Supplementary material (for on-line publication)

The supplementary material includes two appendices. Appendix A contains the details of the estimation procedures. Appendix B presents additional Tables and Figures.

Appendix A: The details of the estimation procedures

VAR models

To save on the notation we write process (9) in matrix form:

$$Y = X\Gamma + Z\Gamma_d + E = \begin{pmatrix} X & Z \end{pmatrix} \begin{pmatrix} \Gamma \\ \Gamma_d \end{pmatrix} + E = \tilde{X}\tilde{\Gamma} + E, \tag{A1}$$

where $\Gamma_{nk\times n} = \begin{pmatrix} A_1 & A_2 & \ldots & A_k \end{pmatrix}'$, $\Gamma_d = \Phi'$, $Y_{T\times n} = \begin{pmatrix} \Delta y_1 & \Delta y_2 & \ldots & \Delta y_T \end{pmatrix}'$, $x_t = \begin{pmatrix} \Delta y'_{t-1} & \Delta y'_{t-2} & \ldots & \Delta y'_{t-k} \end{pmatrix}'$, $X_{T\times nk} = \begin{pmatrix} x_1 & x_2 & \ldots & x_T \end{pmatrix}'$, $E_{T\times n} = \begin{pmatrix} \varepsilon_1 & \varepsilon_2 & \ldots & \varepsilon_T \end{pmatrix}'$, $Z_{T\times l} = \begin{pmatrix} D_1 & D_2 & \ldots & D_T \end{pmatrix}'$, l denotes the number of deterministic components, and $\tilde{X} = \begin{pmatrix} X & Z \end{pmatrix}$, $\tilde{\Gamma}' = \begin{pmatrix} \Gamma' & \Gamma'_d \end{pmatrix}$.

We impose normal-inverted Wishart prior for the parameters of model (A1):

1. $\Sigma_{n\times n} \sim iW(S, q_\Sigma)$, where S is a PDS matrix and $q_\Sigma \geq n$,
2. $\Gamma_{nk\times n}|\Sigma \sim mN(0, \Sigma, \underline{\Omega}_\Gamma)$, where $\underline{\Omega}_\Gamma$ is a PDS matrix of order nk,
3. $\Gamma_d|\Sigma \sim mN(0, \Sigma, \underline{\Omega}_d)$, where $\underline{\Omega}_d$ is a PDS matrix of order l.

The above stated prior distributions for Γ and Γ_d lead to the following matrix normal prior $\tilde{\Gamma}_{nk+l\times n}|\Sigma \sim mN(0, \Sigma, \underline{\Omega})$, where $\underline{\Omega} = \begin{pmatrix} \underline{\Omega}_\Gamma & 0 \\ 0 & \underline{\Omega}_d \end{pmatrix}$. In the presented research $\underline{\Omega}$ is of the form $\begin{pmatrix} \frac{\nu_\Gamma}{nk} I_{nk} & 0 \\ 0 & \nu_d I_l \end{pmatrix}$, where the parameters ν_Γ and ν_d are estimated ($\nu_\Gamma \sim iG(s_\Gamma, n_\Gamma)$, $\nu_d \sim iG(s_d, n_d)$, $iG(s_., n_.)$ denotes an inverted Gamma distribution with parameters $s_.$ and $n_.$, i.e. $p(\nu_.) \propto \nu_.^{-n_.-1} \exp(-\frac{s_.}{\nu_.})$), so the hierarchical prior structure is applied (see, e.g., Koop et al., 2010).

In our analysis we impose the following prior hyperparameters $S = 0.01 I_n$, $q_\Sigma = n + 2$, $s_. = 2$, $n_. = 3$ therefore $E(\nu_.) = 1$, $D(\nu_.) = 1$.

The joint prior distribution is truncated by the stability condition imposed on the VAR parameters.

The assumed distributions belong to the so called conjugate priors family. It means that the posterior distributions are of the same form:

1. $\Sigma|., Y \sim iW(S + E'E + \tilde{\Gamma}'\underline{\Omega}^{-1}\tilde{\Gamma}, q_\Sigma + nk + l + T)$, where $E = Y - \tilde{X}\tilde{\Gamma}$'
2. $\tilde{\Gamma}|., Y \sim mN(\overline{\mu}_{\tilde{\Gamma}}, \Sigma, \overline{\Omega})$, where $\overline{\Omega} = (\underline{\Omega}^{-1} + \tilde{X}'\tilde{X})^{-1}$, $\overline{\mu}_{\tilde{\Gamma}} = \overline{\Omega}\tilde{X}'Y$,
3. $\nu_\Gamma|., Y \sim iG(s_\Gamma + \frac{1}{2}tr(nk\Sigma^{-1}\Gamma'\Gamma), n_\Gamma + \frac{n^2k}{2})$,
4. $\nu_d|., Y \sim iG(s_d + \frac{1}{2}tr(\Sigma^{-1}\Gamma_d'\Gamma_d), n_d + \frac{nl}{2})$.

