The Impact of Foreign Monetary Policy on Eastern European Countries

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Abstract

We use a Bayesian VAR with economically interpretable structural restrictions and zero restrictions on lags, to analyse the transmission channels of external shocks to an extended set of Eastern European Countries. In particular, we study to what extent monetary policy shocks originating from the US and from Germany can explain fluctuations on Eastern European markets. We find that the US monetary policy influences the Eastern European Countries macroeconomic variables at least as much as its German counterpart.

JEL Classification: E5, C5, F3

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1 Introduction

There is a considerable evidence that the large economies' monetary policy shocks are important sources of variation in the macro variables of many small open economies (SOE) around the world. For instance, this appears to be the case of countries exhibiting strong economic linkages to the US, such as the Latin American ones. By extension, one might be tempted to conjecture that the same applies to the Eastern European countries (EEC) with reference to Germany. Should that hold true, then one might also expect the effect of a US monetary policy shocks to be of secondary importance when compared to the one generated by German Bundesbank/ECB. As a matter of fact, studies on how foreign monetary policy impact EEC macro variables typically consider Germany as the source of the external shocks. This paper investigates whether a conjecture of this type finds empirical support, by examining the impact of US monetary policy shocks on key EEC macroeconomic variables. More specifically, my aim is to assess how much of the movements in CPI inflation and GDP growth in the EEC are generated directly by the US monetary policy shock, and how much indirectly through changes in German aggregate demand caused by that shock, under the assumption that the economic performances in Germany and the EEC are closely related.

In order to examine whether US monetary policy shocks might have a significant influence on the EEC macro variables, we run three different estimations.

The first two are in line with the existing literature. First, we estimate the direct influence of a US monetary policy shock on a set of key EEC economic indicators. Then we repeat this estimation using Germany monetary policy shock in isolation. One may argue, however, that the impact of US monetary policy on EEC macro variables might be generated, at least partially, by the effect that the former exercises on German economic indicators; these, in turn, would have a significant impact on the EEC variables via the strong economic linkages between the involved countries. The third estimation assesses the indirect influence of US monetary policy on EEC macro variables through German economic indicators: we perform this exercise by simultaneously considering two large economies, Germany and the US, where it is assumed that Germany is open towards the US and closed towards the EEC. The objective is to investigate how much of a monetary policy shock generated by the FED is simply absorbed by Germany, and how much is instead transmitted to the EEC. As a result, one may expect that the effect of the US shock is significantly weaker than the one generated by German Bundesbank/ECB. In this paper, we show that this is not the case: even if we control for the US impact through Germany (by including German variables), the strength of the effects of both shocks on EEC variables are comparable.

The EEC included in my analysis are the Czech Republic, Hungary, Poland and the Slovak Republic. The rationale for this selection of countries is that they that share similar characteristics: for instance, they started their economic transition in the early 1990's, and rapidly opened their economies to Western trade and investment; furthermore, those years were characterised by higher inflation (especially in Hungary and Poland) caused by price liberalisation. In order to allow for a cross country comparison we use data from 1994 to 2012. Since the number of observations is limited, we keep the number of variables to a minimum, and focus on the movements in key macro variables such as CPI inflation and GDP growth. To alleviate the curse of dimensionality in the model, we follow Banbura et al. (2008) and we implement the natural conjugate prior via artificial observation.

A vast literature analyses exogenous disturbances generated at home or abroad and their impact on key macro variables. About the contribution most closely related to my work,various authors study the impact of foreign shocks on SOE. Kim (2001) examines the effect of US monetary policy on the exchange rate and foreign trade balances on other G-6 countries. He shows that an expansionary US monetary policy shock generates positive spillover effects. Canova (2005) investigates the transmission of US shocks on Latin American countries and finds that the foreign monetary policy shock produces more fluctuations than real demand and supply shocks generated abroad. Mackowiak (2007) finds that US monetary shocks are an important source of macroeconomic fluctuations for small emerging markets in South East Asia and Latin America. These shocks explain more of the variation of real aggregate output and the price level in those countries than the relevant domestic monetary shocks.

Some authors also investigate the effect of monetary policy shocks on EEC. For example, Anzuini and Levy (2007) examine the effects of an EEC domestic monetary policy shock in a given EEC on its own key macro variables. Mackowiak (2006) studies the effect of ECB monetary policy shocks on those variables. My work is tightly related to these two papers; the main difference is that we explore a new channel of foreign monetary policy influence. Using a method similar to Kim (2001) and Canova (2005), we are interested in the impact of US monetary policy shocks on macroeconomic variables on the EEC. we use Mackowiak's (2006) argument that these countries are open to exogenous disturbances in order to show that a monetary shock that originates in the US can explain at least the same amount of EEC macroeconomic fluctuations as a shock generated by the European Central Bank (and previously by the Deutsche Bundesbank).

In this paper, we adopt a BVAR methodology analogous to the ones used by Kim (2001 and 2001b), Canova (2005) and Mackowiak (2006, 2007). The long-run zero restrictions for SOE are based on different findings from Cushman and Zha (1995), Kim and Roubini (2000) and Kim (1999). The sign restrictions are generated in a similar fashion as in Canova (2005) and Scholl and Uhlig (2005), using an algorithm developed by Ramirez *et al.* (2010). Finally, we impose the prior in my model using artificial observations following the work from Banbura *et al.* (2008).

The field of VAR econometrics is wide and several alternative approaches can be found in the literature. A number of papers raise some concerns about small scale SVAR and develop alternative methods. For example, Factor-Augmented VARs (FAVARs), developed by Bernanke *et al.* (2005), incorporate more information so that the monetary policy shock can be better identified. Mumtaz and Surico (2007) use this approach to analyse the effect of world wide monetary policy shocks on a SOE. The Global VAR (GVAR) approach, proposed by Pesaran *et al.* (2002) and di Mauro *et al.* (2007), employs a vector error correction model for individual countries and combines the result to generate an estimate for all the variables simultaneously. Using a multi-country panel VAR model with time varying coefficients and cross unit interdependencies, Canova and Ciccarelli (2006) study the transmission of different shocks on G7 countries focusing on GDP growth and CPI inflation, and emphasise that this model is suitable for the study of the transmission of monetary policy shocks across economic areas and sectors.

The structure of the paper is as follows. Section 2 gives more details about the VAR model adopted for the estimations. Section 3 describes the structural analysis for each country, including the impulse response functions, forecast error variance decomposition (FEVD) and historical decomposition. Section 4 concludes.

