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Macroeconomic Aspects of Real Exchange Rate Volatility in the Central European Countries

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Abstract:

Exchange rate unexpected fluctuations determine economic development of countries the way quite similar to any other type of exogenous shocks. Unpredicted volatility in exchange rate short-run path affects macroeconomic performance the way that may be a subject of academic as well as economic policy discussions. Overall exposure of countries to negative implications of exchange rate volatility represents one of the areas of empirical investigations related to fixed versus flexible exchange rate dilemma. Rigorous analysis of various aspects of exchange rate fluctuations in terms of macroeconomic performance causal effects is considered to be a crucial outcome of not only exchange rate determining potential but also key information for exchange rate policy or policy decisions related to exchange rate regime shifts.

In the paper we analyze macroeconomic aspects of the real exchange rate volatility in the Central European countries. VAR (vector autoregression) methodology is implemented to estimate effects of the real exchange rate fluctuations on the selected main macroeconomic indicators variability. Structural exogenous shocks are identified by applying the Cholesky decomposition of variance-covariance matrix of the reduced-form VAR residuals. Variance decomposition and impulse-response functions of selected endogenous variables to positive one standard deviation real exchange rate shock are computed for two models covering time series for two periods - 2000-2007 (model A) and 2000-2011 (model B) to determine the role of economic crises on presented results (changes in the exchange rate determining potential during the crisis period are expected to be revealed). Ordering of the endogenous variables in both models is also considered to check the robustness of the empirical results of the estimated econometric model in the selected group of countries.

Keywords: exchange rate volatility, economic growth, economic crisis, vector autoregression, variance decomposition, impulse-response function

JEL Classification: C32, F32, F41

1. Introduction

Exchange rate fluctuations unexpected determine economic development of countries the way quite similar to any other type of exogenous shocks. Unpredicted volatility in exchange rate short-run path affects macroeconomic performance the way that may be a subject of academic as well as economic policy discussions. Overall exposure of countries to negative implications of exchange rate volatility represents one of the areas of empirical investigations related to fixed versus flexible exchange rate dilemma. Rigorous analysis of various aspects of exchange rate fluctuations in terms of macroeconomic performance causal effects is considered to be a crucial outcome of not only exchange rate determining potential but also key information for exchange rate policy or policy decisions related to exchange rate regime shifts.

Exchange rate appreciation (depreciation) may suppress economic activity in country causing foreign prices of goods to decrease in comparison with domestic prices of goods. As a result, exchange rate appreciation and subsequent decrease in foreign competitiveness of

domestic goods on foreign as well as domestic markets shifts expenditures from domestic goods to goods produced abroad. Negative impact of exchange rate appreciation on the current account is significantly determined not only by a shift in demand preferences but also by the ability of domestic economy to shift unused production capacities to more perspective areas with growing potential.

While the traditional approaches emphasize negative effects of exchange rate appreciation on the real output in the domestic economy, alternative approaches (Mendoza, 1992) highlight the presence of some positive implications. Exchange rate appreciation causes the prices of exports to rise while it is generally expected the prices of imports are going to decrease. Considering lower exports and imports price elasticity (in short period), exchange rate appreciation causes net export to rise due to export of goods increase while import of goods tends to decrease. As a result, the real domestic income rises.

At the same time, aggregate supply chain can accelerate a positive impact of exchange rate appreciation on performance of domestic economy. In the less developed countries with inputs being mainly imported (in general production of inputs in such countries is expected to be ineffective), exchange rate appreciation reduces costs of domestic companies. As a result, positive effects of costs reduction due to exchange rate appreciation obviously oversize a negative impact of the contractionary effects related to an increase in domestic tradable goods prices.

Finally we may conclude, exchange rate appreciation causes current account deficit (due to net export deficit) and costs of production reduction. Similarly, exchange rate depreciation causes an increase in net export and costs of production increase. Combined effects of demand and supply channels determines the overall determination potential of exchange rate volatility on real output and level of prices.

In the real word it seems to be necessary to consider the role of uncertainty that significantly affects the responses of demand and supply to any type of exogenous shocks. We expect both components are determined by rational expectations of market participants. Short-run real output variability is then affected by unexpected exogenous shocks on both aggregate supply and aggregate demand sides.

In the paper we analyze macroeconomic aspects of the real exchange rate volatility in the Central European countries (Czech republic, Hungary, Poland, Slovak republic). VAR (vector autoregression) methodology is implemented to estimate effects of the real exchange rate fluctuations on the selected main macroeconomic indicators variability. Structural exogenous shocks are identified by applying the Cholesky decomposition of variance-covariance matrix of the reduced-form VAR residuals. Variance decomposition and impulse-response functions of selected endogenous variables to positive one standard deviation real exchange rate shock are computed for two models covering time series for two periods - 2000-2007 (model A) and 2000-2011 (model B) to determine the role of economic crises on presented results (changes in the exchange rate determining potential during the crisis period are expected to be revealed). Ordering of the endogenous variables in both models is also considered to check the robustness of the empirical results of the estimated econometric model in the selected group of countries.

2. Overview of the literature

Effects of the real exchange rate volatility on the macroeconomic performance of countries at the different stages of business cycle are well document in the empirical literature. Aguirre a Calderón (Aguirre a Calderón, 2005) analyzed the role of the real exchange rate in determining the real output volatility on the sample consisting of 60 countries implementing cointegration analysis using panel data. Burdekin a Siklos (Burdekin a Siklos, 1999) investigated implications of the exchange rate regime shifts to price level

development in the United Kingdom, United States, Canada and Sweden. Domac, Peters a Yuzefowich (Domac, Peters a Yuzefowich, 2001) observed mutual relationships between the exchange rate regime and macroeconomic performance of the selected European transition economies (Czech republic, Hungary, Estonia, Poland and Slovenia). Ghosh, Gulde, Ostry a Wolf (Ghosh, Gulde, Ostry a Wolf, 1996) analyzed effects of the alternative exchange rate regimes on inflation and economic growth on the sample of 145 countries during the 30 years period. Levy-Yeyati a Sturzenegger (Levy-Yeyati a Sturzenegger, 2001) observed implications of exchange rate volatility on domestic price level, money supply, real interest rates and real output in 154 countries since 1974 till 1979. Arratibel, Furceri, Martin a Zdzienicka (Arratibel, Furceri, Martin a Zdzienicka, 2011) investigated relationships between exchange rates development and foreign direct investments, domestic loans and current account on the sample of 9 countries from the Central and Eastern Europe. Lee a Chinn (Lee a Chinn, 1998) analyzed implications of real exchange rate fluctuations on the current account development in 7 most developed industrial countries. Sek a Chuah (Sek a Chuah, 2011) explored causality between the exchange rate changes and the current account dynamics in 6 Eas Asian countries. Arghyrou a Chortareas (Arghyrou a Chortareas, 2008) investigated effects of the exchange rate volatility on the current account adjustments in 11 Eurozone member countries. Obstfeld a Rogoff (Obstfeld a Rogoff, 2005) focused their investigation on estimation of effects of global current account imbalances reduction on exchange rates (USD, EUR and Asian currency) equilibrium path in the model with alternative scenarios.