VAR models with reduced rank restrictions

The matrix form of the process (10) reads as follows:

$$Y = X\delta\gamma' + Z\Gamma_d + E, \tag{A2}$$

Where meaning of Γ_d, $Y_{T\times n}$, $X_{T\times nk}$, $E_{T\times n}$, $Z_{T\times l}$, l is left unchanged (see the explanation under equation (A1)).

To deal with the non-identification issues we employ the algorithm proposed by Koop et al. (2010) for the VEC models. This algorithm switches between two parameterisations:

$$\delta\gamma' = \delta O_\Gamma^{-1} O_\Gamma \gamma' \equiv DG', \tag{A3}$$

where O_Γ is an $n - s \times n - s$ symmetric positive definite matrix. On the left-hand side of (A3) it is assumed that δ has orthonormal columns with positive elements in the first row whiles the matrices on the right-hand side are left free, i.e. $G \in \mathbb{R}^{n(n-s)}$ and $D \in \mathbb{R}^{nk(n-s)}$. Knowing this we can write model (A2) in the $G - D$ parameterisation:

$$Y = XDG' + Z\Gamma_d + E = \begin{pmatrix} XD & Z \end{pmatrix} \begin{pmatrix} G' \\ \Gamma_d \end{pmatrix} + E = \tilde{X}_D\tilde{\Gamma}_G + E, \tag{A4}$$

where $\tilde{X}_D = \begin{pmatrix} XD & Z \end{pmatrix}$, $\tilde{\Gamma}_G' = \begin{pmatrix} G & \Gamma_d' \end{pmatrix}$.

For G and D we settle matrix normal priors of the following form:

1. $D \sim mN(0, \frac{1}{nk}I_{n-s}, I_{nk})$, which leads to non-informative prior for δ and for the space spanned by it (see Chikuse, 2002),
2. $G|\nu_G \sim mN(0, \nu_G I_{n-s}, \Sigma)$,
3. $\nu_G \sim iG(s_G, n_G)$.

The priors for the remaining parameters are left unchanged. It is easy to see that $\tilde{\Gamma}_G|\Sigma,\nu_G,\nu_d \sim mN(0,\Sigma,\underline{\Omega}_G)$, where $\underline{\Omega}_G = \begin{pmatrix} \nu_G I_{n-s} & 0 \\ 0 & \nu_d I_l \end{pmatrix}$.

Similarly to VAR models, the joint prior is truncated by the stability condition and the prior hyperparameters are the same, i.e. $S = 0.01I_n$, $q_\Sigma = n+2$, $s_. = 2$, $n_. = 3$ therefore $E(\nu_.) = 1$, $D(\nu_.) = 1$.

The full conditional posteriors (for the $D-G$ parameterisation) are known, so it is possible to employ the Gibbs sampler in order to sample from the posterior distribution:

1. $\Sigma|.,Y \sim iW(S + E'E + \frac{1}{\nu_G}GG' + \frac{1}{\nu_d}\Gamma_d'\Gamma_d, q_\Sigma + n - s + l + T)$,
2. $G|.,Y \sim mN(vec(\overline{\mu}_G), \overline{\Omega}_G, \Sigma)$, where $\overline{\Omega}_G = (\frac{1}{\nu_G}I_{n-s} + D'X'XD)^{-1}$, $\overline{\mu}_G = (Y - Z\Gamma_d)'XD\overline{\Omega}_G$,
3. $vec(D)|.,Y \sim N(\overline{\mu}_{vD}, \overline{\Omega}_{vD})$, where $\overline{\Omega}_{vD} = ((G'\Sigma^{-1}G \otimes X'X) + (nkI_{n-s} \otimes I_{nk}))^{-1}$, $\overline{\mu}_{vD} = \overline{\Omega}_{vD}vec(X'(Y - Z\Gamma_d)\Sigma^{-1}G)$,
4. $\Gamma_d|.,Y \sim mN(vec(\overline{\mu}_d), \Sigma, \overline{\Omega}_d)$, where $\overline{\Omega}_d = (\frac{1}{\nu_d}I_l + Z'Z)^{-1}$, $\overline{\mu}_d = \overline{\Omega}_d Z'(Y - XDG')$,
5. $\nu_G|.,Y \sim iG(s_G + \frac{1}{2}tr(G'\Sigma^{-1}G), n_G + \frac{n(n-s)}{2})$,
6. $\nu_d|.,Y \sim iG(s_d + \frac{1}{2}tr(\Sigma^{-1}\Gamma_d'\Gamma_d), n_d + \frac{nl}{2})$.