2 Methodology

To study the objectives, we use a VAR model with economically interpretable restrictions. VAR models has become a very popular econometric technique for analysing the relationships between different endogenous variables and are mainly being used to study the effects of a shock on macroeconomic variables, using tools such as impulse response functions, FEVD and historical decomposition.

Orthogonalising the shocks can either follow directly from a Cholesky decomposition of the error terms covariance matrix, or from using restrictions derived from an economic interpretation of the model. At the moment, it appears that no clear consensus has formed in the literature regarding whether restrictions following from the Cholesky decomposition should be based on theory. On the one hand, Stock and Watson (2001, p.18) argue that "It is tempting to develop economic "theories" that, conveniently, lead to a particular recursive ordering of the variables. Rarely does it add value to repackage a recursive VAR and sell it as structural." On the other hand, there are authors (*e.g.* Gottschalk, 2001) stating that when using a Cholesky decomposition, the restrictions need to be supported by theoretical interpretation. Canova (2007) emphasises that a Cholesky decomposition without any economic interpretations may be misleading. To explore my research question, we follow Canova (2007) and use a structural VAR with sign restrictions.

Consider T observations of m variables. Take a VAR(p) process, where p is the number of lags of the process with linear structure, to estimate the relationship among a set of endogenous variables as follows

$$Y_t = BX_t + \epsilon_t, \tag{1}$$

with $X_t = (Y_{t-1}, ...Y_{t-p}, 1)'$ and $B = (B_{1,}...B_p, C)$, where Y_t is a $m \times 1$ vector of endogenous variables in period t. The intercept term C is a $m \times 1$ vector, which allows for the possibility of a nonzero $E[Y_t]$, $B(j)$, for $j = 1, .., p$, is a $m \times m$ matrix of regressors. The residual ϵ_t is a Gaussian white noise with zero mean ($i.e.$ $E[\epsilon_t] = 0$) and variance-covariance matrix Σ exhibiting the following characteristics

$$\begin{aligned} E[\epsilon_t \epsilon_s'] &= \Sigma \text{ if } t = s, \\ E[\epsilon_t \epsilon_s'] &= 0 \text{ if } t \neq s. \end{aligned} \tag{2}$$

To obtain an orthogonolised error term from equation (1), we can use an $m \times m$ matrix A such that

$$Y_t = BX_t + Ae_t,$$

where e_t is an orthogonal white noise vector following from $\epsilon_t = Ae_t$ with an identity variance-covariance matrix given by

$$\begin{aligned} E[e_t e_s'] &= I_m \text{ if } t = s, \\ E[e_t e_s'] &= 0 \text{ if } t \neq s. \end{aligned} \tag{3}$$

It follows from (2) and (3) that $E[Ae_t e_t' A'] = AA' = \Sigma$.

In the contemporaneous period, the sign restrictions are implemented in such a way that the impulse responses to a monetary policy shock are consistent with the theory. In this respect, we follow Ramirez *et al.* (2010), who provide an efficient algorithm to find the structural impact matrix $\tilde{A}$ consistent with impulse responses of certain signs. To compute the structural impact matrix $\tilde{A}$, we draw some matrix $J \sim N(0,1)$, and take the QR decomposition $J = QR$ to find an orthonormal matrix Q such that it holds $QQ' = I_m$ and $\tilde{A} = AQ$. Therefore, we can write $\Sigma = \tilde{A}\tilde{A}'$. It is important that the matrix $\tilde{A}$ satisfies the sign restrictions set out below and it still holds that

$$\epsilon_t = \tilde{A}e_t. \tag{4}$$

We distinguish between four different models

The full vector of endogenous variables is given by:

$$Y_t = \left[Y_t^L, Y_t^M, Y_t^S\right]' = \left[FFR^{US}, \Delta GDP^{US}, \Delta CPI^{US}, \Delta GDP^G,\right.$$
$$\left.\Delta CPI^G, XR^G, \Delta GDP^{EEC}, \Delta CPI^{EEC}, XR^{EEC}\right]'.$$

Thus the matrix $\tilde{A}$ (and analogously matrix $B(j)$) can be divided into nine parts, mainly $\tilde{A}_{LL}\left(B_{LL}(j)\right)$ is sub-matrix US on US, $\tilde{A}_{LM}$ $\left(B_{LM}(j)\right)$ US on Germany, and finally $\tilde{A}_{LS}\left(B_{LS}(j)\right)$ US on EEC. $\tilde{A}_{ML}$ $\left(B_{ML}(j)\right)$ Germany on US, $\tilde{A}_{MM}$ $\left(B_{MM}(j)\right)$ Germany on Germany and $\tilde{A}_{MS}\left(B_{MS}(j)\right)$ Germany on EEC. The last three are the influence of EECs on US ($\tilde{A}_{SL}$ and $B_{SL}(j)$), on Germany ($\tilde{A}_{SM}$ and $B_{SM}(j)$) and on their own economies ($\tilde{A}_{SS}$ and $B_{SS}(j)$). Imposing sign restrictions on large economy variables to ensure that positive shocks in the interest rate implies a fall in GDP growth and inflation in the large economy, it holds

$$\tilde{A}_{LL} = \begin{pmatrix} + & . & . \\ - & . & . \\ - & . & . \end{pmatrix}.$$

The sign restrictions on large economy variables ensure that positive shocks in the interest rate implies a fall in GDP growth and inflation in the large economy. The impulse responses for the rest of the variables remain unrestricted on sign. The identification is completed by using zero restrictions on contemporaneous structural parameters so as to ensure that the SOE does not influence the large economy contemporaneously by assuming that $\tilde{A}_{ML}$, $\tilde{A}_{SL}$ and $\tilde{A}_{SM}$ are zero matrices. Beside the contemporaneous restrictions, we impose restrictions on lags. Assuming that large economy cannot be influenced by the EEC, we impose zero restrictions, on the prior beliefs that domestic economies are small and cannot influence the large one with their action at any time, *i.e.*, the matrix $B_{ML}(j)$, $B_{SL}(j)$ and $B_{SM}(j)$ are zero matrices.