3. Econometric model

VAR models represent dynamic systems of equations in which the current level of each variable depends on past movements of that variable and all other variables involved in the system. Residuals of vector ε_t represent unexplained movements in variables (effects of exogenous shocks hitting the model); however as complex functions of structural shocks effects they have no economic interpretation. Structural shocks can be still recovered using transformation of true form representation into reduced-form by imposing a number of identifying restrictions. Applied restrictions should reflect some general assumptions about the underlying structure of the economy and they are obviously derived from economic theory. There are two general (most used) approaches to identify VAR models. Cholesky decomposition of innovations implies the contemporaneous interactions between the exogenous shocks and the endogenous variables are characterized by a Wald causal chain. Ordering of the endogenous variables than reflects expected particular economy structure following general economic theory assumptions. However the lack of reasonable guidance for appropriate ordering led to the development of more sophisticated and flexible identification methods - structural VAR (SVAR) models. Identifying restrictions implemented in SVAR models reflects theoretical assumptions about the economy structure more precisely.

We implement a VAR methodology to analyze macroeconomic aspects of the real exchange rate volatility in the Central European countries. Cholesky decomposition of variance-covariance matrix of the reduced-form VAR residuals is implemented to estimate effects of the real exchange rate fluctuations on the selected main macroeconomic indicators variability.

True model is represented by the following infinite moving average representation:

$$X_t = A_0\varepsilon_t + A_1\varepsilon_{t-1} + A_2\varepsilon_{t-2} + \ldots = \sum_{i=0}^{\infty} A_i\varepsilon_{t-i} = \sum_{i=0}^{\infty} A_i L^i\varepsilon_t = A(L)\varepsilon_t \quad (1)$$

where X_t represents n x 1 a vector including endogenous variables of the model, $A(L)$ is a n x n polynomial consisting of the matrices of coefficients to be estimated in the lag operator L representing the relationship among variables on the lagged values, ε_t is n x 1 vector of identically normally distributed, serially uncorrelated and mutually orthogonal errors (white noise disturbances that represent the unexplained movements in the variables, reflecting the influence of exogenous shocks):

$$E(\varepsilon_t) = 0, \quad E(\varepsilon_t \varepsilon_t') = \Sigma_\varepsilon = \mathrm{I}, \quad E(\varepsilon_t \varepsilon_s') = [0] \quad \forall t \neq s \tag{2}$$

Vector X_t consists of six endogenous variables - real output $(y_{r,t})$, money supply (m_t), core inflation (p_t), short-term nominal interest rates $(ir_{n,t})$, real exchange rate $(er_{n,t})$ and current account (cu_t). In the six-variable VAR model $(X_t = [y_{r,t}, m_t, p_t, ir_{n,t}, er_{n,t}, cu_t,])$ we assume five exogenous shocks that contemporaneously affects endogenous variables - demand shock $(\varepsilon_{y,t})$, nominal shock $(\varepsilon_{m,t})$, inflation shock $(\varepsilon_{p,t})$, monetary policy shock $(\varepsilon_{ir_n,t})$, exchange rate shock $(\varepsilon_{er_n,t})$ a current account shock $(\varepsilon_{cu_n,t})$.

The structural exogenous shocks from equation (1) are not directly observable due to the complexity of information included in true form VAR residuals. As a result structural shocks cannot by correctly identified. It is than necessary to transform true model into following reduced form

$$X_t = C(L)Y_{t-1} + e_t \tag{3}$$

where $C(L)$ is the polynomial of matrices with coefficients representing the relationship among variables on the lagged values and e_t is a n x 1 vector of normally distributed errors (shocks in reduced form) that are serially uncorrelated but not necessarily orthogonal:

$$E(e_t) = 0, \quad \Sigma_u = E(e_t e_t') = A_0 E(\varepsilon_t \varepsilon_t') A_0' = A_0 A_0', \quad E(e_t e_s') = [0] \quad \forall t \neq s \tag{4}$$

Relationship between reduced-form VAR residuals (e_t) and structural shocks (ε_t) can be expressed as follows:

$$e_t = A_0 \varepsilon_t \tag{5}$$

As we have already noted at the beginning of the chapter we implement a Cholesky identification scheme to correctly identify structural shocks. In order to identify our model there must be exactly $n^2 - [(n^2 - n)/2]$ relationships among the endogenous variables of the model, where n represents a number of variables. We have to impose $(n^2 - n)/2$ restrictions on the matrix A_0 based on the Cholesky decomposition of the reduced-form VAR residual matrix that define matrix A_0 as a lower triangular matrix. The lower triangularity of A_0 (all elements above the diagonal are zero) implies a recursive scheme (structural shocks are identified through reduced-form VAR residuals) among variables (the Wald chain scheme) that has clear economic implications and has to be empirically tested as any other relationship. Identification scheme of the matrix A_0 implies that particular contemporaneous interactions between some exogenous shocks and some endogenous variables are restricted

reflecting causal (distribution) chain of interaction transmission. It is clear that the Wald causal chain is incorporated via convenient ordering of the variables.

