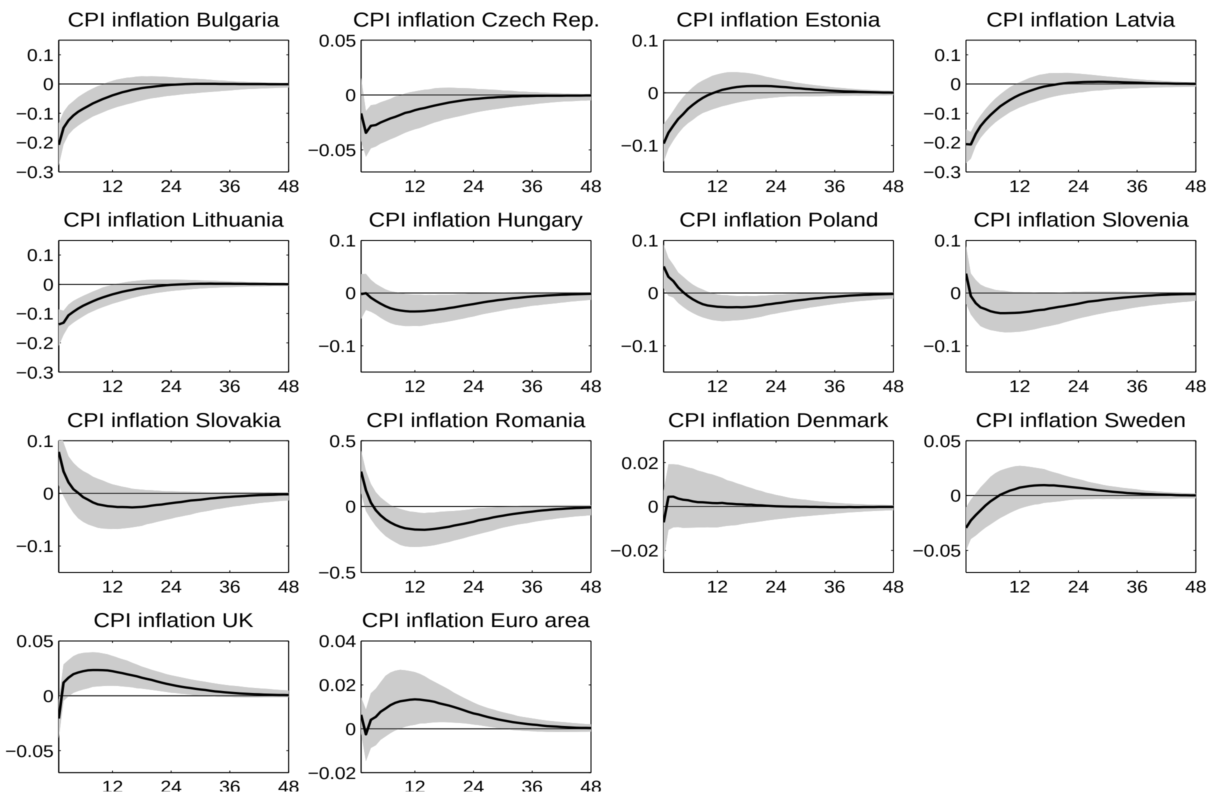


Figure 3: Monetary policy spillovers to non-Euro area consumer price inflation
Notes: Impulse responses of non-Euro area countries' consumer price inflation to a negative 100bp EA monetary policy shock from the baseline FAVAR specification. Solid lines represent median impulse responses in percent. Shaded areas represent 68 percent confidence bands.

Similarly to my findings, Jiménez-Rodríguez et al. (2010) find strong spillover effects on industrial production in Latvia and Lithuania, but they find only weak and insignificant effects in Estonia and asymmetric effects in Czech Republic and Slovenia.

The behavior of producer prices is somewhat more symmetric, indeed. Increases in producer price inflation are observed not only in all Western non-Euro area countries, but also in about half of the CEE economies, albeit in some cases after initial price puzzles (see Figure A2 in the appendix).

Figure 4 shows the impulse responses for real effective exchange rates of thirteen non-EA economies and the Euro area. Here, there are clear differences among countries with different exchange rate regimes. The real effective exchange rate appreciates on impact in most countries that let their currencies fluctuate against the Euro (Hungary, Poland, Romania, Sweden and the UK). Only in the Czech Republic, the effective exchange rate shortly depreciates on impact and returns to zero thereafter. By contrast, the real effective exchange rate persistently depreciates in all countries that fix their currency against the Euro (or have entered the Euro area towards the end of the sample period). In most cases, the exchange rate depreciation is significant and comparable in size to the depreciation in the Euro area.

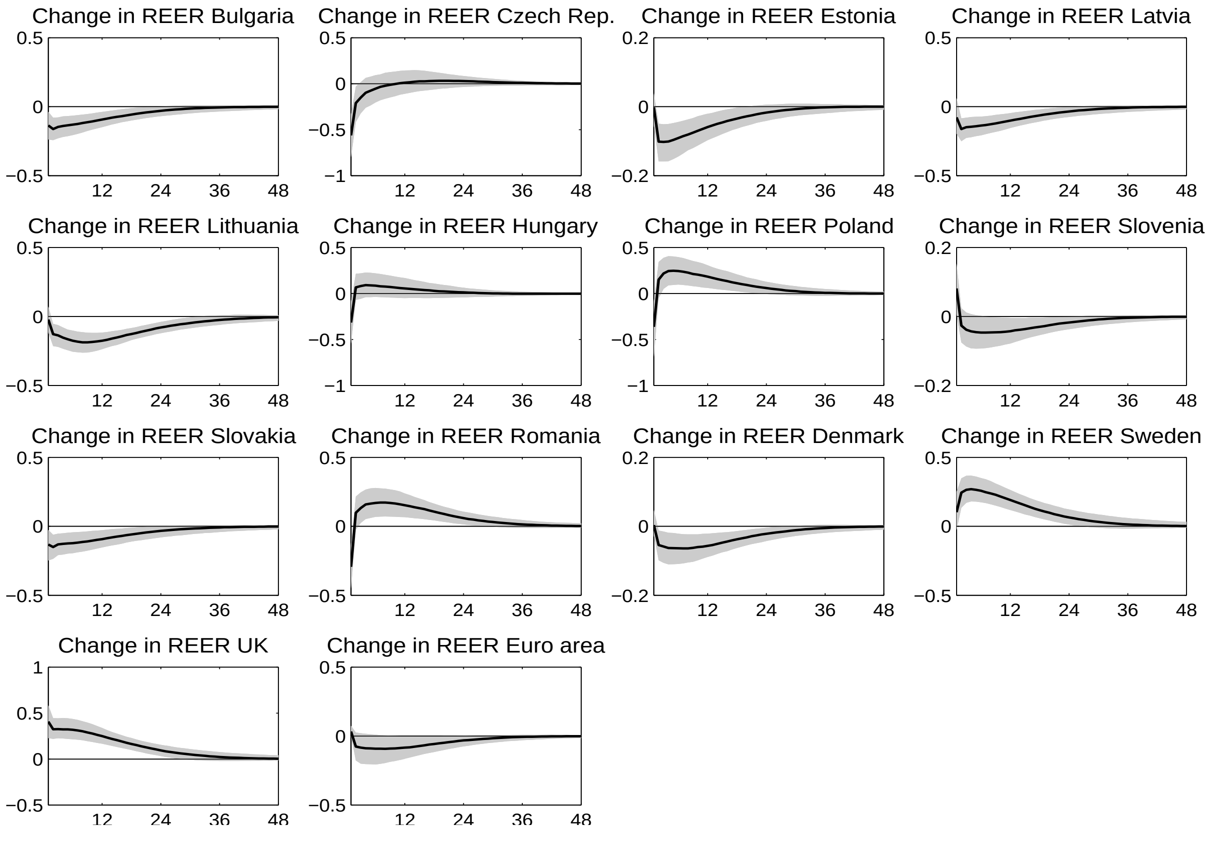


Figure 4: Monetary policy spillovers to non-Euro area real effective exchange rates
Notes: Impulse responses of non-Euro area countries' change in real effective exchange rates to a negative 100bp EA monetary policy shock from the baseline FAVAR specification. Solid lines represent median impulse responses in percent. Shaded areas represent 68 percent confidence bands.

Turning to financial spillovers from the Euro area monetary policy expansion, Figure 5 shows the impulse responses of short-term interest rates in the ten non-Euro area countries that had not joined the Euro area by the end of the analyzed sample. The response of the Euro area short-term interest rate is presented again for comparison. All non-Euro area interest rates follow the Euro area rate, albeit the size and the shape of the responses vary across countries.

In Bulgaria, Denmark, Sweden and the UK the response is very similar to the one of the Euro area rate, with an instantaneous decline by about one percent and a gradual return to zero. In all other countries, the responses of the interest rates set in more gradually, mostly being insignificant on impact and reaching their maximum negative response after about one year. In Romania, the interest rates move asymmetrically to the Euro area rate on impact, but declines thereafter.

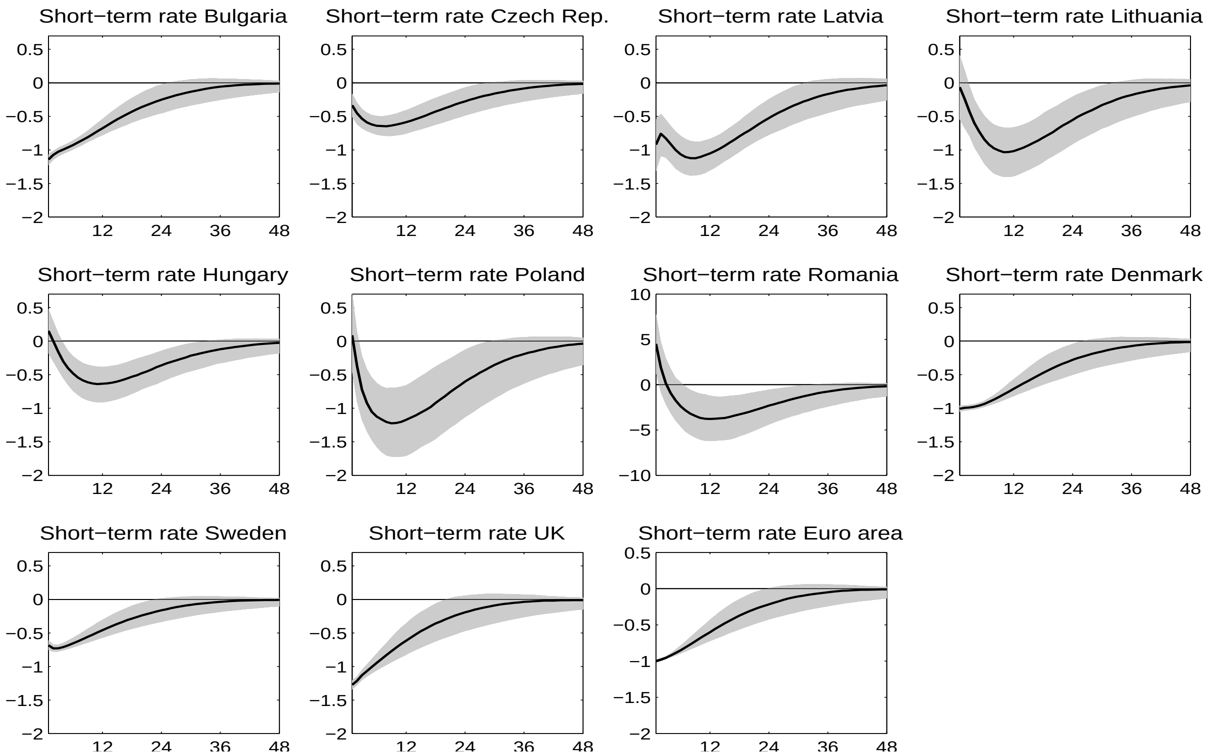


Figure 5: Monetary policy spillovers to non-Euro area short-term interest rates
Notes: Impulse responses of non-Euro area countries' short term interest rates to a negative 100bp EA monetary policy shock from the baseline FAVAR specification. Solid lines represent median impulse responses in percent. Shaded areas represent 68 percent confidence bands.