Samples from the posterior distributions of δ and γ can be obtained by using transformations: $\delta = D(D'D)^{-\frac{1}{2}}O$ and $\gamma = G(D'D)^{\frac{1}{2}}O$, where $O = diag(\pm 1)$ helps to obtain positive elements in the first row of δ.

Bayesian model comparison

To obtain the marginal data density, needed for the model comparison we have to integrate the parameters. Some of them can be integrated analytically (Γ in the model (A1), G in the model (A4) and Γ_d, Σ in both models), which leads us to the following results:

- the data density conditional on ν_Γ and ν_d in the VAR model (A1)

$$\begin{aligned} p(Y|\nu_\Gamma,\nu_d) &= \pi^{-\frac{nT}{2}} \prod_{i=1}^{n} \frac{\Gamma[(q_\Sigma + T + 1 - i)/2]}{\Gamma[(q_\Sigma + 1 - i)/2]} |S|^{\frac{q_\Sigma}{2}} |\underline{\Omega}|^{-\frac{n}{2}} |\overline{\Omega}|^{\frac{n}{2}} \times \\ &\times \; |S + Y'M_{\tilde{X}}Y + \hat{\Gamma}'\tilde{X}'\tilde{X}\overline{\Omega}\underline{\Omega}^{-1}\hat{\Gamma}|^{-\frac{q_\Sigma+T}{2}}, \end{aligned} \tag{A5}$$

where $M_{\tilde{X}} = I_T - \tilde{X}(\tilde{X}'\tilde{X})^{-1}\tilde{X}'$, $\hat{\Gamma} = (\tilde{X}'\tilde{X})^{-1}\tilde{X}'Y$ and $\Gamma(\alpha)$ is the gamma function, that is the function defined by the integral: $\Gamma(\alpha) = \int_0^\infty x^{\alpha-1}\exp(-x)\mathrm{d}x$ for $x > 0$ (see e.g. Bauwens et al., 1999);

- the data density conditional on D, ν_G and ν_d in the VAR models with common serial correlation (A4):

$$\begin{aligned} p(Y|D,\nu_G,\nu_d) &= \pi^{-\frac{nT}{2}}\prod_{i=1}^{n}\frac{\Gamma[(q_\Sigma+T+1-i)/2]}{\Gamma[(q_\Sigma+1-i)/2]}|S|^{\frac{q_\Sigma}{2}}|\underline{\Omega}_G|^{-\frac{n}{2}}|\overline{\Omega}_G|^{\frac{n}{2}}\times \\ &\times\ |S+Y'M_{\tilde{X}_D}Y+\hat{\Gamma}'_G\tilde{X}'_D\tilde{X}_D\overline{\Omega}_G\underline{\Omega}_G^{-1}\hat{\Gamma}_G|^{-\frac{q_\Sigma+T}{2}}, \qquad \text{(A6)} \end{aligned}$$

where $M_{\tilde{X}_D} = I_T - \tilde{X}_D(\tilde{X}'_D\tilde{X}_D)^{-1}\tilde{X}'_D$, $\hat{\Gamma}_G = (\tilde{X}'_D\tilde{X}_D)^{-1}\tilde{X}'_DY$ and $\overline{\Omega}_G = (\tilde{X}'_D\tilde{X}_D+\underline{\Omega}_G^{-1})^{-1}$.

To obtain marginal data density in the compared models, we have to integrate ν_Γ, ν_G, ν_d and D from the above stated equations, for which we employ the arithmetic mean estimator.

Appendix B

Below we provide additional information in Tables and Figures that is summarized in the main text.