We run three different estimations and one simulation. The first one estimates the direct influence of a US monetary policy shock on a set of key EEC economic indicators. Then we repeat this estimation using Germany monetary policy shock in isolation. In both cases, the matrix $\tilde{A}$ and $B(j)$ is a $6x6$ matrix, containing of L and S parts. The third estimation assesses the indirect influence of US monetary policy on EEC macro variables through German economic indicators: we perform this exercise by simultaneously considering two large economies, Germany and the US, where it is assumed that Germany is open towards the US and closed towards the EEC and the model contains full $9x9$ matrices.

In our fourth excercise, we simulate the direct influance of the US monetary policy shock to the EEC by shutting down the German channel. Therefore, using the results of the third estimation the parameters, that determine the US influence on the German economy are set to zero. (Row 7-9, clmn 4-6, *i.e.*, matrix $\tilde{A}_{MS}$). Thus, the parameters stay estimated, but the german influance is shut down.

We follow the literature and apply Bayesian estimation methods using Gibbs sampling to estimate the parameters of the model.[1] There exist several approaches to set the prior. Since we use a prior belief with zero restrictions, we opt for an independent normal inverse Wishart prior. Technically, we impose this prior by following Banbura *et al.* (2008) and incorporating additional artificial data.

To carry out the Bayesian inference, we use a Gibbs sampling procedure, which is a posterior Markov chain Monte Carlo (MCMC) simulation mechanism. The details are described in Appendix B.

3 Empirical Analysis and Results

An important question is how many variables should be included in the VAR model. As in Mackowiak (2007), we use a small scale model with three domestic variables for each country. The founding assumption of the model is that US monetary shocks has a significant influence on the EEC. Nonetheless, it can be argued that Germany is a major trading partner for all the EEC. It attracts between 25 to 30 percent of the total exports from each of these countries and the EEC are also substantial importers of goods produced in Germany. The magnitude of these

[1] See Greene (2003, Chapter 18) for more details.

relationships is clearly not reciprocal, which suggests that the EEC can be characterised as SOE relative to Germany. It follows from the data that the openness of the EEC towards Germany should be significantly stronger than the one towards the US market. An analogous relationship can be found between Germany and the US. Since the US is an important export partner for Germany, covering a 7 percent export share, but not vice versa, Germany might be therefore regarded as a small open economy (SOE) relative to the US.

As representatives of the EEC, we select the Czech Republic, Hungary, Poland and the Slovak Republic. These countries have similar characteristics and underwent similar development paths after the their Soviet-imposed regimes collapsed. During the 1990s, their economies were characterised by a period of privatisation and adopted floating exchange rates regimes. As they undertook market reforms, they also competed with each other for foreign direct and indirect investments. They all initially experienced rapid GDP growth and, in the last two decades, their economies evolved from being classified as emerging markets to fully industrialised parts of the European Union.

In terms of available data, my regressions cover the period 1995 - 2012 for Hungary and Poland, from 1996 to 2012 for the Czech Republic and from 1997 to 2012 for the Slovak Republic. Because of the limited number of observations, we restrict the analysis only to the most important macroeconomic variables such as GDP growth, CPI inflation and the nominal exchange rate for each country, and run a constant, rather than time varying, BVAR. The source of the data is Datastream and the details on each of the particular time series are given in Appendix C. All data, except for the interest rate, are either in logarithms or log differences and aggregated to quarterly values; furthermore, GDP and the price index data series are seasonally adjusted.

We estimate the model for each EEC separately, in combination with either US or German variables, or both. Therefore, we run three groups of estimations. First, we estimate the impact of a US monetary shock directly on the EEC macroeconomic variables. The goal here is to assess the direct impact of US monetary policy shocks on EEC markets. Second, we compare this impact with the direct impact of the Deutsche Bundesbank's interest rate (after 2001, the ECB's). Finally, the third group of estimations analyse the impact of a US monetary shock on EEC, controlling for Germany.

The literature generally opts for two lags for quarterly data, which fits well with Mackowiak (2006), who estimates the model using monthly data with six lags as an optimum. Given my quarterly data, both, the Akaike and the Swarz criteria confirm that a VAR(2) estimation provides the best fit.

The impulse responses for the three groups of estimations are given by the median response function of the domestic variables over 12 periods, due to an increase in the interest rate of the large economy by one standard deviation point, and are displayed in a posterior 68% band extracting the 16th and 84th percentile of the simulated impulse response distribution. The impulse response functions for the estimations are presented in Figures 1 - 3. It is significant that the pattern of the impulse responses are similar for all the three groups of estimations: the monetary shock generated abroad is followed by a decrease in the GDP growth and a depreciation of the domestic currency in all EEC. The impact on CPI inflation is, however, ambiguous.

Figure 1 illustrates the direct impact of the US monetary policy shock on the EEC. In my sample, the income absorption effect is the weakest in Poland (the largest of the EEC), where the GDP growth recovers fully after only three periods (less than one year). Conversely, the biggest effect is on the Slovak Republic (the smallest of the EEC), where the impact is as big as on the US GDP rate of growth itself. A contractionary monetary policy leads unambiguously to the appreciation of the dollar relative to all the other currencies in the model. This is in line with the theoretical predictions, and due to the fact that the investors are willing to invest more in US bonds, thereby causing an increase in demand for US dollars. The effect on CPI inflation is ambiguous for the trade off arising between two effects. On the one hand, the

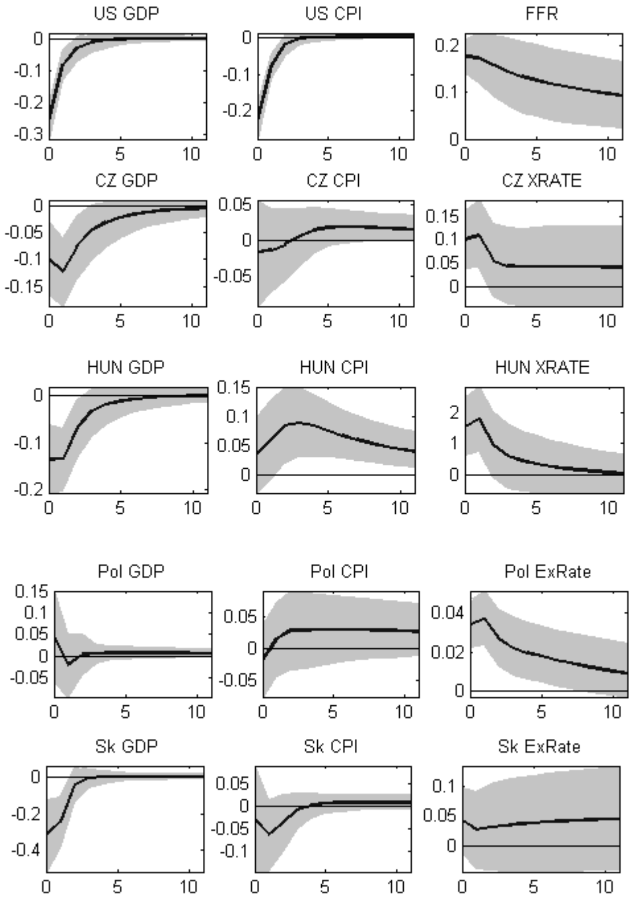

Figure 1: Dynamic Effect of a US monetary shock on EEC macroeconomic variables

slow down in the domestic activity causes the prices to decrease. On the other hand, the depreciation of the domestic currency increases import prices, which generate an increase in the domestic CPI inflation. In my impulse responses, the second effect is clearly dominant in Hungary, but it appears to be strong also in Poland.