Finally, Figure 6 presents the reactions of stock market volatility as a proxy for uncertainty and risk aversion to a Euro area monetary expansion in eleven non-Euro area countries and in the Euro area. Uncertainty significantly decreases in all non-Euro area countries except for Slovakia, where it increases on impact. Interestingly, the responses in most non-Euro area countries are stronger than in the Euro area aggregate. In Sweden, Czech Republic, Romania, Estonia and the UK, the reactions of financial markets to the Euro area monetary expansion are largest, with uncertainty decreasing by about one percent after six to nine months.

Overall, the results point towards strong spillover effects from Euro-area monetary policy, both on the real economy and on financial markets. Whereas industrial production, interest rates and financial uncertainty are subject to symmetric spillovers, prices and, in countries with flexible exchange rate regimes, real effective exchange rates behave asymmetrically. In the following, these findings are discussed in view of existing theoretical predictions on international monetary policy transmission and the role of the openness of a country towards trade and finance for the size of spillover effects is investigated.

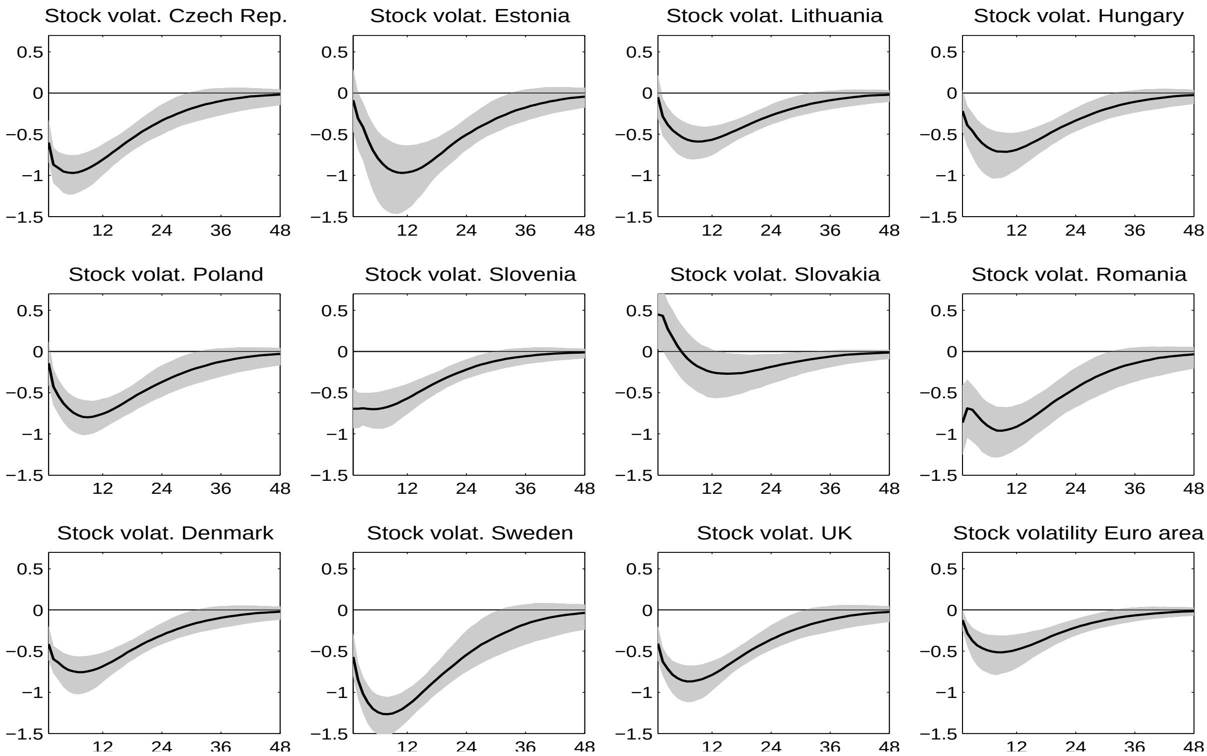


Figure 6: Monetary policy spillovers to non-Euro area stock market volatility
Notes: Impulse responses of non-Euro area countries' stock market volatility to a negative 100bp EA monetary policy shock from the baseline FAVAR specification. Solid lines represent median impulse responses in percent. Shaded areas represent 68 percent confidence bands.

3.2 Discussion of the results

From a theoretical point of view, the spillover effects from Euro area shocks to non-Euro area countries can be driven by various transmission channels. Standard Mundell-Flemming-Dornbusch models focus on international spillover effects via trade. An expansionary foreign monetary policy shock increases foreign demand for domestic goods, which increases domestic exports and raises domestic output (*income absorption effect* or *demand channel*). On the other hand, the domestic exchange rate appreciates after the foreign monetary expansion if it is allowed to move freely against the foreign currency. This worsens the domestic trade balance and decreases domestic output via the *expenditure switching effect* (Dornbusch, 1980; Obstfeld and Rogoff, 1996, chapter 9). Thus, for countries which fix their exchange rate against the foreign currency, the trade channel suggests that domestic output should move in the same direction as foreign output via increased foreign demand. In countries with flexible exchange rates, however, the exchange rate adjustment counteracts the demand channel and the direction of spillovers via trade is a priori ambiguous.

More recent theoretical contributions have emphasized the financial channel of international monetary policy transmission. The channel suggests a symmetric transmission of foreign monetary conditions to the domestic economy in presence of strong financial integration, independently of the level of trade integration and the exchange rate regime. First, if the foreign country is a large open economy, a drop in the foreign interest rate can lower domestic interest rates indirectly via a decline in world interest rates (Svensson and van Wijnbergen, 1989; Obstfeld and Rogoff, 1996, chapter 10; Galí and Monacelli, 2005). Second, the financial channel can operate via the global banking sector and through cross-border leverage. A decrease in the foreign interest rate lowers the costs of loans denominated in the foreign currency and boosts credit demand, particularly if agents were initially credit constraint (Bernanke and Gertler, 1995). On top of that, an appreciation of the domestic exchange rate caused by the foreign monetary expansion cushions debt burdens from existing foreign currency loans, which generates positive wealth effects and improves the creditworthiness of borrowers (Bruno and Shin, 2015b). Finally, credit supply is stimulated by the foreign monetary expansion because foreign owned banks can obtain funds from their head offices at lower cost (Cetorelli and Goldberg, 2012). Thus, foreign monetary policy boosts domestic credit growth and capital inflows by improving funding conditions. On the one hand, this stimulates domestic investment and leads to symmetric international co-movements in output (Devereux and Yetman, 2010). On the other hand, persistently low costs of foreign funding can increase risk-taking and enhance credit booms or surges in capital flows (Bruno and Shin, 2015a; Rey, 2015).

The results presented in Section 3.1 indicate that both the trade and the financial channels operate in the transmission of Euro area monetary policy to non-Euro area countries. Industrial production increases in most non-Euro area economies after the Euro area monetary expansion. This points towards the presence of foreign demand effects via the trade channel, in accordance with the predictions of the Mundell-Flemming-Dornbusch model. Moreover, short-term interest rates outside the Euro area rate closely mimic the decrease in the Euro area interest rate. On the one hand, such a pronounced cross-border synchronization in interest-rates can be explained by a transmission of monetary policy via world interest rates. On the other hand, central banks outside the Euro area might have incentives to follow the monetary policy of the ECB with the aim to reduce spreads between domestic and foreign interest rates and to limit exchange rates appreciations, which could otherwise induce large capital inflows into the domestic economy and motivate search for yield behavior of foreign investors. Indeed, the strong symmetric effects on stock market volatility in most non-Euro area countries imply that a Euro area monetary expansion reduces uncertainty and risk-aversion in non-Euro area countries. This finding is in line with a transmission of Euro area monetary policy via the banking sector and the existence of a risk-taking channel of monetary policy.

There is also some evidence for the presence of an expenditure switching effect: after a Euro area monetary expansion, the real effective exchange rate appreciates in most non-Euro area countries with flexible exchange rate regimes, whereas it moves in line with the Euro area exchange rate in all countries with pegs. However, exchange rate movements seem to have only a limited impact on the real economy. Even though the response of industrial production is on average higher in countries with pegs than in countries with flexible regimes, the difference is rather small and symmetric spillover effects are observed for both country groups. Thus, in countries with flexible exchange rates, any asymmetric effect on production via expenditure switching seems to be outweighed by stimulating effects from increased foreign demand and from easier funding conditions and lower uncertainty in the banking sector. At the same time, the observed differences in the size of production responses across countries with different exchange rate regimes might actually be driven by characteristics of the two country groups other than the exchange rate regime. The next subsection will consider this possibility by examining the role of trade and financial openness for the size of spillovers.