Considering lower triangularity of a matrix A_0 the equation (5) can be rewritten as follows:

$$\begin{bmatrix} e_{y_r,t} \\ e_{m,t} \\ e_{p,t} \\ e_{ir_n,t} \\ e_{er_n,t} \\ e_{cu,t} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & 1 & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & 1 & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & 1 \end{bmatrix} \begin{bmatrix} \varepsilon_{y_r,t} \\ \varepsilon_{m,t} \\ \varepsilon_{m,t} \\ \varepsilon_{p,t} \\ \varepsilon_{er_n,t} \\ \varepsilon_{cu,t} \end{bmatrix} \tag{6}$$

Correct identification of the exogenous structural shocks reflecting Cholesky ordering of variables denotes following assumptions:

- Real output doesn't contemporaneously respond to the shock from any other endogenous variable of the model.
- Money supply doesn't contemporaneously respond to inflation, interest rates, exchange rate and current account shocks, while it is contemporaneously affected only by the real output shock.
- Inflation doesn't contemporaneously respond to the interest rates, exchange rate and current account shocks, while it is contemporaneously affected by the real output and money supply shocks.
- Interest rates don't contemporaneously respond to the exchange rate and current account shocks, while it is contemporaneously affected by the real output, money supply and inflation shocks.
- Exchange rate doesn't contemporaneously respond to current account shock, while it is contemporaneously affected by the real output, money supply, inflation and interest rates shocks.
- Current account is contemporaneously affected by the shocks from all of the endogenous variables of the model.

After initial period endogenous variables may interact freely without any restrictions.

Estimated VAR model is used to compute variance decomposition and impulse response functions to analyse the contribution of the exchange rate shock to variability of endogenous variables (real output, money supply, inflation, interest rates and current account) as well as responses of endogenous variables to one standard deviation positive exchange rate shock in the Central European countries. To check the robustness of the empirical results we estimate the model considering different ordering of the endogenous variables in both models (model A (2000Q1-2007Q4) and model B (2000Q1-2011Q4)):

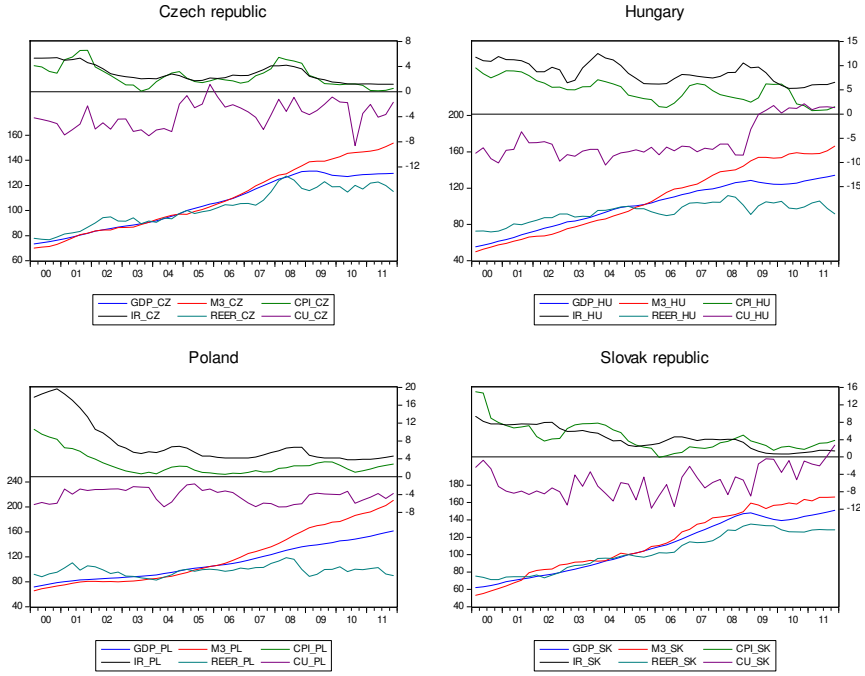
- model A1, B1 $\left(X_t = \left[y_{r,t}, m_t, p_t, ir_{n,t}, er_{n,t}, cu_t\right]\right)$
- model A2, B2 $\left(X_t = \left[y_{r,t}, er_{n,t}, m_t, ir_{n,t}, p_t, cu_t\right]\right)$
- model A3, B3 $\left(X_t = \left[y_{r,t}, p_t, m_t, ir_{n,t}, er_{n,t}, cu_t\right]\right)$

4. Data and results

To estimate effects of the real exchange rate variability on the macroeconomic performance (represented here by selected macroeconomic indicators) in the Czech republic,

Hungary, Poland and Slovak republic we use quarterly data with period 2000Q1-2007Q4 (model A) consisting of 32 observations and with period 2000Q1-2011Q4 (model B) consisting of 44 observations for the following endogenous variables - real output (nominal GDP deflated by GDP deflator), money supply (monetary aggregate M3), inflation (core inflation), short-term interest rates (interbank offered rates with 3 months maturity[1]), exchange rate (real effective exchange rate) and balance of payment's current account (Figure 1). Estimation of two models is in line with the primary objective of the paper to estimate effects of the real exchange rate variability to real output, money supply, inflation, interest rates and current account considering possible implications of economic crisis on presented results. Time series for all endogenous variables were drawn from IMF database (International Financial Statistics, June 2012). Time series for real output, money supply and inflation were seasonally adjusted.

Figure 1 Real output, money supply, inflation, interest rates, real effective exchange rate and current account in the Central European Countries (2000Q1-2011Q4)



Note: Endogenous variables - gross domestic product (GDP), money supply (M3) and real effective exchange rate (REER) are expressed as indexes (left axis in figures) (2005 = 100). Inflation (INF) and interest rates (IR) are expressed in percentage (right axis in figures). Current account is expressed as percentage share in GDP (CU) (right axes in graph).
Source: Compiled by author based on data taken from IMF - International Financial Statistics (May 2012).

To correctly identify exogenous shocks hitting the model as well as to compute variance decomposition and impulse-response functions it is necessary VAR model to be stationary. To check the model it is necessary to test the time series for unit roots and cointegration.

[1] Short-term interest rates in the Slovak republic (BRIBOR) we replaced by EURIBOR since 2009.

A. Unit Root Test

The augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) tests were computed to test the endogenous variables for the unit roots presence. Results of unit root tests are summarized in the table 1 (detailed results of unit root are not reported here to save space. Like any other results, they are available upon request from the author).

Table 1 Unit Root tests

country	model	Order of integration of endogenous variables											
		GDP		M3		CPI		IR		REER		CU	
		ADF	PP	ADF	PP	ADF	PP	ADF	PP	ADF	PP	ADF	PP
Czech republic	A	I(1)	I(1)	**I(0)**	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	B	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
Hungary	A	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	B	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	**I(0)**	I(1)	I(1)	I(1)	I(1)	I(1)
Poland	A	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	B	I(1)	I(1)	I(1)	I(1)	I(1)	**I(0)**	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
Slovak republic	A	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	B	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)

Source: Author's calculations.