The impulse responses in Figure 2 show the direct impact of a German (later,

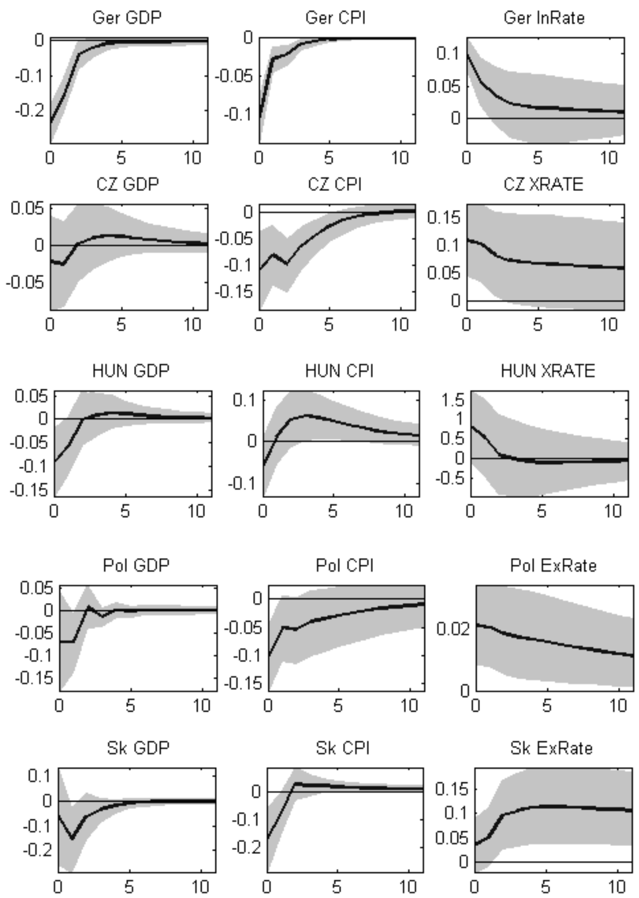

Figure 2: Dynamic effect of a ECB monetary shock on EEC macroeconomic variables.

European) monetary shock on EEC variables. Similar to the first estimation, here the effect on GDP growth in Poland is lowest and in the Slovak Republic it is strongest. On the contrary, in all countries, except for the Slovak Republic, GDP growth may increase after a short period (half a year), showing that after a while the income absorption effect may be dominated by the expenditure switching effect.

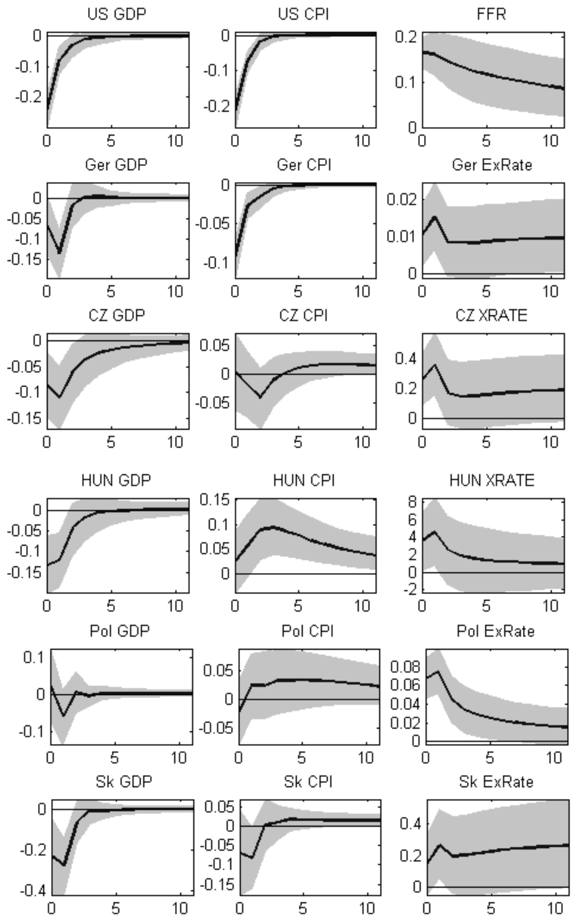

Figure 3: Dynamic effect of a US monetary shock on German and EEC macroeconomic variables

There is no such a positive effect on Slovak output, which is consistent with the fact that the exchange rate is not allowed to depreciate since Slovakia is a member of the Eurozone and therefore only the income absorption effect takes place.

Figure 3 illustrates the impact of US monetary shock and its effect on Germany as well as on other countries (though Germany is considered a large economy relative to the EEC). The relevant impulse responses show that an unanticipated increase in the Federal Funds rate leads to a contraction in US macroeconomic variables as well as in those of all other countries. However, adding German macroeconomic variables into the model does not alter the reaction of the EEC variables to the innovation in the Federal Funds rate. Furthermore, comparing the result with the one from second estimation, it is clear that German GDP growth and inflation react similarly to the unanticipated increase in Federal Funds rate than to its own shock.

To summarise, three findings can be identified from my analysis. First, an exogenous contractionary monetary shock reduces output growth in all EEC significantly (except for Poland), regardless the origin of the shock. Second, the effect of the German (later, ECB's) shock on EEC GDP growth rate is smaller and dies out quicker than the one generated in the United States. Third, both exogenous monetary shocks induce a depreciation in the domestic currency and have an ambiguous effect on domestic inflation.