Finally, spillover effects on consumer prices are asymmetric for all countries from Central and Eastern Europe, independently of the exchange rate regime, whereas they are symmetric for the three countries from Western Europe. The detachment of consumer prices in the CEE economies from Euro area monetary policy could potentially be explained by prices in the service sector, which are subject to relatively strong regulations in Central and Eastern Europe (Égert et al., 2003). In addition, services are non-tradables and thus their price level might be driven by the so-called Balassa-Samuelson effect: during the catching-up process of an emerging economy, the tradable sector becomes more productive compared to the non-tradable sector, but nominal wages tend to rise over all sectors. Hence, the relative prices of non-tradable goods increase and drive up inflation differentials towards advanced countries. This effect might explain asymmetric consumer price behavior in particular during the beginning of the sample period, when productivity increases that were enhanced by the run-up to EU accession created strong inflation differentials between CEE countries and the Euro area.[15]

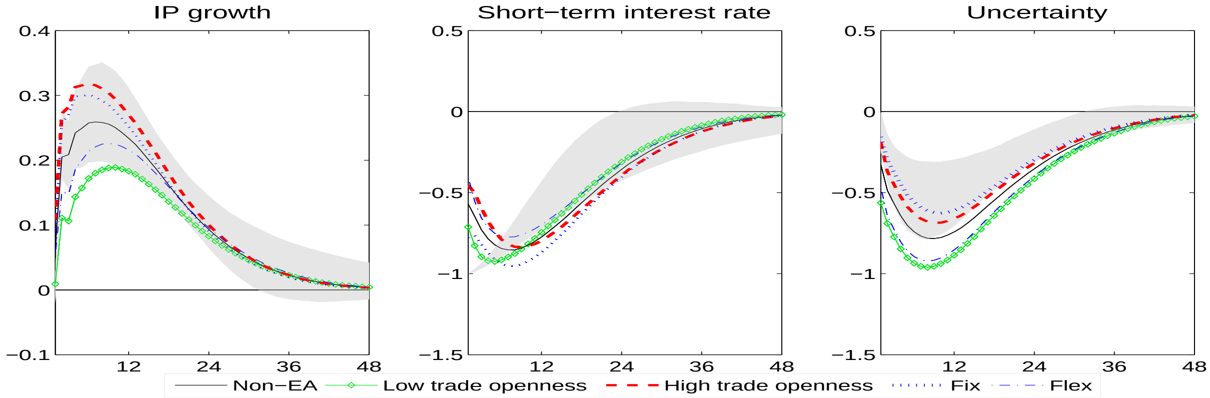
3.3 Trade openness versus financial openness

Even though the observed spillover effects from Euro area monetary policy are rather homogeneous across non-Euro area countries, some differences in the size of the effects are observed between countries with fixed and flexible exchange rate regimes. As pointed out in the previous subsection, a possible explanation for weaker production responses in countries with flexible exchange rate regimes can be an expenditure switching effect. At the same time, the countries with fixed exchange rate regimes are also the smallest economies in the sample and are highly open to trade, but less financially developed than countries with flexible exchange rate regimes. Thus, strong responses of production among countries with fixed exchange rates could actually result from a relatively high degree of trade openness and from relatively strong foreign demand effects via the trade channel. Moreover, the different levels of financial development across non-Euro area countries can play a role for the size of spillover effects via the financial channel. Therefore, this section investigates whether the size of spillover effects from Euro area monetary policy varies with the degree of trade and financial openness of non-Euro area economies by looking at impulse responses of country groups.

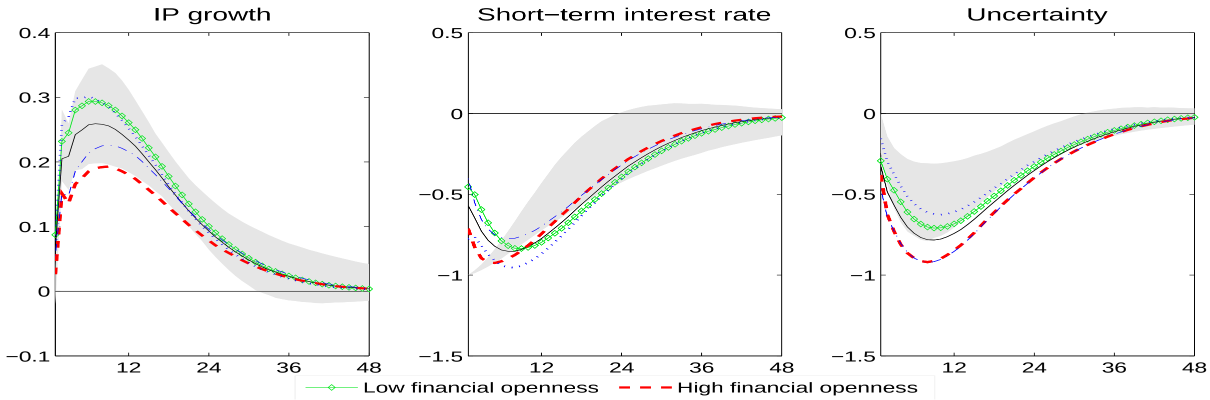
To this end, Figure 7 separates between non-Euro area countries with low trade openness, i.e., countries whose levels of trade to GDP ratios were below the average of all non-Euro area countries in the year 2012 (UK, Romania, Sweden, Poland, Denmark) and countries with high, in the sense of above average, trade openness (upper panel). In the same vein, the lower panel distinguishes between countries with low financial openness defined as countries whose levels of

[15] Égert (2002) and Mihaljek and Klau (2008) provide empirical evidence for the role of the Balassa-Samuelson effect in driving inflation differentials between CEE countries and the Euro area. Considering a more recent sample period, Hałka and Kotłowski (2016) show that, in Poland and in the Czech Republic, fluctuations in CPI inflation, and in particular fluctuation in service prices, are mostly determined by domestic factors such as cyclical movements of the domestic output gap. By contrast, in Sweden the largest contribution to inflation fluctuations stems from external factors such as commodity price shocks.

stock market capitalization were below the country average in 2012 (Poland, Sweden, Denmark, UK) and countries with high, i.e., above average, financial openness.[16] For comparison, both panels also show average impulse responses over all non-Euro area countries and over countries with fixed and flexible exchange rates. Shaded areas represent the 68% confidence bands for the Euro area aggregate.



(a) Trade openness



(b) Financial openness

Figure 7: Trade and financial openness, impulse responses over country groups

Notes: Impulse responses to a negative 100bp EA monetary policy shock from the baseline FAVAR specification, averaged over all non-Euro area countries (black, solid lines), countries with fixed exchange rates (blue, dotted lines) and countries with flexible exchange rates (blue, dashed-dotted lines; flexible exchange rate countries are Czech Rep., Poland, Hungary, Romania, Sweden, UK). The upper panel additionally separates between countries with relatively low (green lines with diamond marker) and relatively high (red, dashed lines) trade openness in terms of the trade to GDP ratio in the year 2012. The lower panel shows average impulse responses for countries with relatively low and relatively high financial openness in terms of the stock market capitalization to GDP ratio in 2012. Shaded areas show the 68% confidence bands for the Euro area aggregate, as in Figure 1. All averages over responses of short-term interest rates exclude the response in Romania, where interest rates respond much stronger compared to all other countries and would thus drive average responses.

The upper panel of Figure 7 reveals that cross-country heterogeneities in spillover effects to industrial production are larger when accounting for different degrees of trade openness, as

[16] Data on trade to GDP and stock market capitalization to GDP come from the World Bank's World Development Indicators and Global Financial Development database, respectively. The groupings are based on data for the year 2012, which is the latest year for which data are available for all countries. However, groupings remain roughly similar when based on trade to GDP and stock market capitalization data from earlier years. Also, results remain largely similar when the country groups are formed based on the median instead of the medium values of the trade to GDP and stock market capitalization shares.

compared to simply distinguishing between different exchange rate regimes. The initial response of industrial production in countries with a high degree of trade openness is about three times higher compared to countries with relatively low trade openness. This is in line with theoretical predictions according to which an increase in foreign demand for domestic exports should have a stronger pass-through to domestic output the larger the share of exports in the economy. The stronger demand channel in countries with high trade openness seems to play an important role particularly during the first months after the shock. Over time, differences in the response of industrial production between the two country groups become smaller and disappear after two years. Thus, in countries with relatively low trade openness, second round effects, probably driven by financial spillovers, seem to be relatively stronger.

Indeed, the responses of the two financial variables are larger in countries with low degrees of trade openness, but with more developed financial markets (upper and lower panels of Figure 7). In countries with higher financial openness, interest rates are more synchronized with the Euro area rate and the risk-taking channel of Euro area monetary policy, captured by the response of uncertainty, is stronger compared to countries with relatively low financial development. This finding is in line with some of the theoretical predictions discussed in Section 3.2. Countries with more open financial markets are typically also more integrated in global financial markets and thus financial spillovers via the global banking sector are likely to be larger.[17] In addition, all highly financially open countries in the sample experience exchange rate appreciations after the Euro area monetary expansion, which can enhance risk taking because of reduced debt burdens from existing foreing currency loans.

However, spillovers effects on the financial side seem to have only a limited pass-through to industrial production. Countries with lower financial development, but higher trade openness show stronger production responses and, hence, the trade channel seems to dominate. Nonetheless, stimulating effects on production via enhanced risk taking might be at play at somewhat larger horizons. In countries with high financial openness, the spillover effects on production reach their maximum about one year after the Euro area expansion, when the effect in less financially open economies is already declining.

Overall, the strong symmetric spillovers from a Euro area monetary expansion on industrial production in non-Euro area countries with fixed exchange rate regimes seem to be the result of relatively strong foreign demand effects, driven by a high degree of trade openness, but to a lesser extent the result of financial spillovers. On the other hand, the somewhat weaker, but more persistent symmetric reactions of industrial production in countries with flexible exchange rate regimes seem to stem from a combination of a positive foreign demand effect, a rather weak negative expenditure switching effect and relatively strong financial spillovers which operate via a sustained reduction in risk aversion.

[17]See Ehrmann and Fratzscher (2009) for similar findings regarding international financial spillovers from US monetary policy.

4 Robustness analysis

In this section, I conduct a series of robustness checks to verify the validity of my results. First, I check the stability of the baseline results over time by running estimations over two sub-samples. I then use the shadow rate of Wu and Xia (2014) instead of the short-term interest rate to account for the zero lower bound of monetary policy which the ECB approached towards the end of the analyzed sample. Finally, I experiment with different numbers of Euro area and non-Euro area factors and I estimate alternative specifications of the FAVAR model. For space constraints, only the impulse responses of the Euro area and three selected non-Euro area countries are presented in this section, namely Poland (a relatively large CEE country with a flexible exchange rate regime), Lithuania (a small CEE country with a fixed exchange rate regime and euro adoption towards the end of the sample) and the UK (a Western EU country). Results of the robustness checks for the other countries are mostly comparable to the four countries presented here and are shown in the appendix.