Both ADF and PP tests indicate that most of the variables are non-stationary on the values so that the null hypothesis of a unit root cannot be rejected for any of the series. Testing variables on the first differences indicates the time series are stationary so that we conclude that the variables are I(1).

B. Cointegration Test

Because there are endogenous variables with a unit root on the values it is necessary to the test the time series for cointegration using the Johansen and Juselius cointegration test (we found reasonable to include variables I(0) for testing purposes following economic logic of expected results). The test for the cointegration was computed using two lags as recommended by the AIC (Akaike Information Criterion) and SIC (Schwarz Information Criterion). Results of cointegration tests are summarized in the table 2 (detailed results of cointegration tests are not reported here to save space. Like any other results, they are available upon request from the author).

Table 2 Johansen and Juselius cointegration tests

Country	Number of cointegrating equations											
	model A1		model A2		model A3		model B1		model B2		model B3	
	trace stat	max eigvalue stat	trace stat	max eigvalue stat	trace stat	max eigvalue stat	trace stat	max eigvalue stat	trace stat	max eigvalue stat	trace stat	max eigvalue stat
Czech republic	0	0	0	1	1	0	0	0	1	0	0	0
Hungary	0	0	0	1	0	0	0	0	0	0	0	1
Poland	0	0	0	0	0	0	0	0	1	0	0	0
Slovak republic	0	0	1	0	1	0	0	0	0	0	0	1

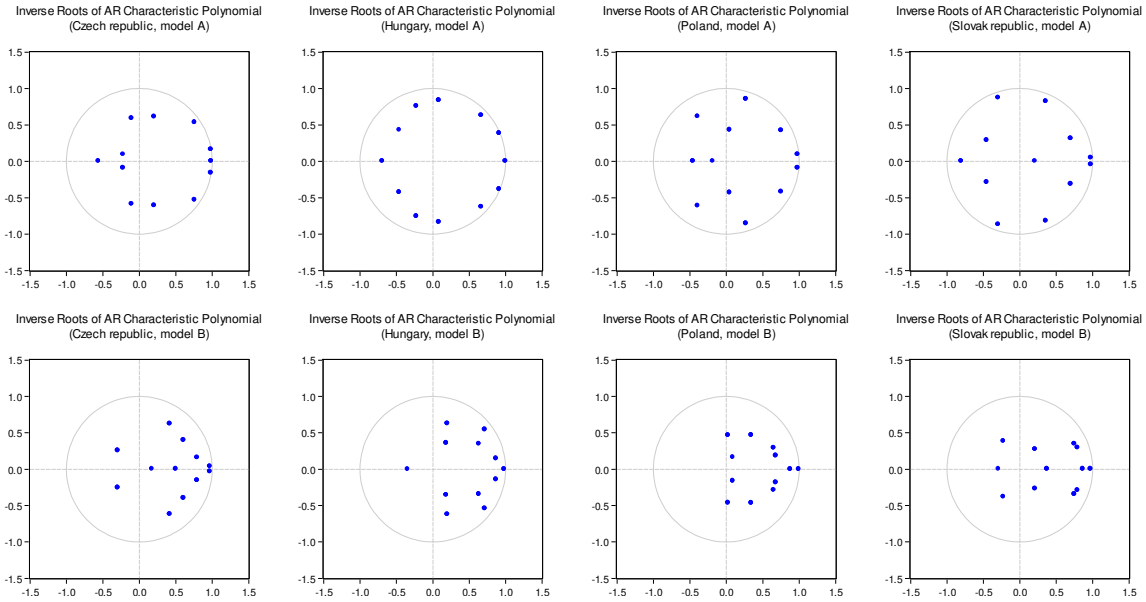
Source: Author's calculations.

The results of the Johansen cointegration tests confirmed the results of the unit root tests. Both trace statistics and maximum eigenvalue statistics (both at 0.05 level) indicate that there is no cointegration among the endogenous variables of the model.

C. VAR stability

To test the stability of the VAR model we also applied a number of diagnostic tests. We found no evidence of serial correlation, heteroskedasticity and autoregressive conditional heteroskedasticity effect in the disturbances. The model also passes the Jarque-Bera normality test, so that errors seem to be normally distributed. The VAR models seem to be stable also because the inverted roots of the model for each country lie inside the unit circle (figure 2).

Figure 2 VAR stability condition check



Source: Authors calculation.

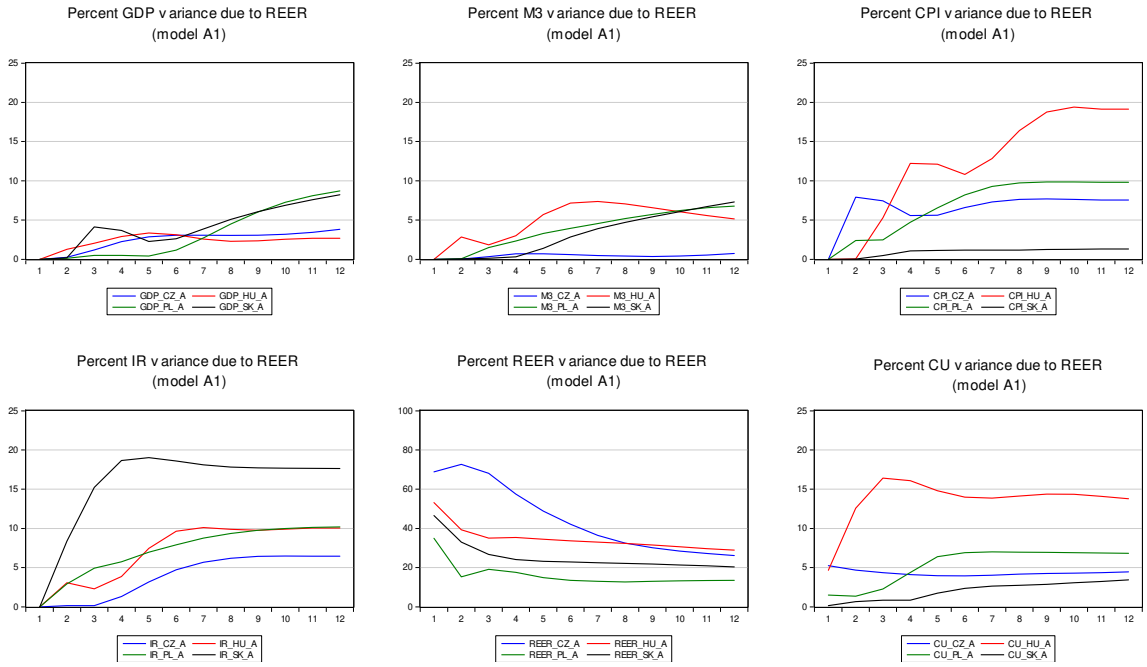
Following the results of the unit root and cointegration tests we estimated the model using the variables in the first differences so that we can calculate variance decompositions and impulse-response functions for all four countries from the region of the Central Europe. In line with the main objective of the paper we focus on interpretation of the real exchange rate shock contribution to the real output, money supply, inflation, interest rate and current account conditional variance. At the same time we analyse responses of real output, money supply, inflation, interest rate and current account on the positive one standard deviation exchange rate shock. We also observe effects of economic crisis on the exchange rate determination potential in the Central European countries by comparing the results for models estimated using time series for two different periods - model A (2000Q1-2007Q4) and model B (2000Q1-2011Q4).