Tables 1 and 2 report the median share of the FEVD for forecast horizons of 1 quarter (refer to as the short-run), 4 quarters (1 year, the medium run) and 12 quarters (3 years, the long-run).[2] Although the contribution of the German

[2] In the tables, the three estimations are in short referred to as: 1) direct US monetary shock (US_EEC); 2) direct German monetary shock (GER_EEC); and 3) US monetary shock with control for German variables (US_GER_EEC).

shock is higher in the short run, the contribution of US shocks and German shocks after three years are of similar magnitude for both the EEC output growth and inflation.

US_EEC				
	CZ CPI	Hun CPI	Pol CPI	SK CPI
1	0.75	0.83	0.60	0.63
4	3.59	1.97	1.41	3.10
12	6.98	5.97	3.14	4.38
Ger_EEC				
	CZ CPI	Hun CPI	Pol CPI	SK CPI
1	5.60	1.37	0.91	0.65
4	9.60	2.40	2.00	2.91
12	12.93	7.41	4.63	4.59
US_Ger_EEC				
	CZ CPI	Hun CPI	Pol CPI	SK CPI
1	1.33	0.64	0.52	0.60
4	6.20	1.75	1.31	2.96
12	10.98	5.68	3.23	4.38

Table 1: Forecasting Error Variance Decompositions (FEVDs) for CPI inflation

Table 1 compares the FEVD for the CPI inflation for all three groups of estimations, and shows that the German monetary policy shock explains more of the CPI inflation for all countries than its US counterpart, mainly in the short run. The difference is especially large for the Czech Republic (although, when controlling for Germany, the difference dies out in the long run). Generally, in the long run, the US monetary shock accounts for 3 to 7 percent of the variability of the CPI inflation, and when we control for Germany, it explains

US_EEC

	CZ CPI	Hun CPI	Pol CPI	SK CPI
1	13.77	7.20	7.05	0.76
4	22.48	14.58	8.12	10.48
12	22.88	16.29	8.78	11.09

Ger_EEC

	CZ CPI	Hun CPI	Pol CPI	SK CPI
1	21.28	11.40	4.30	12.57
4	19.56	10.42	5.55	17.20
12	24.18	13.16	6.74	18.10

US_Ger_ECC

	CZ CPI	Hun CPI	Pol CPI	SK CPI
1	12.91	6.12	8.40	0.77
4	19.78	12.12	9.26	10.14
12	19.80	12.94	9.94	10.61

Table 2: Forecasting Error Variance Decompositions (FEVDs) for GDP growth

up to 11 percent. The German (later, ECB's) shock explains mostly the Czech inflation, in the long run up to 13 percent. Generally, the exogenous monetary policy shocks explains more of the inflation in the Czech Republic and less of it in Poland. Table 2 shows that a sizeable fraction of the variation in real GDP growth can be attributed to external monetary policy shocks. The US generates higher variation in Hungarian and Polish GDP, even when controlled for Germany, whereas the Czech and the Slovak Republic are the countries most exposed to the German (later, ECB's) monetary shock. In general, in a 12-period horizon, the exogenous monetary shocks explain more of the variation in GDP growth than in CPI inflation.

What would it happen in the absence of any shock but those generated by monetary policy? The historical decomposition shows the contribution of the monetary policy shock to the endogenous variables, and therefore the overall effects of the exogenous monetary policy shock in specific periods. Figures 4 - 6 show the detrended variables (represented by the line) and its decomposition in the structural shocks to the data, where the dark bars measure the contribution of the monetary policy shock for the estimated model for the period 2005-2012 for all the three groups of estimations. By looking at the specific period, the US monetary shock plays a significant role in explaining GDP growth in the Czech Republic and Hungary, and less in Poland and the Slovak Republic. Slovak GDP growth is better explained by the German (later, ECB's) shock. Again, this is consistent with the Slovak Republic joining the Eurozone in 2009. Although the contribution of the exogenous monetary policy shock is relatively small, there are some sub-periods, *i.e.* during the recession, in which these shocks are significant. For example, the bottom-left panel of Figure 4 is clearly suggestive of the recession in Poland being driven by the US shock. Similar but weaker results are found for the other countries as well.