4.1 Stability of results over sub-samples

Even though the time period covered in the baseline analysis excludes the transition period of the CEE economies and the period before the introduction of the Euro during the 1990s, the cross-country transmission of Euro area monetary policy shocks might have changed over the period in question. In particular, changes in monetary policy transmission can be expected around the years 2007 and 2008 when the financial crisis unfolded. The pre-crisis boom period characterized by a catching-up process of the CEE countries and increasing integration with the Euro area came to a halt with a reversal of capital flows and a recession in most non-Euro area countries. At the same time, Euro area monetary policy became more aggressive, with larger interest rate cuts than in the pre-crisis period. Also, some of the non-Euro area countries let their currency depreciate strongly against the euro and Hungary moved from a managed to a floating exchange rate regime. In order to address this issue, I reestimate the FAVAR model for two sub-samples. The first sub-sample covers the years 1999 to 2006 and hence the pre-crisis boom period and the catching up process of the CEE economies. The second sub-sample covers the years 2007 to 2013 and thus the financial and Eurozone crises and the subsequent recoveries. Whereas the sub-sample results can be indicative of whether the baseline results suffer from serious instabilities, they should also be treated with caution as they are estimated based on rather short samples and thus with relatively high estimation uncertainty.

Figure 8 presents the results of the sub-sample analysis for the selected countries and variables. In addition, Figure A3 in the appendix shows the results for the remaining countries. Dotted (dashed) lines represent median impulse responses from the estimation over the 1999-2006 (2007-2013) sub-sample, whereas solid lines and shaded areas represent the baseline results with confidence bands. The first row of the figure compares sub-sample results for the Euro area. In most cases, results for the Euro area variables are qualitatively similar over the two sub-samples. Quantitatively, the response of industrial production is stronger in the 2007-2013 sub-sample, whereas the responses of the real effective exchange rate and of uncertainty are weaker. The results are less robust for CPI inflation, which shows an initial price puzzle and subsequently almost no reaction in the pre-crisis sample. These rather weak CPI effect in the baseline estimation thus seems to be the result of different effects during the two sub-periods.

The results for the spillover effects from Euro area monetary policy to non-Euro area countries are also largely robust over sub-samples, even though impulse responses are slightly more volatile and estimated with a larger uncertainty for the rather short sub-samples. Spillover effects to the selected countries and variables are in some cases weaker during the pre-crisis period, but mostly of the same sign. The strongest differences over sub-samples arise for the responses of short-term interest rates to the Euro area monetary policy expansion. Whereas interest rate comovements with the euro area are stronger in the later sub-sample in Lithuania, the UK, Hungary, Latvia and Bulgaria, they become weaker over time in Poland and Romania. In addition, the sign of the response of real effective exchange rates changes over the two sub-samples for Hungary, Slovakia and Latvia, where changes of the exchange rate regime occurred between the two sub-samples.[18] In Slovakia and Latvia, the change towards more rigid exchange rate regimes leads to symmetric spillover effects of industrial production in the second sub-sample.

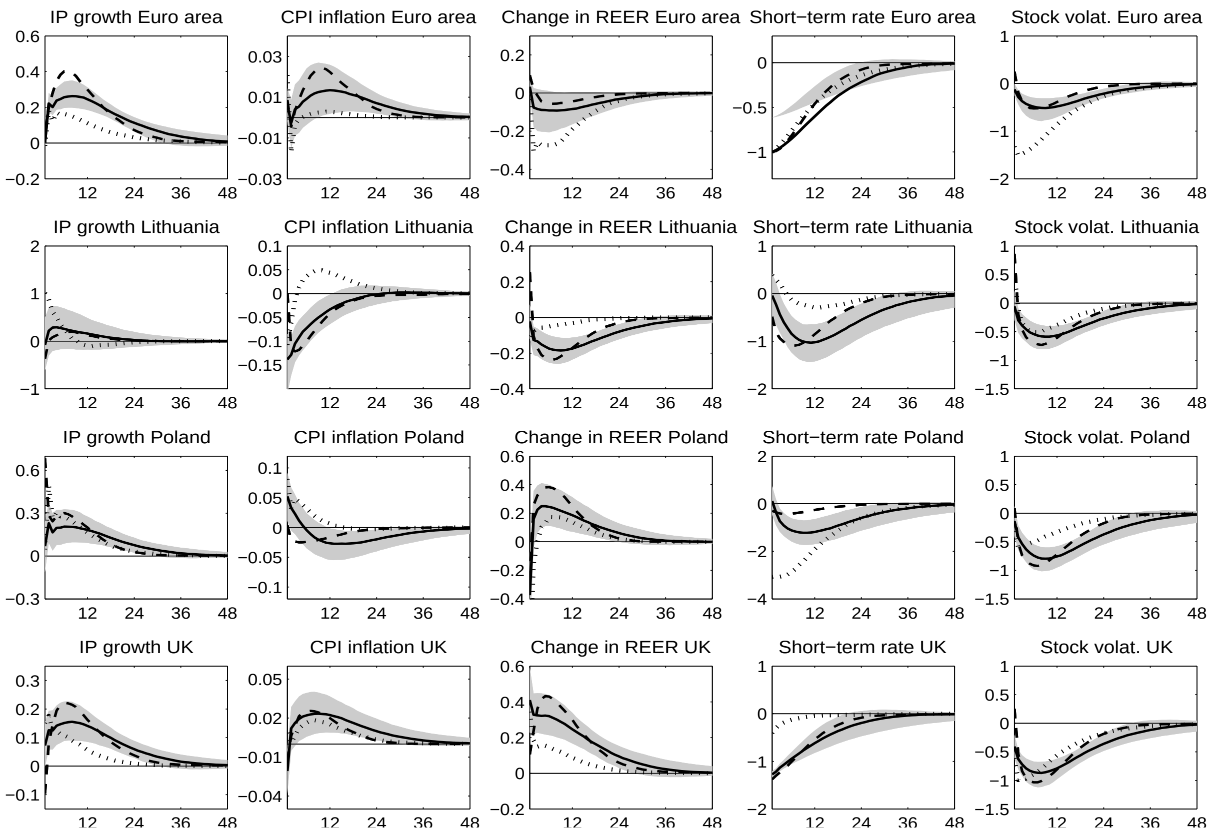


Figure 8: Estimation over 1999-2006 and 2007-2013 sub-samples
Notes: Solid lines (shaded areas) represent median impulse responses (68 percent confidence bands) to a negative 100bp Euro area monetary policy shock from the baseline estimation. Dotted (dashed) lines represent median impulse responses for the 1999-2006 (2007-2013) sub-sample.

Overall, the sub-sample analysis indicates that the general implications from the analysis

[18] Slovakia entered the ERM II mechanism by the end of 2005 and adopted the Euro in 2009, after having pursued a floating exchange rate regime against the Euro during the preceding years. Also Latvia entered the ERM II mechanism in 2005 which constituted a tighter monetary regime than the pegged exchange rate Latvia had pursued until then. Hungary moved from a managed to a floating exchange rate regime in 2008.

do not change due to instabilities in the sample. However, the estimated effects tend to be stronger during the second sub-sample. Expansionary Euro area monetary policy seems to have been more effective in raising domestic consumer prices during the later sample, albeit spillovers effects on CPI inflation in many non-Euro area countries remained asymmetric.

4.2 Accounting for the zero lower bound on monetary policy

The baseline analysis considers spillover effects from conventional monetary policy measured by an unexpected one percent increase in the short-term interest rate. However, after the global financial crisis the ECB conducted a set of unconventional monetary policy measures in form of asset purchase programmes and open market operations that are not captured by the baseline analysis. At the same time, the interest rate on the main refinancing operations set by the ECB approached the zero lower bound, although it did not reach it during the analyzed sample as it was the case, for instance, in the United States. While an exact identification of unconventional monetary policy measures is empirically challenging and exceeds the scope of this paper, I nonetheless account for the use of unconventional monetary policy measures and the zero lower bound as a robustness check.[19]

In particular, I estimate an alternative specification of the FAVAR model in which the shadow interest rate measure by Wu and Xia (2014) is included as policy variable instead of the short-term interest rate. This measure is estimated on the basis of latent factors extracted from data on different forward rates along the yield curve and should therefore capture the effects of unconventional monetary policy measures. At the same time, it is an estimate of the level of the short-term interest rate that would prevail in the absence of the zero lower bound and it can take negative values. Indeed, the shadow interest rate measure closely follows the short-term interest rate up to 2007, but then drops up to one percentage point below the short-term rate and turns negative during four quarters in 2009 and again during the year 2012.

Figure 9 shows the results from this robustness check for the four selected countries. Dashed (dotted) lines show median impulse responses (68 percent confidence bands) from the FAVAR model with the shadow rate, while solid lines and shaded areas show results from the baseline model for comparison. Figure A4 in the appendix shows the corresponding results for the remaining countries. The estimated reactions to a expansionary shock in the shadow rate are qualitatively very similar to the baseline. The identified shock in the shadow interest rate is somewhat less persistent than the shock in the baseline. In turn, this leads to slightly weaker

[19] A few recent papers have provided more in-depth analyses of spillover effects from Euro area unconventional policies to non-Euro area countries. In an event-study framework, Georgiadis and Gräb (2015) find strong effects of the announcements of various unconventional monetary policy measures by the ECB on exchange rates and equity returns in a large set of countries, including non-Euro area EU members. Bluwstein and Canova (2015) apply a Bayesian mixed frequency SVAR approach and find that unconventional monetary policy measures of the ECB generate important fluctuations of real and financial aggregates of European countries not adopting the Euro, particularly in countries with more advanced financial systems. Similarly to my approach, Halova and Horváth (2015) identify unconventional monetary policy shocks via the Euro area shadow interest rate and estimate spillover effects to non-Euro area countries within a Panel VAR framework over the period 2008 to 2014. They also find that spillover effects on output are stronger than those on CPI and that unconventional monetary policy reduces market uncertainty. In contrast to my findings, they do not observe a significant effect on non-Euro area real exchange rates. This could be due to the fact that the authors take averages over responses of countries with different exchange rate regimes, which hides cross-country heterogeneities in the responses of exchange rates.

effects of most of the other euro area variables, as well as somewhat weaker spillover effects to non-Euro area variables. Hence, using the shadow rate as monetary policy instrument reveals that monetary policy in the Euro area was somewhat less expansionary than it is assumed in the baseline because the policy rate approached the zero lower bound towards the end of the sample. Nonetheless, the impulse responses of the alternative specification stay within the confidence bands of the baseline specification in most cases such that the main implications from the analysis do not change when accounting for the zero lower bound on monetary policy.