Changed ordering of the variables didn't seem to affect the results of the analysis. Considering variance decompositions and impulse-response functions are not very sensitive to the endogenous variables ordering we present the results of the models (model A1 and B1) with default ordering of the endogenous variables (detailed results for models A2, A3, B2, B3 are available upon request from the author).

D. Variance decomposition

In the figure 3 we summarize variance decomposition of the endogenous variables for the model with pre-crisis time series (model A1) in the Central European countries.

Figure 3 Variance decomposition of endogenous variables (2000Q1-2007Q4)

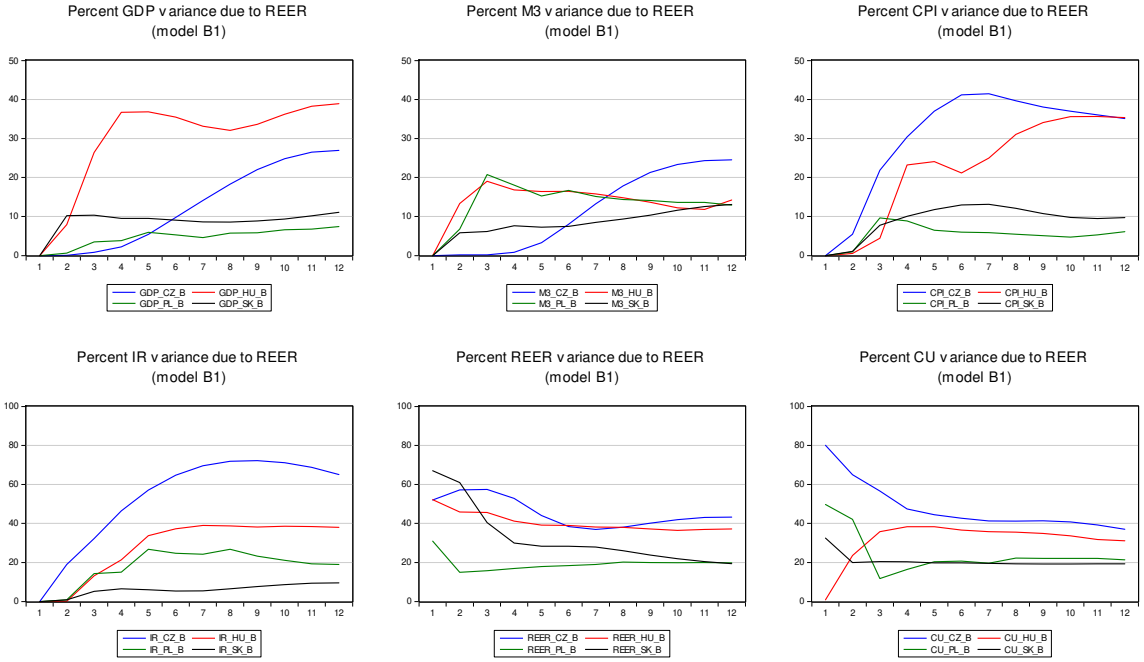


Note: Curves represents a relative contribution of the exchange rate shock to the endogenous variables conditional variance in each individual country from the Central Europe.
Source: Authors calculation.

The figure 3 shows estimated variance decomposition of the endogenous variables to the Cholesky positive one standard deviation REER shocks in the Central European countries during the pre-crisis period. The contribution of the exchange rate shock to the *real output (GDP)* conditional variance immediately after the shock seems to be quite small in all four countries. Although the relevancy of the shock slightly rose within one year lag even after two years it didn't exceed five percent. While in the Czech republic and Hungary the contribution of the exchange rate shock to the GDP variability remained stable in the long-run, in Poland and the Slovak republic we have experienced a rising trend. Quite similar picture we have observed from variance decomposition of *money supply (M3)* in the short-run. While in Hungary the contribution of the exchange rate shock increased over time (during first six quarters) in the Czech republic it remained negligible even in the long-run. On the hand after first few quarters the contribution of the exchange rate shock continuously rises in Poland and the Slovak republic. Quite differing results we have obtained from the variance decomposition of *inflation (CPI)*. Relative importance of the exchange rate shock rises over time in all countries but the Slovak republic. The most significant increase in the exchange rate shock relative contribution to CPI variability we have observed in Hungary. Variance decomposition of *interest rates (IR)* revealed fairly large importance of positive exchange rate shock in determining short term interest rates in the Slovak republic. With much less but still significant contribution the exchange rate shock affected interest rates in Hungary and Poland. Delayed increase in the exchange rate shock relevancy we have experienced in the Czech republic. While the immediate contribution of the exchange rate shock to the current account (CU) conditional variance seems to be quite similar, within one year after the shock it has significantly changed in all four countries but the Czech republic.

In the figures 4 we summarize variance decomposition of the endogenous variables for the model with extended time series (model B1) in the Central European countries.

Figure 4 Variance decomposition of endogenous variables (2000Q1-2011Q4)



Note: Curves represents a relative contribution of the exchange rate shock to the endogenous variables conditional variance in each individual country from the Central Europe.
Source: Authors calculation.