Table B1: Data description

Variable	Description	Source
Real GDP	Gross domestic product at market prices, chain linked volumes, index 2005=100, seasonally and calendar adjusted data; for Bulgaria (1998:1-1998:4) and Croatia (1998:1-1999:4) unadjusted data data from ESA 1995 (Tramo/seats method used for seasonal adjustment); for Poland (1998:1-2001:4) data from ESA 1995; for Slovakia seasonally adjusted data but not calendar adjusted data	Eurostat
Nominal interest rate	Three-month money market nominal interest rate; for Bulgaria (1998:1-1998:2 and 1999:1-1999:2) and Slovenia (1998:1)the deposit rate used; for Croatia (1998:1-2000:1) lending rate used; average of four adjacent quarters used for missing value for Hungary (2004:3).	Eurostat and IMF/IFS (for deposit and lending rates)
Nominal exchange rate	Quarterly average nominal exchange rate index (2005 = 100); an increase is an appreciation of domestic currency against the euro.	based on Eurostat data
Price level	Harmonized index of consumer prices (HICP); monthly data used to calculate quarterly averages.	Eurostat
Relative output	The log-difference between domestic and the euro area real GDPs.	based on Eurostat data
Real interest rate differential	The difference between domestic and euro are real interest rates. The real interest rate defined as a difference between nominal interest rate and actual HICP inflation.	based on Eurostat data
Real exchange rate	The (log of the) real exchange rate calculated as the nominal exchange rate corrected for price ratio; its rise means an appreciation of domestic currency against the euro in real terms	based on Eurostat data
Relative price level	The log-difference between domestic and euro area price levels.	based on Eurostat data

Table B2: Exchange rate regimes in Central and Eastern European countries, 2000-2015[†]

Bulgaria	Czech Rep.	Croatia	Hungary	Poland	Romania	Slovakia	Slovenia
Currency board July 1, 1997	Managed floating[a)]	Managed floating[a)] Sept 30, 1999	Crawling band	Crawling band	Managed floating[a)]	Managed floating[a)]	Managed floating[a)]
	Independent-ly floating June 30, 2001		Pegged band[b)] Oct 1, 2001	Independent-ly floating Apr 12, 2000	Crawling band June 30, 2001		Crawling band Feb 1, 2002
	Managed floating[a)] Jan 1, 2002				Managed floating[a)] Nov 2, 2004	Pegged band[b)] Nov 25, 2005	Pegged band[b)] June 27, 2004
	Independent-ly floating Jan 1, 2006	Conventional peg Sept 1, 2006	Independent-ly floating Feb 26, 2008				Currency union Jan 1, 2007
	Free floating* Apr 30, 2008	Stabilized arrangement* Apr 30, 2008	Free floating* Apr 30, 2008	Free floating* Apr 30, 2008	Floating* Apr 30, 2008		
	Other managed[c)] Nov 7, 2013	Other managed[c)] Jan 1, 2009	Floating Mar 1, 2009	Floating Sept 23, 2011		Currency union Jan 1, 2009	
	Stabilized arrangement Nov 19, 2013	Crawl-like arrangement Jun 17, 2010	Free floating Dec 31, 2011				

Notes: [†] A date below the arrangement corresponds to the introduction of the regime; if there is no date, the regime was adopted before 2000.
Formal categories in the AREAER: [a)] 'Managed floating with no predetermined path for the exchange rate.' [b)] 'Pegged exchange rate within horizontal bands.' [c)] 'Other managed arrangement.' * No change in the regime: effective Feb 2, 2009 the classification has been changed retroactively to April 30, 2008, due to the revision of the classification methodology.
Source: based on the IMF *Annual Report on Exchange Arrangements and Exchange Restrictions*, various issues from 1999-2015.

Table B3: Relative frequency of exchange rate regimes in CEE countries under alternative classifications (in percent)

Country	LYS classification[a)]			DPS classification[b)]		
	pegger[c)]	floater[d)]	other[e)]	pegger	floater	other[f)]
Bulgaria	81	0	19	100	0	0
Czech Rep.	0	100	0	0	94	6
Croatia	44	56	0	71	18	12
Hungary	13	88	0	12	88	0
Poland	13	88	0	0	94	6
Romania	25	75	0	12	88	0
Slovakia	13[g)]	81	6	59[h)]	41	0
Slovenia	63[i)]	38	0	88	0	12

Notes: [a)] Levy-Yeyati and Sturzenegger classification, includes years 1998-2013.
[b)] Dąbrowski, Papież and Śmiech classification, includes years 1998-2014.
[c)] Includes 'peg' and 'crawling peg.' [d)] Includes 'float' and 'dirty float.'
[e)] Includes 'inconclusive' and 'unclassified.' [f)] Includes 'inconclusive.'
[g)] It rises to 63 if years in the ERM II and euro area included into a 'peg' category.
[h)] It rises to 82 if years in the euro area included into a 'peg' category.
[i)] It rises to 94 if years in the ERM II and euro area included into a 'peg' category.
Source: based on data from Levy-Yeyati and Sturzenegger (2016) and Dąbrowski et al. (in press).