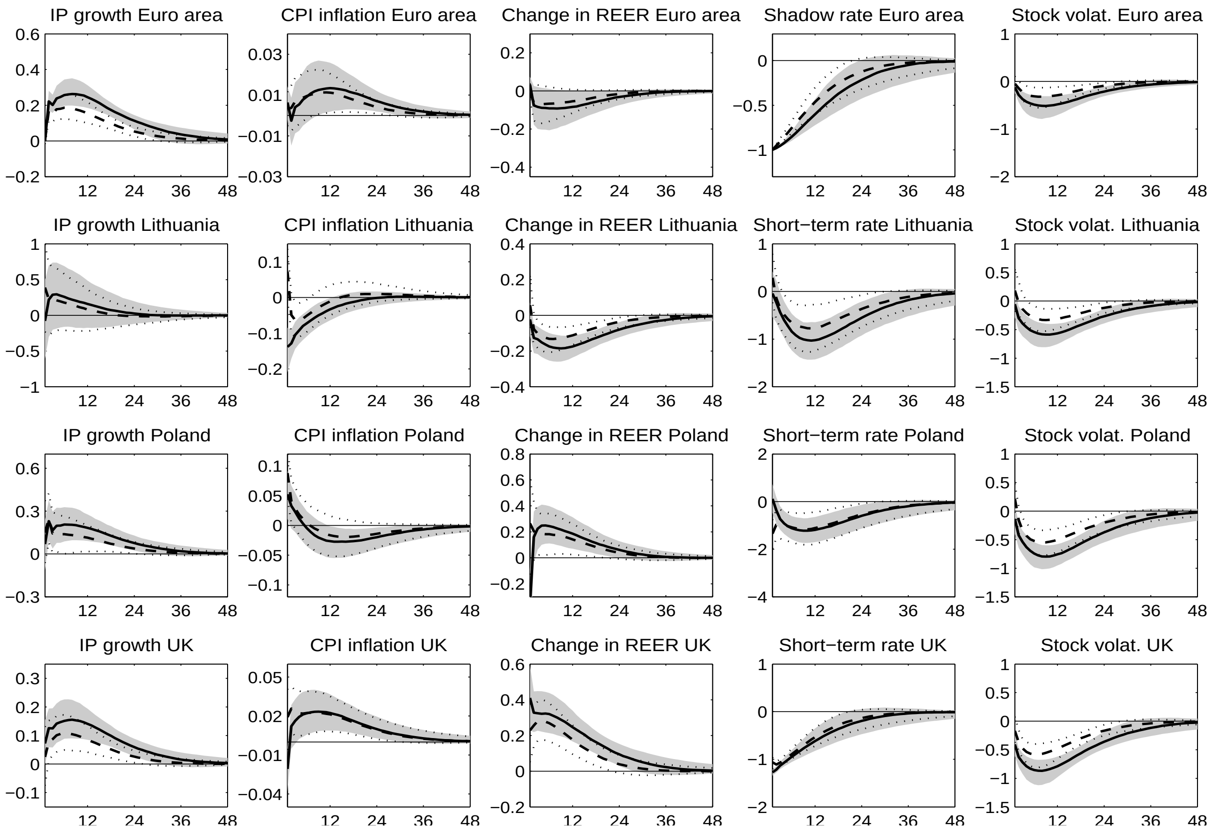


Figure 9: FAVAR model with shadow interest rate

Notes: Median impulse responses and 68 percent confidence bands of selected countries to a negative 100bp Euro area shock in the Euro area short-term interest rate (solid lines and shaded areas) and to a negative 100bp shock in the Euro area shadow interest rate (dashed and dotted lines), in percent.

4.3 Robustness with respect to the number of factors

In order to verify that the results are not driven by a too small or too large number of Euro area and non-Euro area factors included in the FAVAR model, I check the robustness of the baseline results to the inclusion of different numbers of factors. Figure 10 and Figure A5 in the appendix present the impulse responses of the main variables to an expansionary Euro area monetary policy shock from FAVAR models that include two to eight Euro area estimated factors and one to five non-Euro area factors, together with the Euro area short-term rate as policy variable (i.e. overall 4 to 14 variables in the VAR). Confidence bands for the alternative models are not presented for readability, but become somewhat larger when increasing the number of factors. Overall, results are highly robust when changing the number of Euro area factors. The model with two Euro area and one non-Euro area factors (dashed lines) yields less robust results, with strong instantaneous declines in short-term interest rates and CPI inflation and with weaker effects of production and uncertainty compared to the other models. However, once the total number of factors is increased up to around six, differences between the models become small.

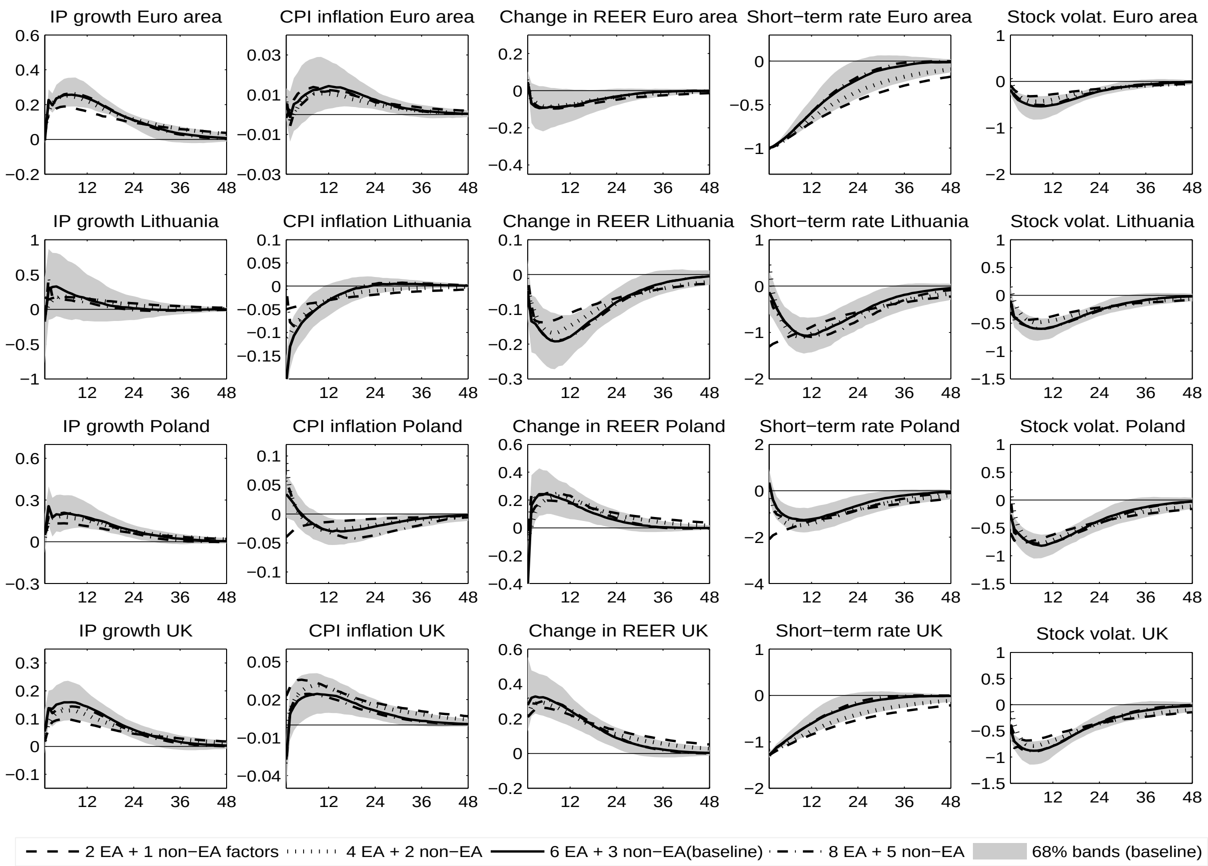


Figure 10: Alternative numbers of estimated factors
Notes: Solid lines (shaded areas) represent median impulse responses (68 percent confidence bands) to a negative 100bp shock in the Euro area short-term interest rate for the baseline FAVAR model. Dashed lines represent median impulse responses from a FAVAR specification with two Euro area factors and one non-Euro area factor and dotted (dashed-dotted) lines for specifications with four (eight) Euro area factors and two (five) non-Euro area factors.

4.4 Robustness with respect to the factor structure

In the baseline specification of the FAVAR model, I impose the assumption that the joint dynamics in the data can be summarized by two blocks of factors, with Euro area factors assumed to be block-exogenous to non-Euro area factors. Here, I check whether my results are robust to alternative assumptions regarding the factor structure. First, I estimate an alternative model with a single group of estimated factors extracted from the total data set. I thus assume that all European countries in the sample are driven by a common business cycle.[20] Second, I estimate an unrestricted model with two blocks of factors, i.e., without imposing the block-exogeneity

[20] In this model, I separate both Euro area and non-Euro area time series into slow-moving and fast-moving variables in order to extract the Euro area short-term interest rate from the estimated factors. I then order the Euro area short-term interest rate last in the VAR.

assumption. In this specification, I allow Euro area factors to respond to lagged non-Euro area factors in the VAR equation and I allow individual Euro area time series to respond to non-Euro area factors via equation (2).[21]

Figure 11 and Figure A6 in the appendix compare the results from the baseline model with the results from the two alternative models. Shaded areas represent confidence bands for the alternative model without block-exogeneity (i.e., the unrestricted model). Confidence bands for the model with one factor group are not presented for space contraints, but are of similar size as in the baseline specification. The model with one single factor group yields, for many non-Euro area countries, strong instantaneous responses of short-term interest rates and more instantaneous responses of CPI inflation compared to the other models. Given that the factors in this model are extracted from Euro area and non-Euro area data jointly, the model seems less suitable to describe the transmission of a shock that originates in the Euro area and affects non-Euro area interest rates and prices with a delay. It might, instead, mix up shocks originating in non-Euro area countries with the identified Euro area shock.