The figure 4 shows estimated variance decomposition of the endogenous variables to the Cholesky positive one standard deviation REER shocks in the Central European countries during the extended period. Relative contribution of the exchange rate shock to the endogenous variables conditional variance markedly changed. The role of the exchange rate shock in determining *real output (GDP)* the most significantly rose in Hungary. Together with the Slovak republic an increased contribution of the shock became already clear after the initial period. While in Poland we have observed the decreased contribution of the exchange rate shock to GDP variance in the long-run, in the Czech republic its relevance steadily rose since third quarter after the shock. *Money supply (M3)* seems to more sensitive to the positive exchange rate shock in the extended period too. The early effect is clear especially in Hungary, Poland and the Slovak republic, while in the Czech republic the contribution of the shock increased especially in long-run. Substantial increase of sensitivity to the base period extension we have observed in decomposing the conditional variance of *inflation (CPI)*. Medium-run effects are clear especially in Czech republic and Hungary. The contribution of the exchange rate shock in the long-run slightly decreased in Poland, while in the Slovak republic remained quite stable since the end of the fourth quarter after the shock. Variance decomposition of short-term *interest rates (IR)* revealed a noticeable increase of the exchange rate shock contribution in all countries but the Slovak republic. The most significant change we observed in the Czech republic with reduced delay at which the contribution of the exchange rate shock to the interest rates variance started to grow notably. Finally, the contribution of the one standard deviation positive exchange rate shock to the *current account (CU)* variability in the model B significantly grew in the all four Central European countries

too. The crisis period increased the effect of the shock especially in the Czech republic and Hungary.

Results of the endogenous variables variance decomposition reflecting the relative contribution of the exchange rate shock in their variability in the model A for pre-crisis period and the model B for extended period may be concluded as follows. Relative contribution of the exchange rate shock to the endogenous variables variance increased in most cases. As the most probable vehicle of accelerated effects of the exchange rate shock to the real performance of the Central European countries we emphasize an increased contribution of the shock to the current account development. The role of the exchange rate shock in determining the current account significantly rose in all four countries.

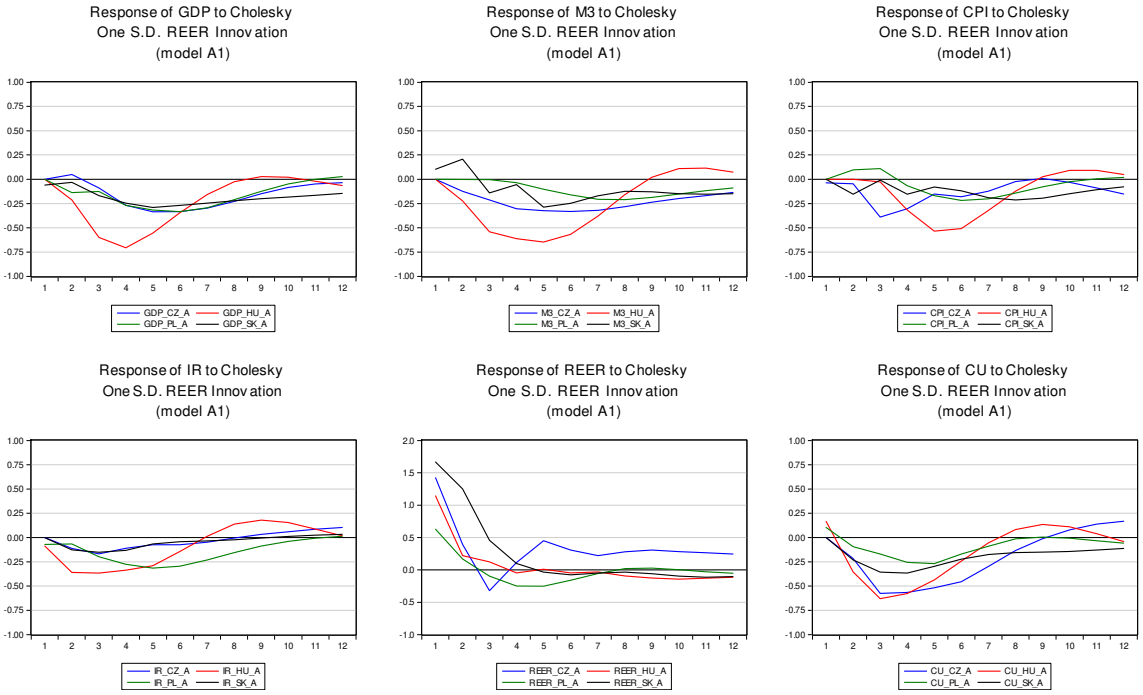
As the most crucial outcome we emphasize an increased contribution of the exchange rate shock to the endogenous variables conditional variance in the short-run in model B. In general, various effects of higher exchange rate volatility in the Central European countries increased overall exposure of their economies to the unpredicted short-run changes in the traditional key determinants of the macroeconomic performance. The only exception represents the variance decomposition of short-term interest rates in the Slovak republic. We suggest it is generally expected implication of the Slovakia's euro adoption in 2009. Decreased contribution of the exchange rate shock to the interbank interest rates (replaced by Eurozone interbank interest rates since 2009) in the Slovak republic can be explained in several ways. In the first place we emphasize higher level of European Central Bank (ECB) discretion in key interest rates adjustments during the crisis period causing Eurozone interbank interest rates being much less determined by the exchange rate path. Interbank interest rates of Eurozone seem to be much more sensitive to the endogenous determinants (i.e. real output, employment, productivity, inflation, fiscal deficit, etc.) during the crisis period in comparison to the exogenous shocks (i.e. unpredicted exchange rate shifts). Considering this interpretation, higher contribution of the exchange rates shocks to domestic interest rates variability in individual countries (like the Czech republic, Hungary and Poland in our model) seems to be reasonable.

At the same time we have observed remarkable changes in the exchange rate shock contribution to the endogenous variables variance in the Slovak republic during the extended period (in comparison with the per-crisis period). The main aspect of the variance decomposition analysis for the extended period is the significant stability of the exchange rate shock contribution to the main macroeconomic indicators variability in the Slovak republic. Here again we expect the most common explanation is Eurozone membership. While the loss of mutual interconnections between the exchange rate path and the macroeconomic indicators is considered to be one of the main trade-off to common currency benefits, stable exchange rate expectations anchored by the euro credibility may still reduce the way the new Eurozone member country suffers from sacrificing their monetary sovereignty.