Table B4: Basic macroeconomic characteristics of CEE countries, 2005-2015

Country	Income per capita[a)]	Current account[b)]	CPI Inflation[c)]	Unemployment rate[d)]	Absence of corruption[e)]
Bulgaria	14,888	-7.7	4.1	9.6	0.41
Czech Rep.	26,540	-1.8	2.1	6.4	0.54
Croatia	20,083	-2.6	2.4	13.0	0.63
Hungary	21,972	-1.6	3.8	8.9	0.57
Poland	20,905	-3.8	2.2	10.2	0.66
Romania	17,619	-6.2	4.9	6.8	0.51
Slovakia	24,414	-3.3	2.3	13.0	n.a.
Slovenia	28,371	0.5	2.1	7.3	0.60
Averages:					
All	21,849	-3.3	3.0	9.4	0.56
Pegs	21,939	-3.3	2.7	10.7	0.52
Floats	21,759	-3.3	3.2	8.1	0.59

Notes: [a)] Gross national income per capita converted to (constant 2011) international dollars using purchasing power parity rates.
[b)] In percent of GDP. [c)] The annual percentage change of consumer price index. [d)] In percent of the labour force (International Labour Organization estimate). [e)] One of the subindices of the World Justice Project Rule of Law Index that measures the extent to which countries adhere to the rule of law in practice. It ranges from 0 (the lowest score) to 1 (the highest score).
Source: all data from the *World Development Indicators* database except for the absence of corruption index that is from the World of Justice Project website: `www.worldjusticeproject.org`.

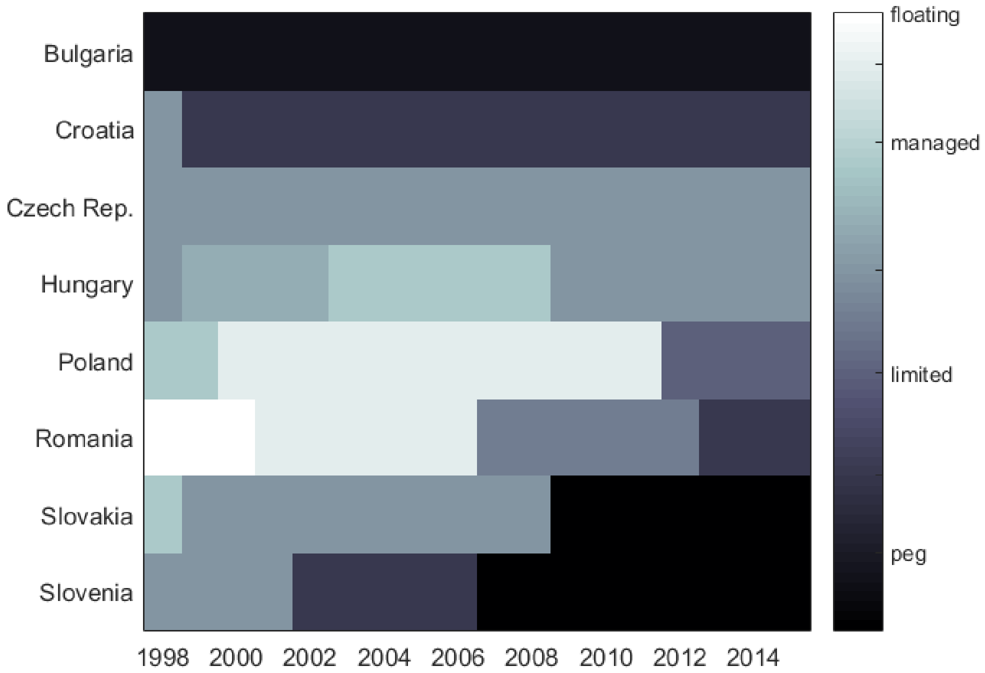
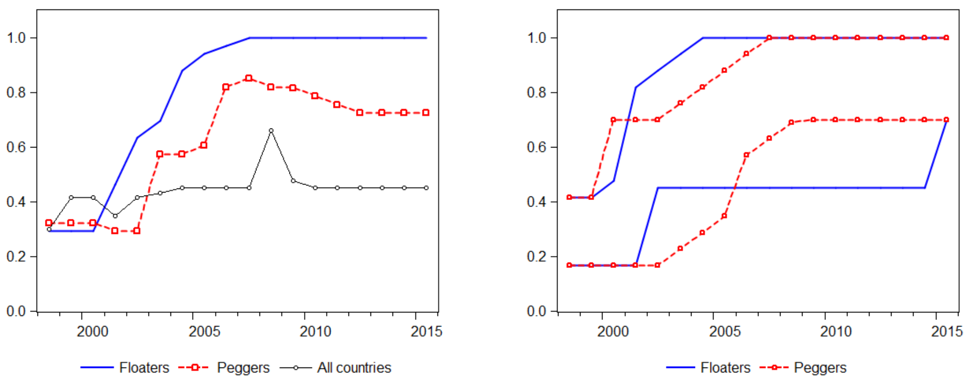


Figure B1: The evolution of exchange rate regimes in CEE countries, 1998-2015
Notes: Exchange rate arrangements: 'peg' stands for a coarse peg category, 'limited' for limited flexibility, 'managed' for managed floating and 'floating' for freely floating. Romania classified as 'freely falling' in 1998-2000.
Source: data from the updated classification of Reinhart and Rogoff (Ilzetzki et al., 2019).