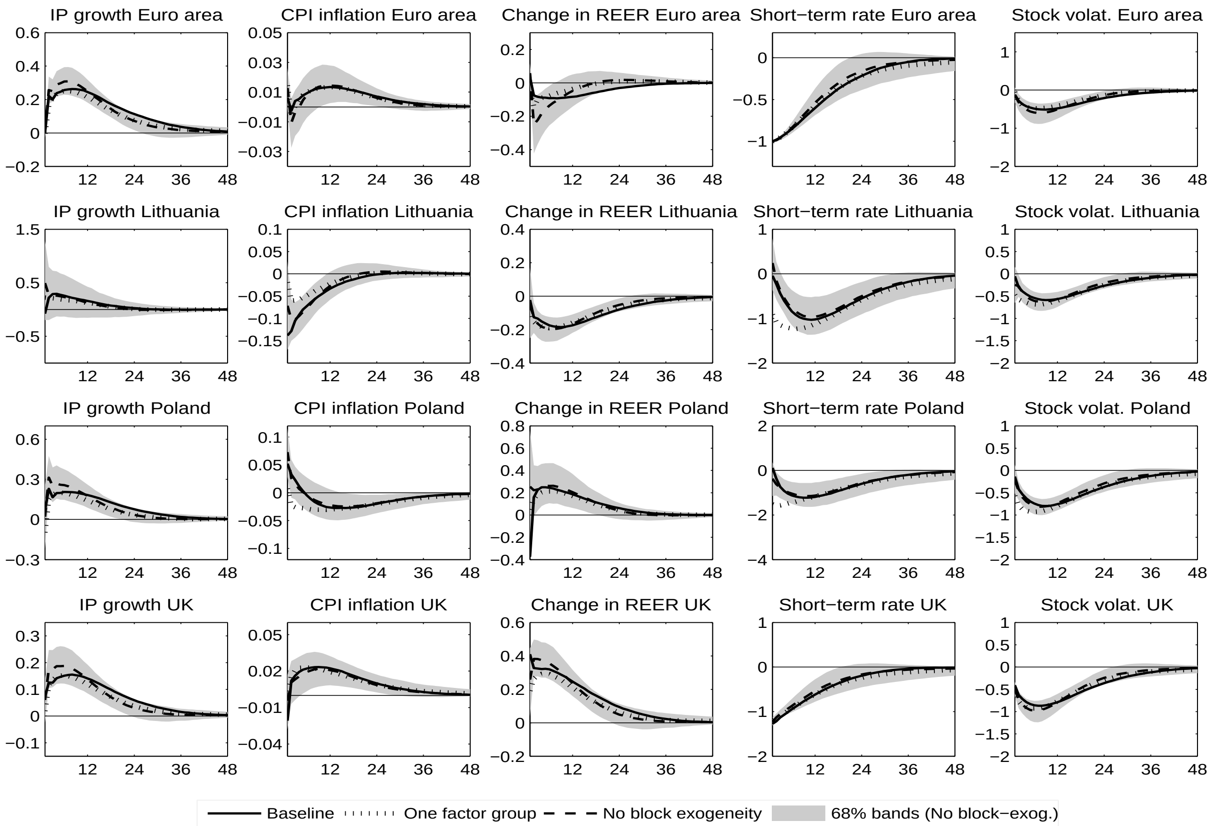


Figure 11: FAVAR models with alternative factor structure
Notes: Estimated impulse responses of selected countries to a negative 100bp Euro area monetary policy shock from the baseline FAVAR model (solid lines), the model with a single set of factors (dotted lines) and the model without block-exogeneity restrictions and two groups of factors (dashed lines, shaded areas are the corresponding 68% confidence bands).

The unrestricted model, on the other hand, provides results which are very similar to

[21] In another robustness check, I also estimated a model excluding Sweden, Denmark and the UK, with and without block-exogeneity assumption. Results for the Euro area and for CEE countries were highly robust and are available upon request.

the baseline model for most variables and countries, indicating that the assumption of block-exogeneity does not distort the results. However, when the unrestricted model is estimated over sub-samples, impulse responses turn out more volatile and are estimated with a higher degree of uncertainty than in the more parsimonious baseline model.

5 Conclusion

This paper has applied a FAVAR model with two blocks to analyze the transmission of Euro area monetary policy shocks to macroeconomic aggregates of thirteen EU countries outside the Euro area. The analysis has been based on a large cross-country data set including data on real activity, prices and financial market variables. Further, impulse responses to a Euro area monetary policy shock have been compared across countries with different exchange rate regimes and with different degrees of trade and financial openness in order to investigate the role of these country characteristics on the size of Euro area monetary policy spillover effects.

An expansionary Euro area monetary policy shock is found to raise production in most EU countries that are outside the Euro area. These effects are on average comparable to the response of industrial production in the aggregate Euro area. Somewhat larger and more instantaneous responses of production are observed in small open economies with fixed exchange rate regimes, where foreign demand effects are particularly strong. Nonetheless, spillovers to real activity in countries with flexible exchange rates are also sizable and result as a combination of positive foreign demand effects, negative expenditure switching effects and stimulating financial spillovers. Finally, prices tend to increase in the three Western EU countries, but behave asymmetrically in most transition economies from Central and Eastern Europe.

The results suggest that monetary policy actions of the ECB substantially affect European economies outside the monetary union, without being directly monitored or internalized by the ECB. In this, a flexible exchange rate is at most partially able to isolate non-Euro area economies from Euro area monetary policy. On the one hand, spillover effects from Euro area monetary policy via the trade channel are indeed weaker in non-Euro area countries with flexible exchange rates compared to countries with pegs, due to the the relatively lower degree of trade openness of countries with floats and due to negative expenditure switching effects. On the other hand, monetary policy spillovers on uncertainty and risk aversion are relatively stronger in countries with floats because these countries also tend to have more developed financial markets and because exchange rate appreciations after the Euro area monetary expansion enhance risk taking by cushioning debt burdens from foreign currency loans. Hence, even though a flexible exchange rate regime can provide some scope for monetary policy independence of non-Euro area countries through expenditure switching effects, it is not able to shield these economies from financial spillovers in presence of highly developed and globally integrated financial markets.

Overall, this implies that central banks and policy makers of non-Euro area countries need to closely monitor both the economic developments in the Euro area and the decisions of the ECB, independently of the exchange rate regime which they pursue against the euro. In addition, appropriately designed macroprudential policies might be a helpful tool for non-Euro area economies to mitigate undesired effects from foreign monetary policies on capital inflows and on risk perceptions in the domestic economy, while sustaining monetary policy autonomy.

This paper has provided some tentative evidence on the role of the trade and the financial channel in the transmission of Euro area monetary policy shocks across different countries. However, more research remains to be done with this regard. An empirical setup which can explicitly identify spillover effects via the financial channel, as opposed to spillovers via the trade channel, would certainly provide highly relevant insights. Also, the development of a theoretical framework which jointly models the international transmission of monetary policy via trade and financial variables and via their interactions remains to be developed in the future.

Moreover, this paper has presented results based on an estimated shadow rate measure as monetary policy variable in order to control for the effects of unconventional monetary policy. Nonetheless, a more sophisticated strategy for the analysis of international spillovers from Euro area unconventional monetary policy measures remains a challenging task for future research. A contribution into this direction has recently been provided by Georgiadis and Gräb (2015) who use an event-study framework based on daily data in order to identify the effects of the announcement of the ECB's extended asset purchase programme on financial variables in different regions outside the Euro area. Such an approach could be extended to an analysis of spillovers to individual countries, to real activity variables or to an examination of the underlying transmission mechanisms.

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A Additional Tables and Figures

Table A1: Variables and countries included, data sources and transformations

Variable	Country/ country group included	Countries missing	Source	Transform.	Slow/Fast
Industrial production, total, volume index	EA aggr., EA, non-EA	Bulgaria	MEI, IFS, National sources	2, sa	s
Industrial production by components (manufacturing, energy, intermediate goods, non-durable consumer goods, durable consumer goods, capital goods)	EA aggr.		Eurostat	2, sa	s
Unemployment rate, 25 to 74 years	EA aggr., EA, non-EA	Estonia	Eurostat, National sources	3, sa	s
Domestic producer price index (PPI), total	EA aggr., EA, non-EA		MEI, IFS	2, saf	s
PPI by components (manufacturing, energy, intermediate goods, non-durable consumer goods, durable consumer goods, capital goods)	EA aggr.		MEI	2, saf 2, saf	s
Consumer price index, all items	EA aggr., EA, non-EA, USA, Japan		MEI, IFS, Eurostat	2, saf	s
Consumer price index, food	EA aggr., EA core		MEI, Eurostat	2, saf	s
Consumer price index, energy	EA aggr.; EA core		MEI,Eurostat	2, saf	s
Crude Oil price	World		IFS	2, na	s
HWWI Commodity price index, total, in euro	World		HWWI	2, na	s
Short-term money market rate, 3 months, nominal	EA aggr., non-EA, USA, Japan	Estonia, Slovenia, Slovakia	MEI, Eurostat, IFS, National s.	0, na	f
ECB Overnight deposit rate	EA aggr.		ECB	0, na	f
ECB Main Refinancing Repo Rate	EA aggr.		ECB	0, na	f
Long-term interest rate (gov. bonds), nom.	EA aggr., USA, Japan		ECB, National s.	0, na	f
Money Supply: M1, M2, M3	EA aggr.		National s.	2, saf	f
Real effective exchange rate, 27 trading partners	EA aggr., EA, non-EA		Eurostat	2, na	f
Nominal exchange rate against Euro	USA		Eurostat	2, na	f
Main stock price index	EA aggr., non-EA, USA, Japan	Latvia	Thomson Reuters, S&P	2, na	f
Stock price volatility	EA aggr., non-EA, USA, Japan	Bulgaria, Latvia	Based on daily stock prices from Datastream and HSBC	0, na	f
Consumer and industrial confidence indicators	EA aggr.		European Commission	3, na	f

Abbreviations

Sources	**Country groups**	**Transformation**
MEI – OECD Main Economic Indicators	EA aggr. – Euro area aggregate	0 – none
ECB – European Central Bank	EA core – Germany, France, Italy, Spain, Belgium, Netherlands	1 –logs
IFS – IMF Financial Statistics	EA – EA core, Ireland, Greece, Austria, Portugal, Finland	2 – log difference
HWWI – Hamburg Institute of International Economics	non-EA – Bulgaria, Czech Republic, Estonia, Latvia, Lithuania, Hungary, Poland, Slovenia, Slovakia, Romania, Denmark, Sweden, UK	3 – difference
S&P – Standard & Poors		sa – seasonally adjusted data
HSBC – The Hongkong and Shanghai Banking Corporation		saf – seasonally adjusted with stable seasonal filter
s – slow moving variable		na – not seasonally adjusted
f – fast moving variable		

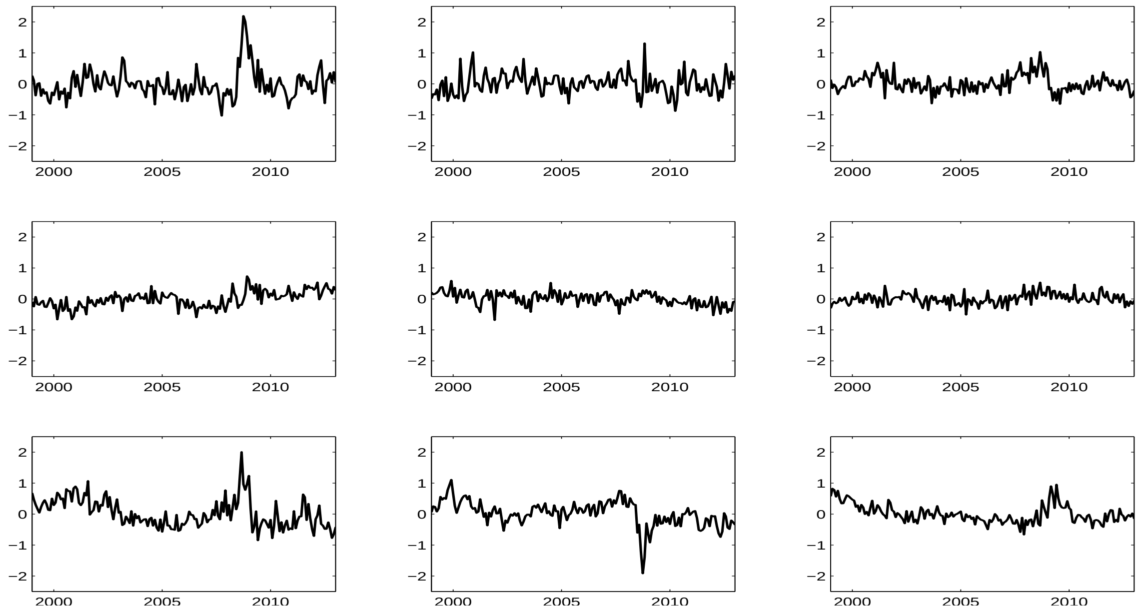

Figure A1: Factors extracted by principal component analysis.
Notes: Specification with 6 Euro area factors (first two rows) and 3 non-Euro area factors (last row).