E. Impulse-response function

In the figure 5 we summarize impulse-response functions of the endogenous variables for the model with pre-crisis time series (model A1) in the Central European countries.

Figure 5 Responses of endogenous variables to REER shock (2000Q1-2007Q4)



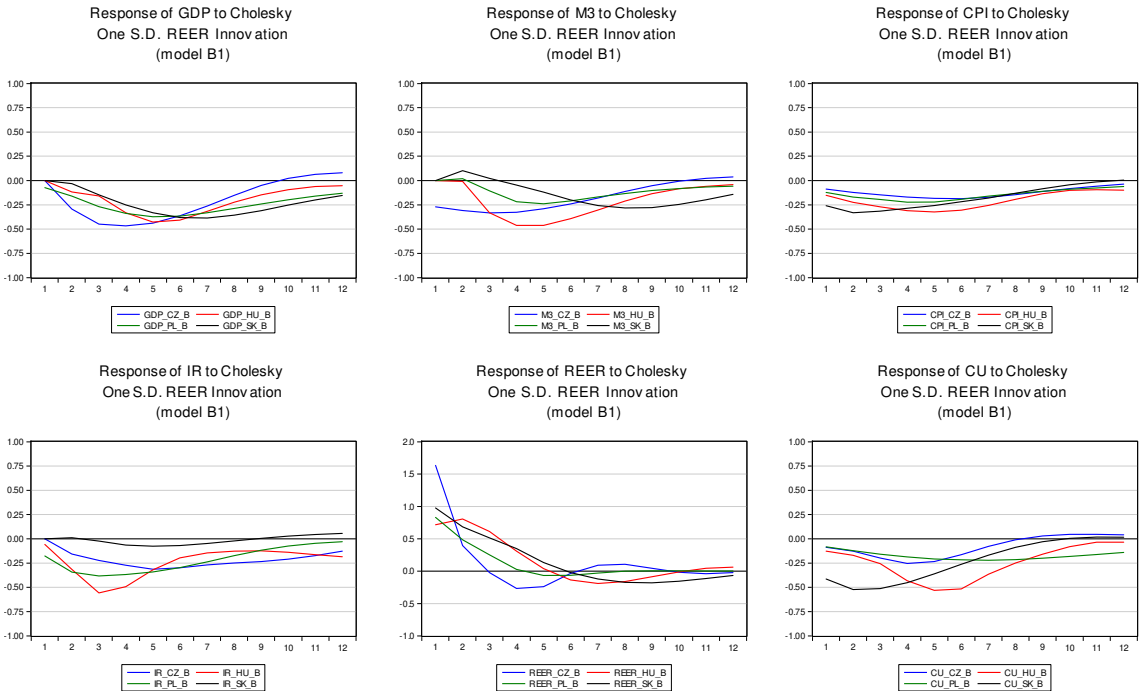
Note: Curves represents responses of the endogenous variables to the one standard deviation positive exchange rate shock in each individual country from the Central Europe.
Source: Authors calculation.

The figure 5 shows estimated responses of the endogenous variables to the Cholesky positive one standard deviation REER shock in the Central European countries during the pre-crisis period. It seems to be clear that the exchange rate shock was followed by the *real output (GDP)* decline in the all four Central European countries. This investigation is in line with a general empirical experience considering the exchange rate appreciation causes a drop in the real output through the current account deficit. At the same time we observed a little difference in the initial lag that was followed by the GDP decline after the exchange rate shock in each particular country. While in Hungary and Poland real output declined almost immediately with one quarter lag, in the Czech republic and the Slovak republic the negative effect of the shock was lagged by two quarters. The exchange rate seems to be neutral in determining the real output in the long-run as its effect was subsequently disappearing since the first year after the shock. Quite similar picture we observed from the overview of the *money supply (M3)* impulse-response functions. While in general the exchange rate shock was followed by the money supply decrease, the length of lag in the responses notably differed in comparison with the real output responses in all four countries (decrease in the money supply outran the real output fall in the Czech republic while in Poland and the Slovak republic responded with the lag) but Hungary. We suggest that changes in the money supply caused by the exchange rate shock could be only partially explained by related changes in the transaction demand for the money. As a result, the exchange rate shock caused liquidity preference changes. We suppose that is why the subsequent money supply decrease could not be clearly explained by the real activity shifts only (related portfolio adjustment motives may be considered to explain subsequent changes in the international capital flows). Negative effect of the exchange rate shock continuously died out and became neutral in the long-run. In general the exchange rate shock caused a decrease in the *inflation (CPI)* in all four countries

but with a different length of the lag. While in the Czech republic, Poland inflation started to fall after one quarter, the positive effect of the exchange rate shock to the price level in the Czech republic became clear after two quarters and in Hungary after four quarters. On the other hand the size of the effect seems to be the most notable in Hungary. In the long-run the overall effect of the exchange rate shock to the domestic prices remained neutral. After the positive exchange rate shock short-term *interest rates (IR)* decreased in all four countries. Although the positive impact on the interest rates occurred one quarter after the shock the size of the effect differed among the countries. The most significant decrease in the short-term interest rates we observed in Hungary and with slightly reduced intensity as well as durability in the Czech republic and the Slovak republic. At the same time, much more persisting positive effect of the exchange rate shock to the short-term interest rates we experienced in Poland. Overall effect of the shock completely died out after around fifteen quarters. One standard deviation positive exchange rate shock was accompanied with a sharp worsening in the current account in each particular country. The size of the negative effect culminated at the end of the first year after the shock while it was significantly reduced till the end of the second year after the shock. We suggest that changes in the international competitiveness of the Central European countries represent the most crucial channel the exchange rate shock (negatively) affects the real output in the short-run while the price effects (disinflation) of the exchange rate appreciation (positively) affects the real output in medium-term.

In the figure 6 we summarize impulse-response functions of the endogenous variables for the model with extended time series (model B1) in the Central European countries.

Figure 6 Responses of endogenous variables to REER shock (2000Q1-2011Q4)



Note: Curves represents responses of the endogenous variables to the one standard deviation positive exchange rate shock in each individual country from the Central Europe.
Source: Authors calculation.