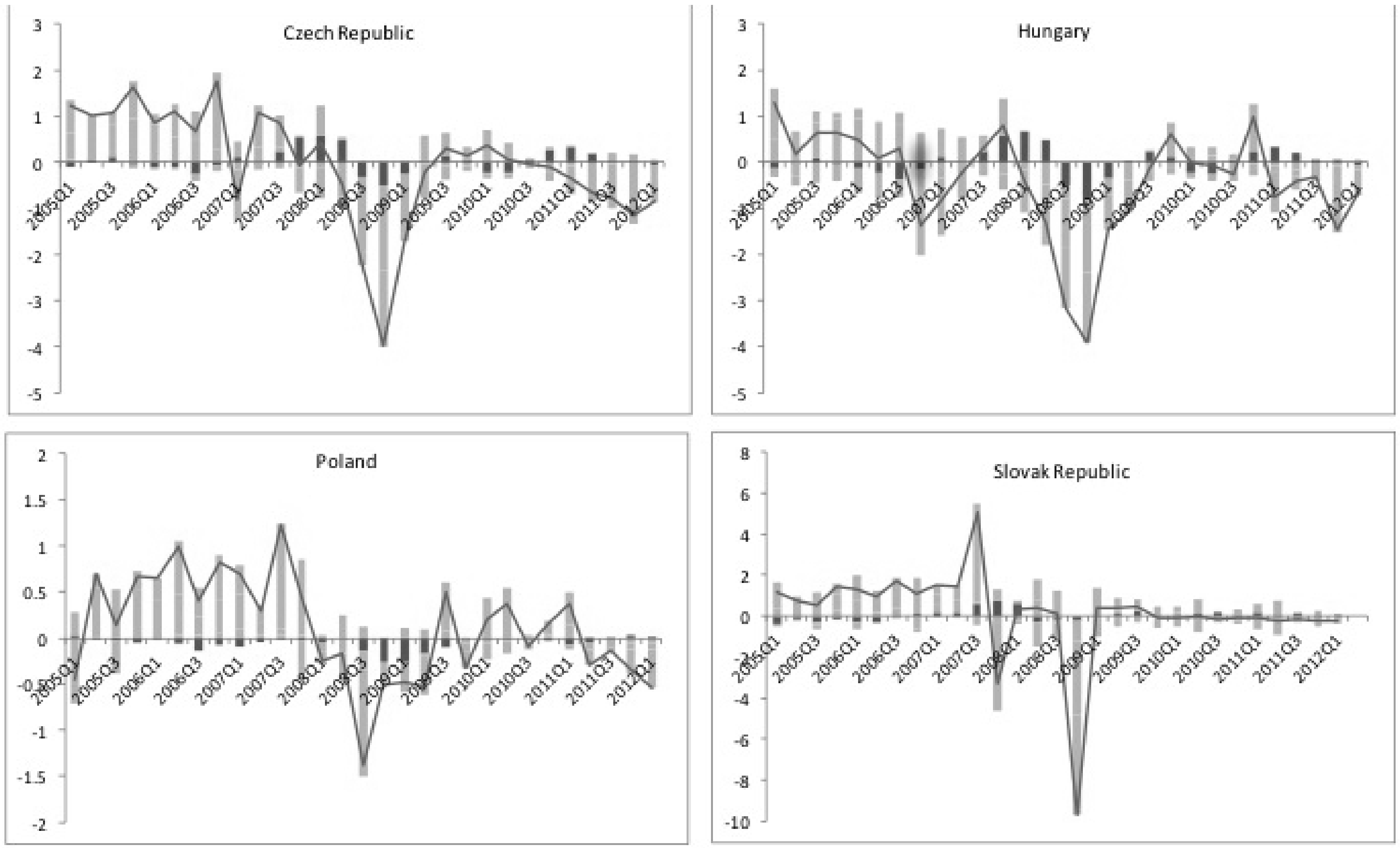

Figure 4: Contribution of a US monetary policy shock to the EEC GDP Growth

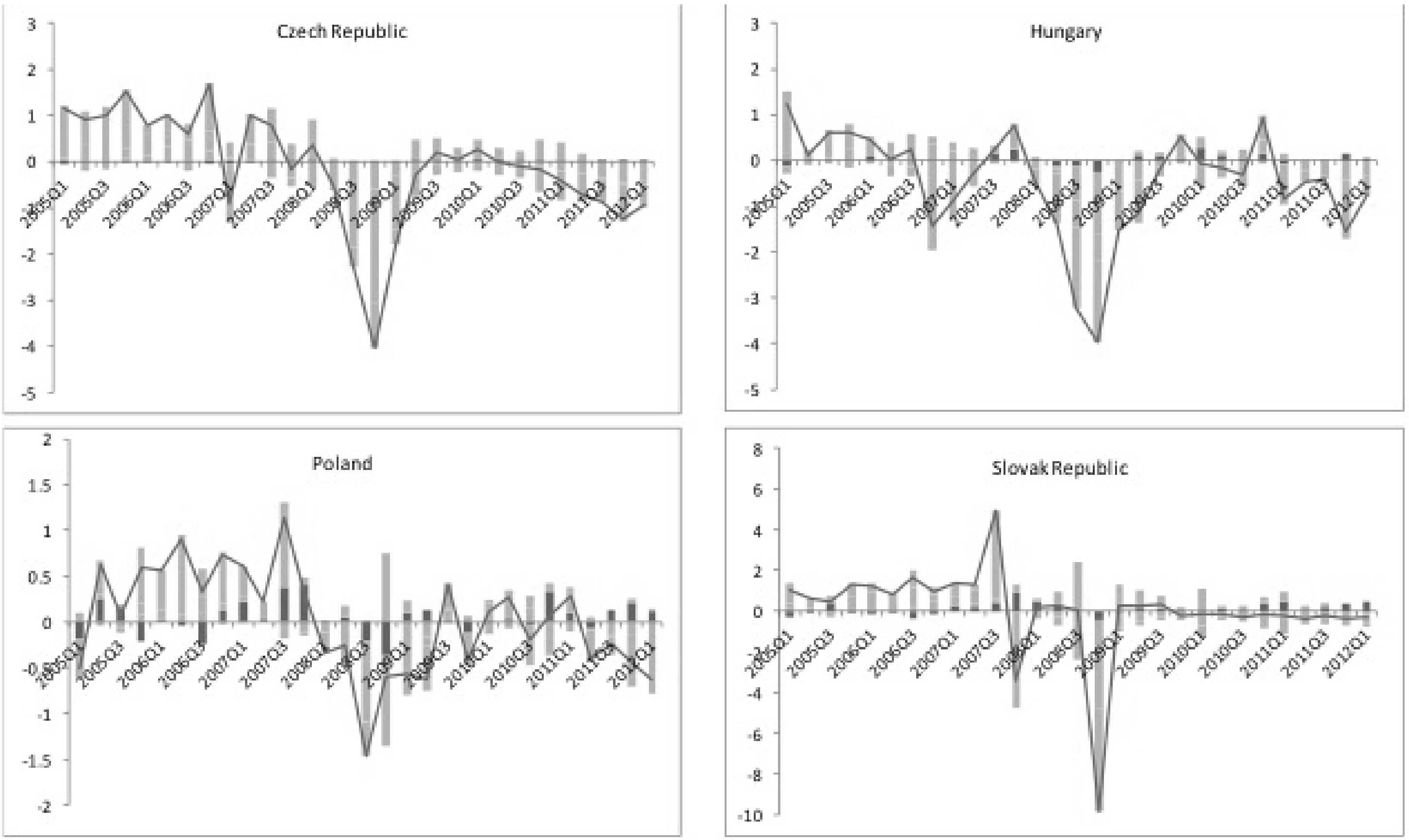

Figure 5: Contribution of a ECB monetary policy shock to the EEC GDP Growth

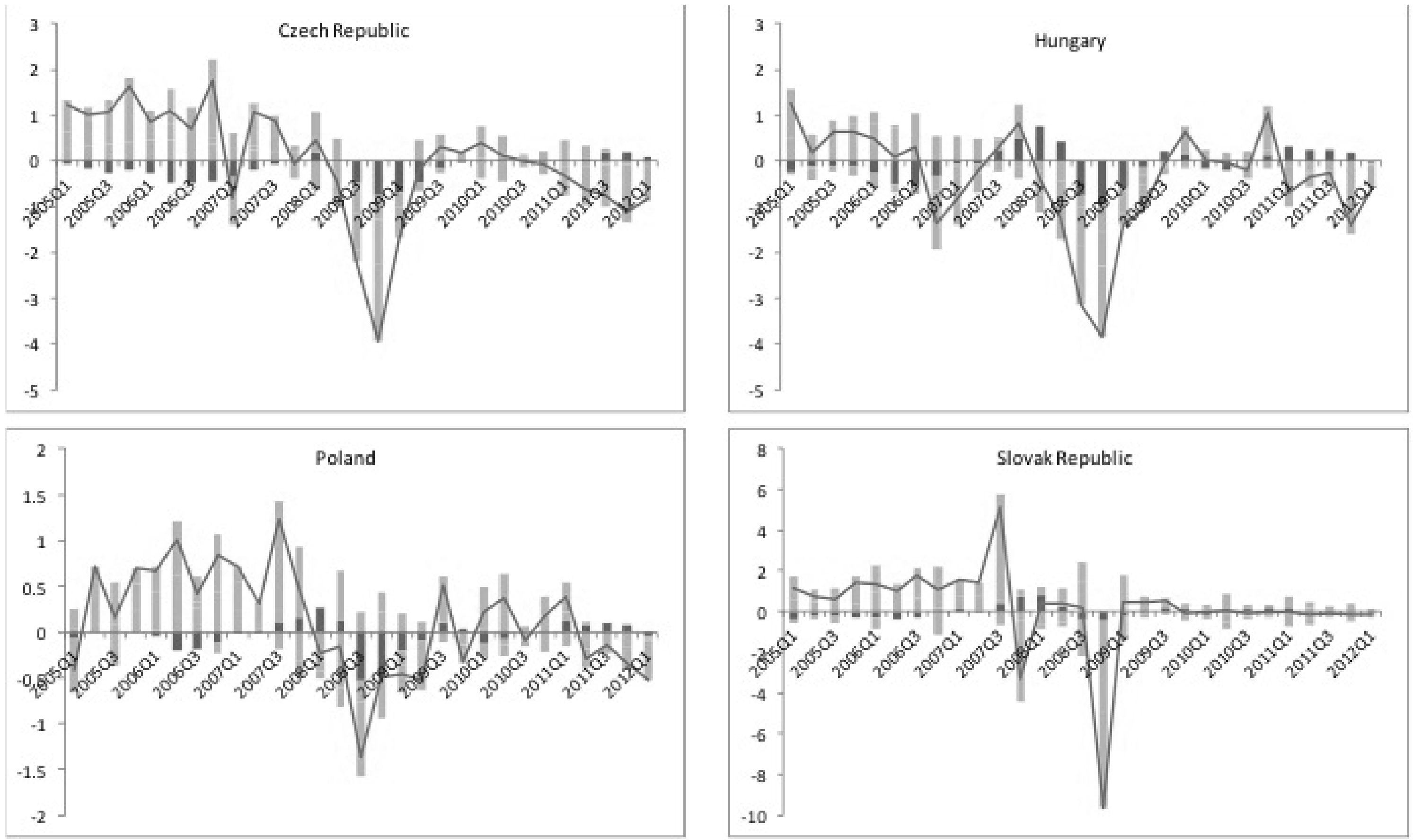

Figure 6: Contribution of a US monetary policy shock to the German and EEC GDP Growth

4 Conclusion

This paper investigated the impact of US monetary policy shock on four Eastern European Countries, namely the Czech Republic, Hungary, Poland and the Slovak Republic. The structural VAR process is identified using two types of restrictions. First, we introduce sign restrictions to ensure that a contractionary monetary policy shock in the large economy causes a decrease both in its inflation and output. Second, we impose zero restrictions on the channels feeding back from the small open economy to the large economy, in order to guarantee that the economic variables of the former has no influence on those of the latter.

We find that a contractionary monetary policy in the large economy significantly reduces output growth in all EEC, independently of whether the large economy is represented by the US or Germany. In particular, US monetary policy appears to influence EEC macroeconomic variables at least as much as its German (later, ECB's) counterpart, even after controlling for the indirect effect of the former through German macroeconomic variables.

For future research, it would be interesting to extend the analysis by including more endogenous variables, such as the real exchange rate, the current account balance and other trade data. When dealing with these extensions, it would be preferable to use a FAVAR method, which is more suitable for large scale models with small numbers of observations.