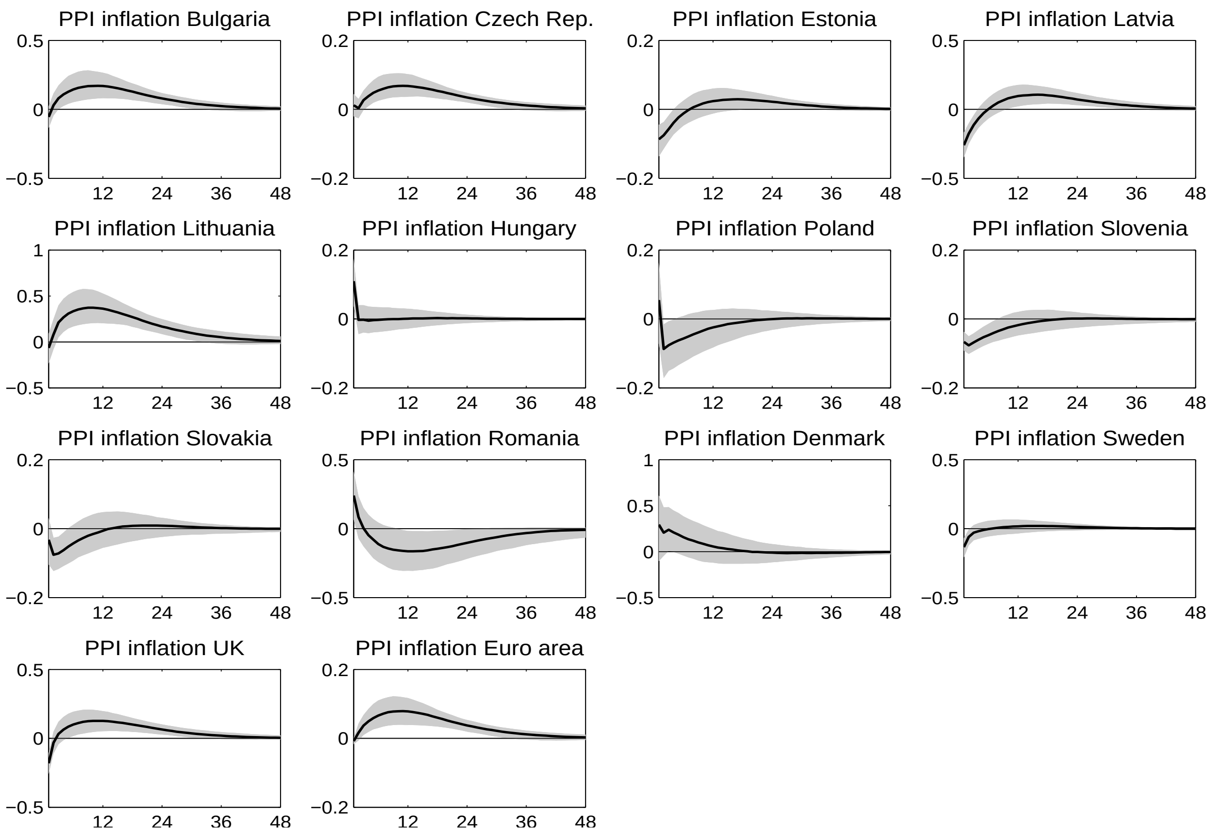

Figure A2: Monetary policy spillovers to non-Euro area producer price inflation
Notes: Estimated impulse responses of non-Euro area countries' producer price inflation to a negative 100bp EA monetary policy shock from the baseline FAVAR specification. Solid lines represent deviations from the baseline in percent. Shaded areas represent 68 percent confidence bands.

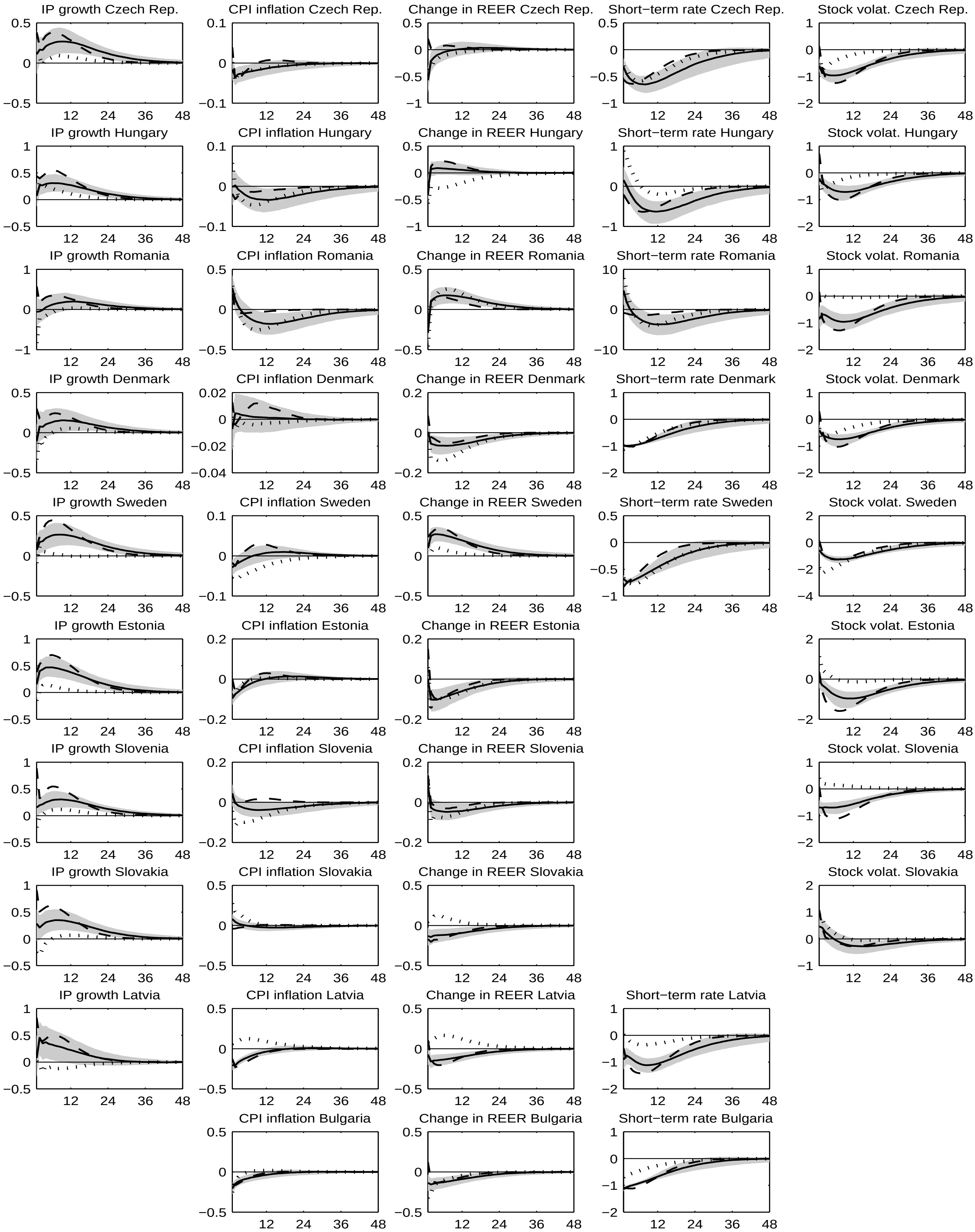

Figure A3: Estimation over 1999-2006 and 2007-2013 sub-samples, countries not presented in Figure 8

Notes: Solid lines (shaded areas) represent median impulse responses (68 percent confidence bands) to a negative 100bp Euro area monetary policy shock from the baseline estimation. Dotted (dashed) lines represent median impulse responses for the 1999-2006 (2007-2013) sub-sample.