The figure 6 shows estimated responses of the endogenous variables to the Cholesky positive one standard deviation REER shock in the Central European countries during the extended period. Crisis period affected responses of endogenous variables to the exchange rate shock. *Real output (GDP)* decreased in all four countries with slightly reduced lag. At the same time the durability of the GDP response increased in Hungary, Poland and the Slovak republic while its reduction we experienced only in the Czech republic. Despite the long-run neutrality of the exchange rate shock its short-term potential to determine the real output in the Central European countries increased as a result of the crisis period effects. Quite distorting effects (in comparison with the pre-crisis results) we observed in the responses of the *money supply (M3)*. While the changes in the intensity of the effect don't seem to be meaningful, we emphasize substantial changes in the behavior of the money supply responses (lag length, path of response) as well as the durability of the effect caused by the exchange rate shock. It seems the lag in the money supply response reduced in the Czech republic (money supply decreased immediately after the shock) and Poland. On the other hand slightly lagged response we experienced in Hungary and the Slovak republic. We suggest distorting effects of the money supply response to the exchange rate shock (changes in the transaction demand for money became much less important in determining the response of the money supply) originated in the international capital flows adjustments reflecting price effects on the value of capital assets. Significant reduction in the lagged response to the exchange rate shock we observed from the impulse-response functions of *inflation (CPI)* in all four Central European countries. Because the price effects of the exchange rate shock during the crisis period seems to be more persisting (and slightly more intensive) we expect that the price mechanisms of the domestic markets tends to be more sensitive to unpredicted exchange rate shifts. Responses of short-term *interest rates (IR)* to the positive exchange rate shock seem to be also affected by the crisis period. The intensity of the effect seems to be higher in all countries but the Slovak republic. We suggest that the unpredicted exchange rate shifts during the crisis period determines (especially) short-term interest rates with higher intensity in individual Central European countries with monetary sovereignty[2]. However this is not a case of the Slovak republic that became the Eurozone member country in 2009. We assume the reason why the interest rates[3] in the Slovak republic responded to the exchange rate shock (considering the model B1 with data sets for the extended period) with significantly lower intensity is a much higher degree of a discretion in the ECB's interest rate policy that weaken the causality relationship between the Euro exchange rate shifts and the interest rates path especially in the short-run. Impulse-response functions of the *current account (CU)* revealed the following conclusions about the exchange rate shock determining potential. Lag length in the current account response slightly reduced in the Czech republic, Hungary and Poland in comparison with the pre-crisis period. While the short-term responsiveness (within one year after the shock) of the current account decreased, the durability of the effect increased in Hungary and Poland. On the other hand the significant immediate increase in the current account responsiveness to the exchange rate shock we observed in the Slovak republic. Extended period covering the euro adoption since 2009 revealed increased sensitivity of the Slovakia's current account and subsequently the real output development to the unpredicted exchange rate shifts in the short-run. The one standard deviation exchange rate shock seemed

[2] The current exchange rate regime in the Czech republic, Hungary and Poland (managed floating) allows their exchange rates to freely float, their path is still significantly determined by the euro exchange rate that is positioned as the reference currency. Despite this fact we suggest that in the time of the crisis period the exchange rates of all three Central European countries diverged from the euro leading path causing distorting effects on domestic interest rates as well as other macroeconomic indicators.

[3] Since 2009 the domestic interest rates in the Slovak republic (BRIBOR) were replaced by the Eurozone interest rates (EURIBOR).

to be neutral in determining the leading path of all endogenous variables in the long-run in all four Central European countries.

5. Conclusion

Exchange rates determined the main macroeconomic indicators in four Central European countries in the line with the general empirical investigations though we observed some specific implications of the distorting effects caused by the unpredicted exchange rate shifts in the crisis period that may be a subject of a further academic discussion focusing on the wide causalities of the economic crisis. Variance decompositions and impulse-response functions computed from estimated VAR model revealed notable differences in the behavior of the selected macroeconomic indicators after being hit by the one standard deviation positive exchange rate shock as well as in the its contribution to their variability.

Considering the complexity of the particular results presented in the paper we highlight the distorting effects of the crisis period that contributed to the significantly different way the short-term interest rates were determined in the group of three Central European countries (the Czech republic, Hungary and Poland) in comparison to the Slovak republic. We suggest that the Slovakia's Eurozone membership since 2009 and related loss of the monetary sovereignty probably represents the key aspect of the different exchange rate determining potential in relation to the interest rate development. Decreased contribution of the exchange rate shock to the interbank interest rates (replaced by Eurozone interbank interest rates since 2009) in the Slovak republic can be explained in several ways. In the first place we emphasize higher level of European Central Bank (ECB) discretion in key interest rates adjustments during the crisis period causing Eurozone interbank interest rates being much less determined by the exchange rate path. Interbank interest rates of Eurozone seem to be much more sensitive to the endogenous determinants (i.e. real output, employment, productivity, inflation, fiscal deficit, etc.) during the crisis period in comparison to the exogenous shocks (i.e. unpredicted exchange rate shifts). Considering this interpretation, higher contribution of the exchange rates shocks to domestic interest rates variability in individual countries (like the Czech republic, Hungary and Poland in our model) seems to be reasonable.

At the same time we have observed remarkable changes in the exchange rate shock contribution to the endogenous variables variance in the Slovak republic during the extended period (in comparison with the per-crisis period). The main aspect of the variance decomposition analysis for the extended period is the significant stability of the exchange rate shock contribution to the main macroeconomic indicators variability in the Slovak republic. Here again we expect the most common explanation is Eurozone membership. While the loss of mutual interconnections between the exchange rate path and the macroeconomic indicators is considered to be one of the main trade-off to common currency benefits, stable exchange rate expectations anchored by the euro credibility may still reduce the way the new Eurozone member country suffers from sacrificing their monetary sovereignty.

As of the changed way the short-term interest rates responded to the one standard deviation positive exchange rate shock we suggest that the unpredicted exchange rate shifts during the crisis period determined (especially) short-term interest rates with higher intensity in individual Central European countries with monetary sovereignty (the Czech republic, Hungary, Poland). However this is not a case of the Slovak republic that became the Eurozone member country in 2009. We assume the reason why the interest rates in the Slovak republic responded to the exchange rate shock (considering the model B1 with data sets for the extended period) with significantly lower intensity is a much higher degree of a discretion in the ECB's interest rate policy that weaken the causality relationship between the Euro exchange rate shifts and the interest rates path especially in the short-run.

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