Appendix A

In the particular case of three countries, *e.g.*, the US, Germany and a (domestic) EEC like the Czech Republic, the matrix $B\left(j\right)$ can be written as

$$B\left(j\right)=\begin{pmatrix} B_{11}(j) & 0 & 0 \\ B_{21}(j) & B_{22}(j) & 0 \\ B_{31}(j) & B_{32}(j) & B_{33}(j) \end{pmatrix}, \tag{5}$$

where $B_{12}(j)$, $B_{13}(j)$ and $B_{23}(j)$ are zero matrices with $m\times(m\times p+1)$ parameters, meaning that EEC variables have impact on neither German nor the US economy, and where $B_{31}(j)$ and $B_{32}(j)$ respectively give the direct impact of US and German variables on the EEC. The first line represents US economy.

The identification scheme has the following form

$$\begin{pmatrix} \epsilon\left\{FFR^{US}\right\} \\ \epsilon\left\{\Delta GDP^{US}\right\} \\ \epsilon\left\{\Delta CPI^{US}\right\} \\ \epsilon\left\{\Delta GDP^{G}\right\} \\ \epsilon\left\{\Delta CPI^{G}\right\} \\ \epsilon\left\{XR^{G}\right\} \\ \epsilon\left\{\Delta GDP^{EEC}\right\} \\ \epsilon\left\{\Delta CPI^{EEC}\right\} \\ \epsilon\left\{XR^{EEC}\right\} \end{pmatrix}=\begin{pmatrix} + & . & . & 0 & 0 & 0 & 0 & 0 & 0 \\ - & . & . & 0 & 0 & 0 & 0 & 0 & 0 \\ - & . & . & 0 & 0 & 0 & 0 & 0 & 0 \\ . & . & . & . & 0 & 0 & 0 & 0 & 0 \\ . & . & . & . & . & 0 & 0 & 0 & 0 \\ . & . & . & . & . & . & 0 & 0 & 0 \\ . & . & . & . & . & . & . & 0 & 0 \\ . & . & . & . & . & . & . & . & 0 \\ . & . & . & . & . & . & . & . & . \end{pmatrix}\begin{pmatrix} e\left\{FFR^{US}\right\} \\ e\left\{\Delta GDP^{US}\right\} \\ e\left\{\Delta CPI^{US}\right\} \\ e\left\{\Delta GDP^{G}\right\} \\ e\left\{\Delta CPI^{G}\right\} \\ e\left\{XR^{G}\right\} \\ e\left\{\Delta GDP^{EEC}\right\} \\ e\left\{\Delta CPI^{EEC}\right\} \\ e\left\{XR^{EEC}\right\} \end{pmatrix}.$$