(a) Median

(b) Minimum and maximum

Figure B2: Capital account openness in CEE countries, 1998-2015
Notes: The Chinn-Ito index ranges from 0 to 1.
Source: Data from the dataset developed by Chinn and Ito (2008).

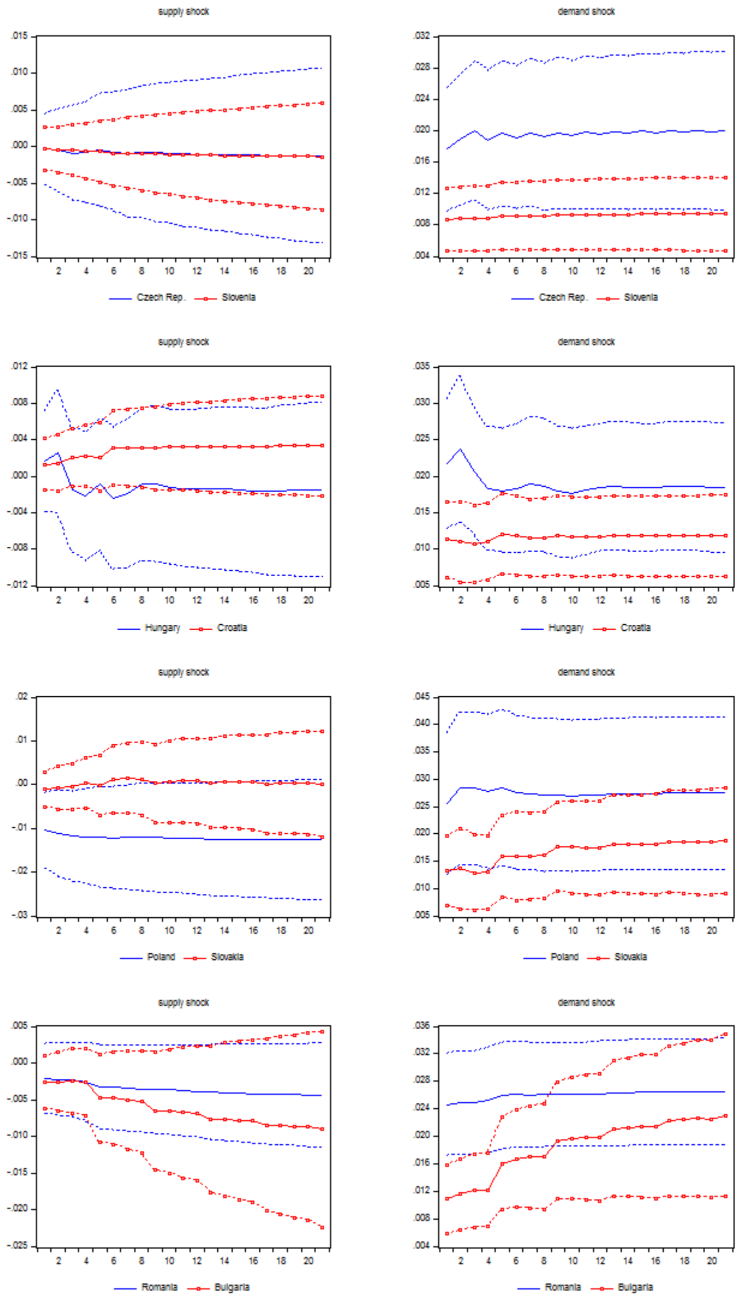


Figure B3: Impulse response functions of the real exchange rate in CEE countries to real shocks