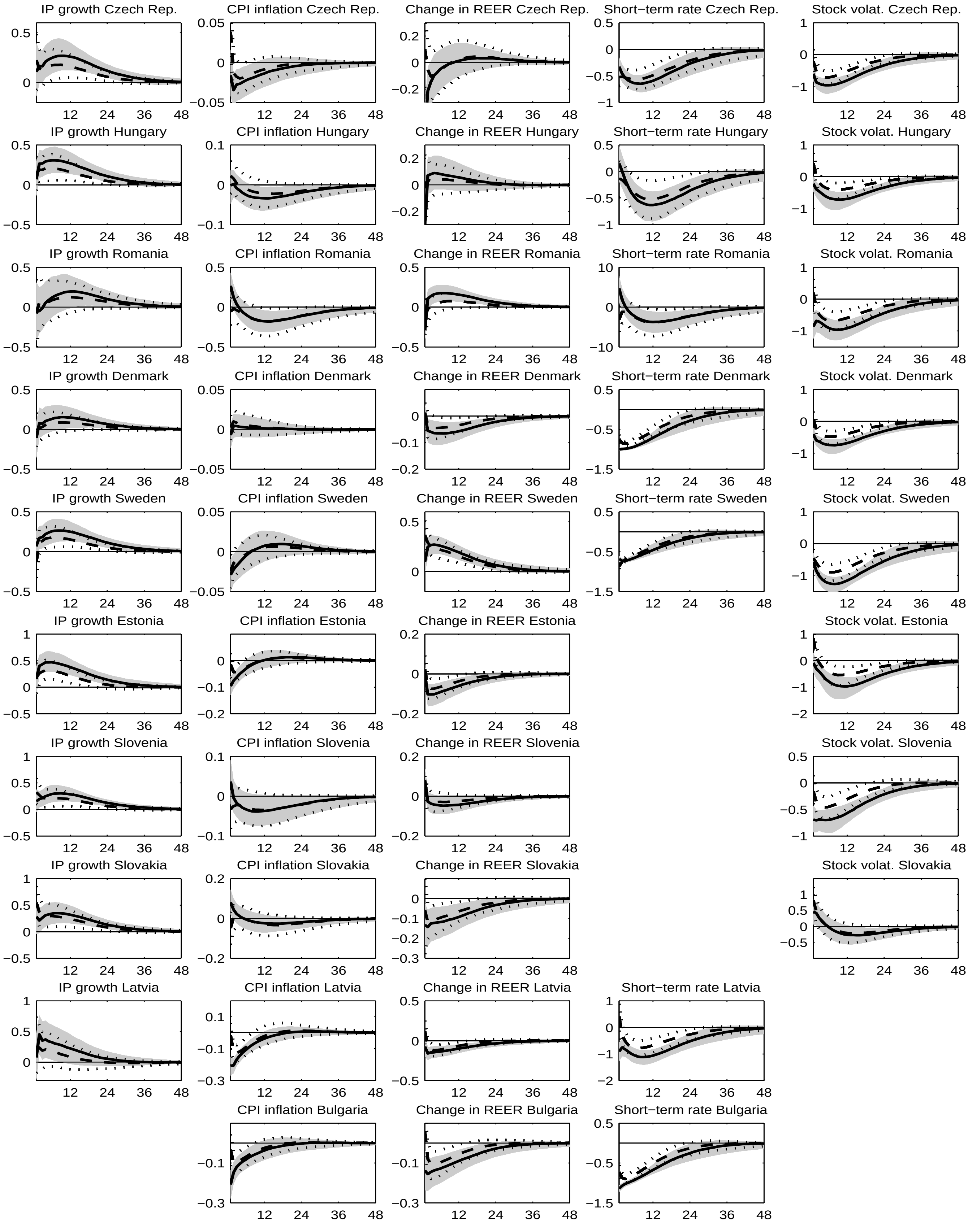

Figure A4: FAVAR model with shadow rate, countries not presented in Figure 9

Notes: Solid lines (shaded areas) represent median impulse responses (68 percent confidence bands) to a negative 100bp shock in the Euro area short-term interest rate (baseline estimation). Dashed (dotted) lines represent median impulse responses (and 68 percent confidence bands) to a negative 100bp shock in the Euro area shadow interest rate.

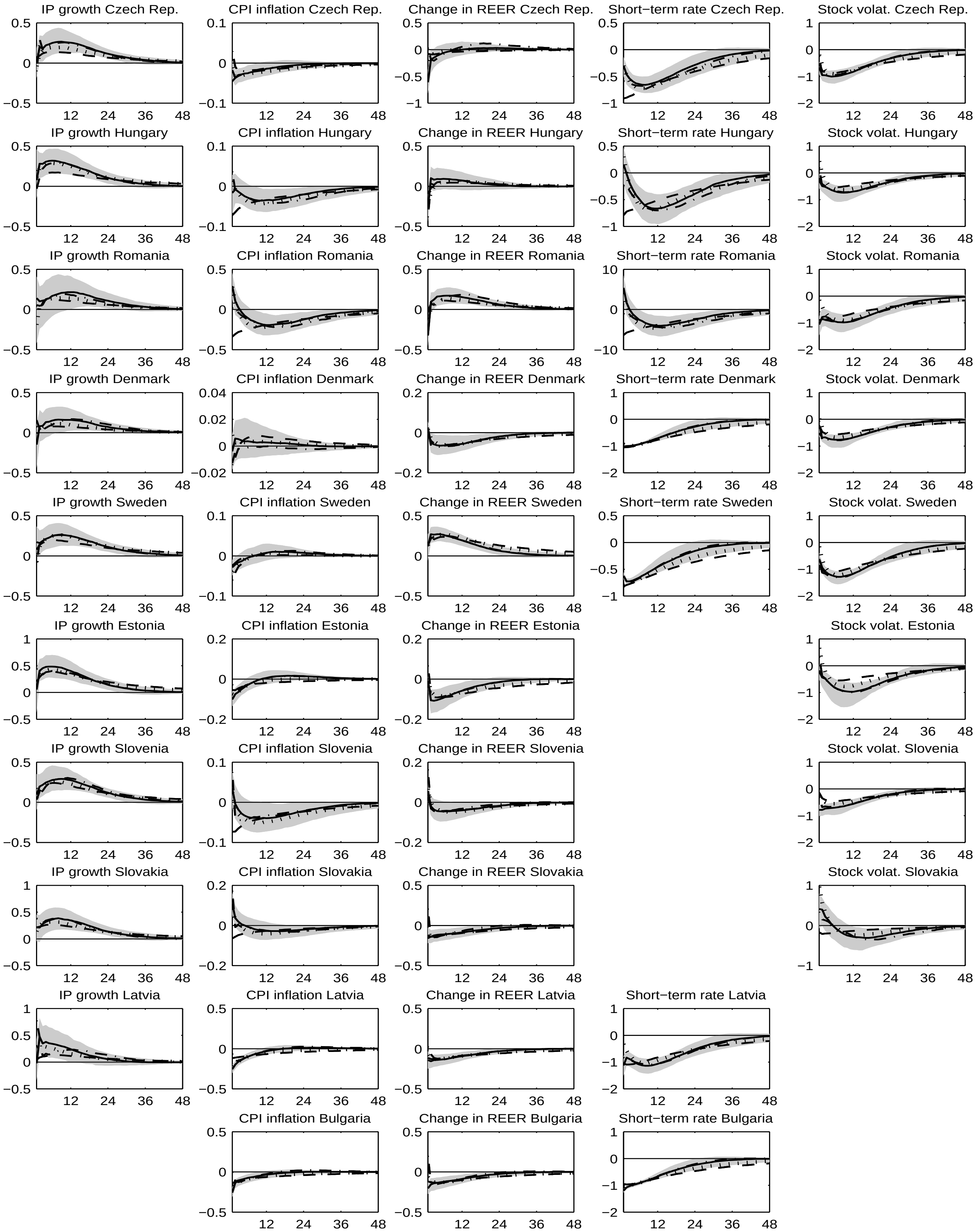

Figure A5: Alternative numbers of factors, countries not presented in Figure 10

Notes: Solid lines (shaded areas) represent median impulse responses (68 percent confidence bands) to a negative 100bp shock in the Euro area short-term interest rate for the baseline FAVAR model. Dashed lines represent median impulse responses from a FAVAR specification with two Euro area factors and one non-Euro area factor and dotted (dashed-dotted) lines for specifications with four (eight) Euro area factors and two (five) non-Euro area factors.

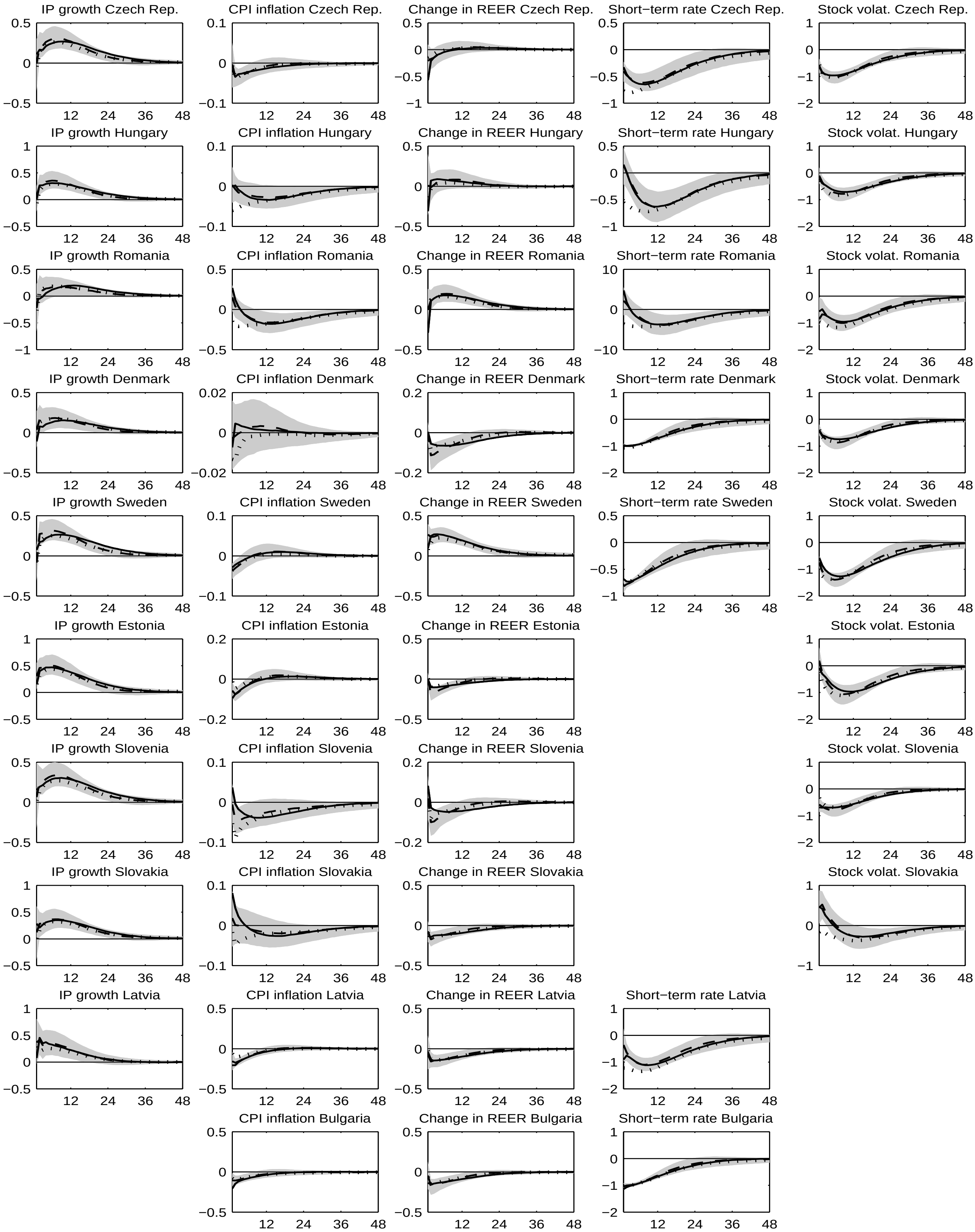

Figure A6: FAVAR with alternative factor structure, countries not presented in Figure 11

Notes: Solid lines represent median impulse responses to a negative 100bp shock in the Euro area short-term interest rate for the baseline FAVAR model. Dashed lines (shaded areas) represent median impulse responses (68 percent confidence bands) for the model without block-exogeneity restrictions and two factor groups. Dotted lines represent median impulse responses for the model with one group on factors, extracted from a combined data set including Euro area and non-Euro area data.