For VAR(2), the model has the following form

$$Y_t = B_1 Y_{t-1} + B_2 Y_{t-2} + C + \epsilon_t.$$

The prior mean for $vec\,(B_0)$ is set to be equal 0.95 for coefficients on own first lags and equal zero on all other remaining coefficients. The VAR(2) model under the prior can be written as

$$\begin{pmatrix} Y_t^{US} \\ Y_t^{G} \\ Y_t^{EEC} \end{pmatrix} = \begin{pmatrix} diag(0.95) & 0 & 0 \\ 0 & diag(0.95) & 0 \\ 0 & 0 & diag(0.95) \end{pmatrix} \begin{pmatrix} Y_{t-1}^{US} \\ Y_{t-1}^{G} \\ Y_{t-1}^{EEC} \end{pmatrix}$$
$$+ \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} Y_{t-2}^{US} \\ Y_{t-2}^{G} \\ Y_{t-2}^{EEC} \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} + \begin{pmatrix} \epsilon_t^1 \\ \epsilon_t^2 \\ \epsilon_t^3 \end{pmatrix},$$

where Y_t^{US} is a 3×3 matrix of US variables, the interest rate, GDP growth and CPI inflation, Y_t^G and Y_t^{EEC} are 3×3 matrices of German and EEC variables respectively, namely the GDP growth, CPI inflation and nominal exchange rate.

Assuming 9 endogenous variables, the prior variance matrix H is a 171×171 diagonal matrix, where diagonal elements are set close to zero for coefficients restricted to zero and large for the remaining coefficients. In particular, with reference to the part of the matrix H corresponding to either matrix $B(j)$, $j = 1, 2$ as given by (5), the elements are all given a very high value (10 000) except for those corresponding to $B_{12}(j)$, $B_{13}(j)$ and $B_{23}(j)$, which are set very low (1/10.000) to impose the prior strictly.

Appendix B

The Gibbs algorithm iterates M times and produces draws for B and Σ. Each iteration requires sampling from the conditional posterior distribution, which after the burn-in draws are discarded converges to the marginal distribution. Samples from the beginning of the chain, the first J draws are discarded to remove the influence of starting values. Once draws from the posterior distribution are obtained, we implement a structural analysis to ensure that the sign restrictions hold. Appendix C shows the convergence of the algorithm via recursive mean plots.

The Gibbs algorithm is given as follows

1. Set the priors for coefficient matrix $p(vec(B)) \sim N(vec(B_0), H)$ and for the variance - covariance matrix $p(\Sigma) \sim IW(\bar{S}, \alpha)$ as described above, and the starting values obtained from OLS estimation.

2. Sample conditional posterior distribution of B, the first coefficient vector $vec(B_1)$, with variance V^* and mean M^* as given in (**??**).

3. Given $vec(B_1)$, draw variance-covariance matrix Σ_1 from Inverse Wishart distribution.

4. Compute a matrix $\tilde{A}$, such that $\tilde{A}\tilde{A}' = \Sigma$ using a Cholesky and QR decomposition according to (**??**).

5. Identify the signs on $\tilde{A}$. If they satisfy the sign conditions, matrix $\tilde{A}$ will be used for further analysis, if not this step is repeated.

6. Repeat 1-6 M times to obtain $vec(B_1), ..., vec(B_M)$, $\Sigma_1, ...\Sigma_M$ and burnt the first J iterations. Use the remaining last $M - J$ iterations to approximate the marginal posterior distribution, the posterior mean and variance.

We set $M = 50000$ iterations of which the first $J = 45000$ are discarded and keep $M - J$ draws to use for further inference. First, it is worth mentioning that the $\tilde{A}$ matrix is not unique. That is, it is possible to find different $\tilde{A}$ matrices that satisfy the sign restrictions. One of the options to deal with this is to draw $\tilde{A}$ matrix 100 times and choose the one closest to the median. This is the matrix, which we use for analysing the impulse response functions, FEVD and historical decomposition.

Appendix C

For the analysis, Datastream was a source for following data:

- As an indicator of monetary policy shock:
  - US Money market rate - federal funds rate (USI60B..)
  - Day to Day money market rate monthly average (BDSU0101R)

  - Exchange rate, used in percentage logarithm values
  - German Mark to US $ (USWGMRK)
  - Czech Koruna to US $ (USCZECK)
  - Hungarian Forint to US $ (USHUNGF)
  - Polish Zloty to US $ (USPOLZL)
  - Slovak Koruna to US $ (SXUSDSP)

The FRED database was used as a source for following time series:

- As a measure of aggregate price level, seasonally adjusted and in the first difference of the logarithm values
  - Consumer Price Index of All Items in United States (USACPIALLQINMEI)
  - Consumer Price Index of All Items in Germany (DEUCPIALLQINMEI)
  - Consumer Price Index: All Items for the Czech Republic (CZECPIALLMINMEI)
  - Consumer Price Index: All Items for Hungary (HUNCPIALLMINMEI)
  - Consumer Price Index: All Items for Poland (POLCPIALLMINMEI)
  - Consumer Price Index: All Items for the Slovak Republic (SVKCPIALLQINMEI)

- As a measure of real GDP activity, seasonally adjusted and in the first difference of the logarithm values
  - Real Gross Domestic Product for US (GDPC96)

– Current Price Gross Domestic Product in Germany (DEUGDPNQDSMEI)
– GDP Implicit Price Deflator in Germany (DEUGDPDEFQISMEI)
– Current Price Gross Domestic Product in Czech Republic(CZEGDPNQDSMEI)
– GDP Implicit Price Deflator in Czech Republic (CZEGDPDEFQISMEI)
– Current Price Gross Domestic Product in Hungary (HUNGDPNQDSMEI)
– GDP Implicit Price Deflator in Hungary (HUNGDPDEFQISMEI)
– Current Price Gross Domestic Product in Poland (POLGDPNQDSMEI)
– GDP Implicit Price Deflator in Poland (POLGDPDEFQISMEI)
– Current Price Gross Domestic Product in Slovak Republic (SVKGDPNQDSMEI)
– GDP Implicit Price Deflator in Slovak Republic (SVKGDPDEFQISMEI)

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