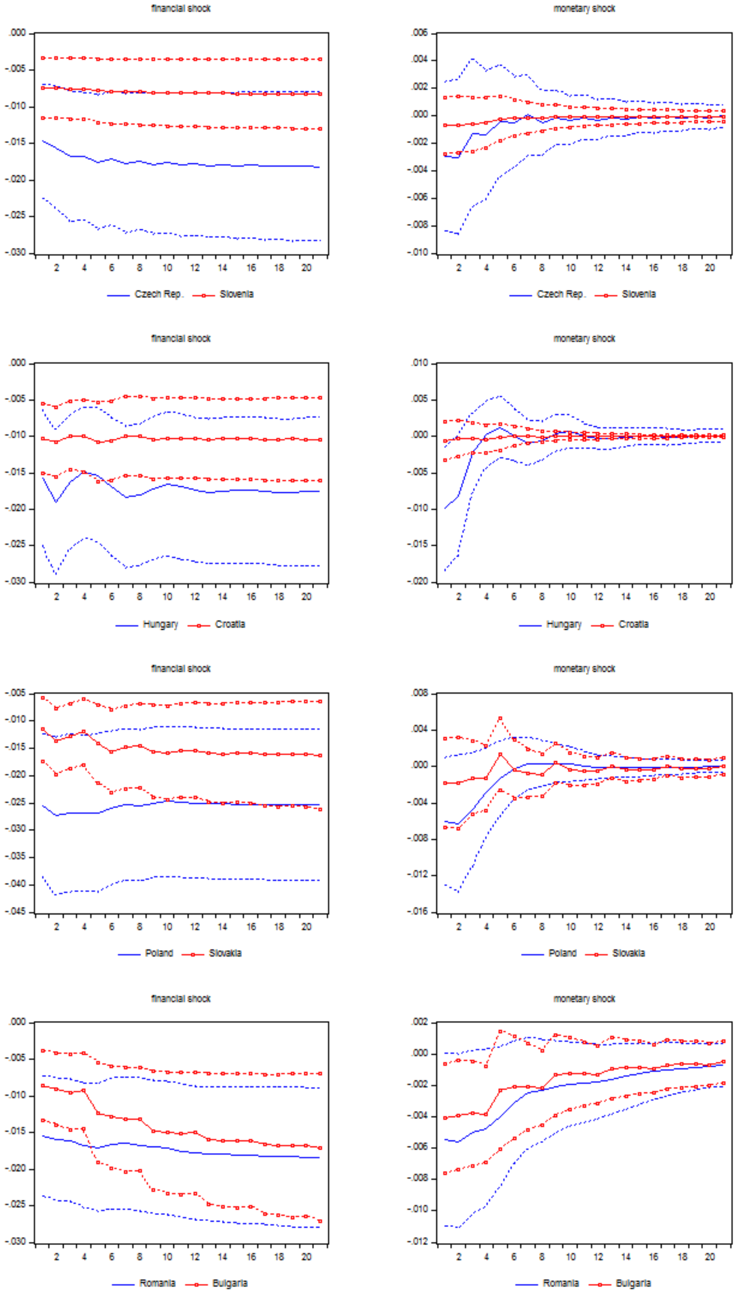


Figure B4: Impulse response functions of the real exchange rate in CEE countries to nominal shocks

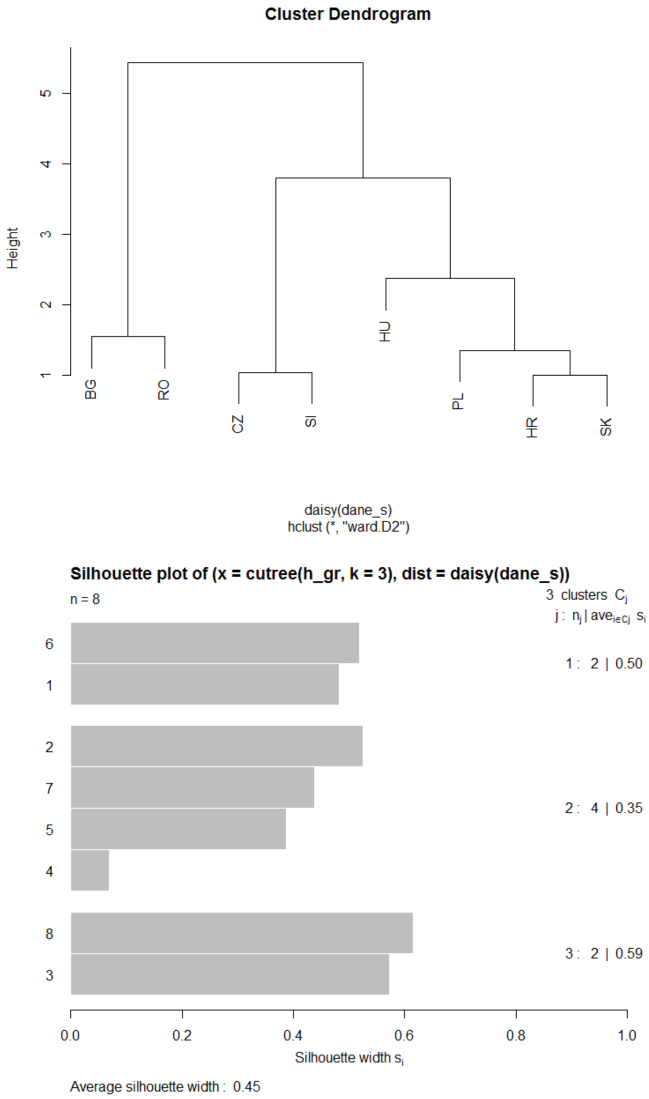


Figure B5: Clustering analysis for CEE countries
Notes: Numbers on the left hand side of the silhouette plot correspond to: 1 – Bulgaria, 2 – Croatia, 3 – the Czech Republic, 4 – Hungary, 5 – Poland, 6 – Romania, 7 – Slovakia, 8 – Slovenia.

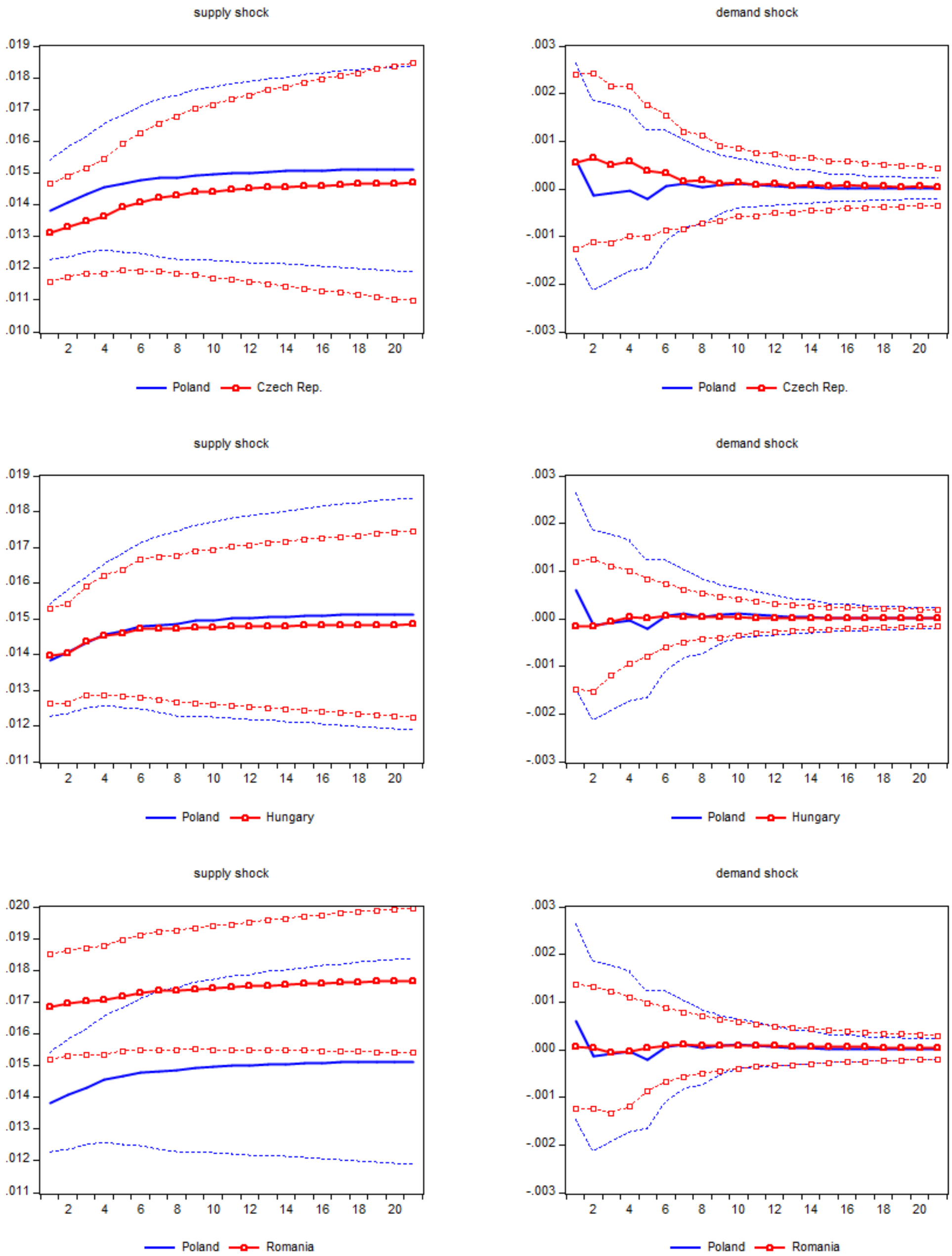


Figure B6: Impulse response functions of the relative output in CEE floaters against Poland

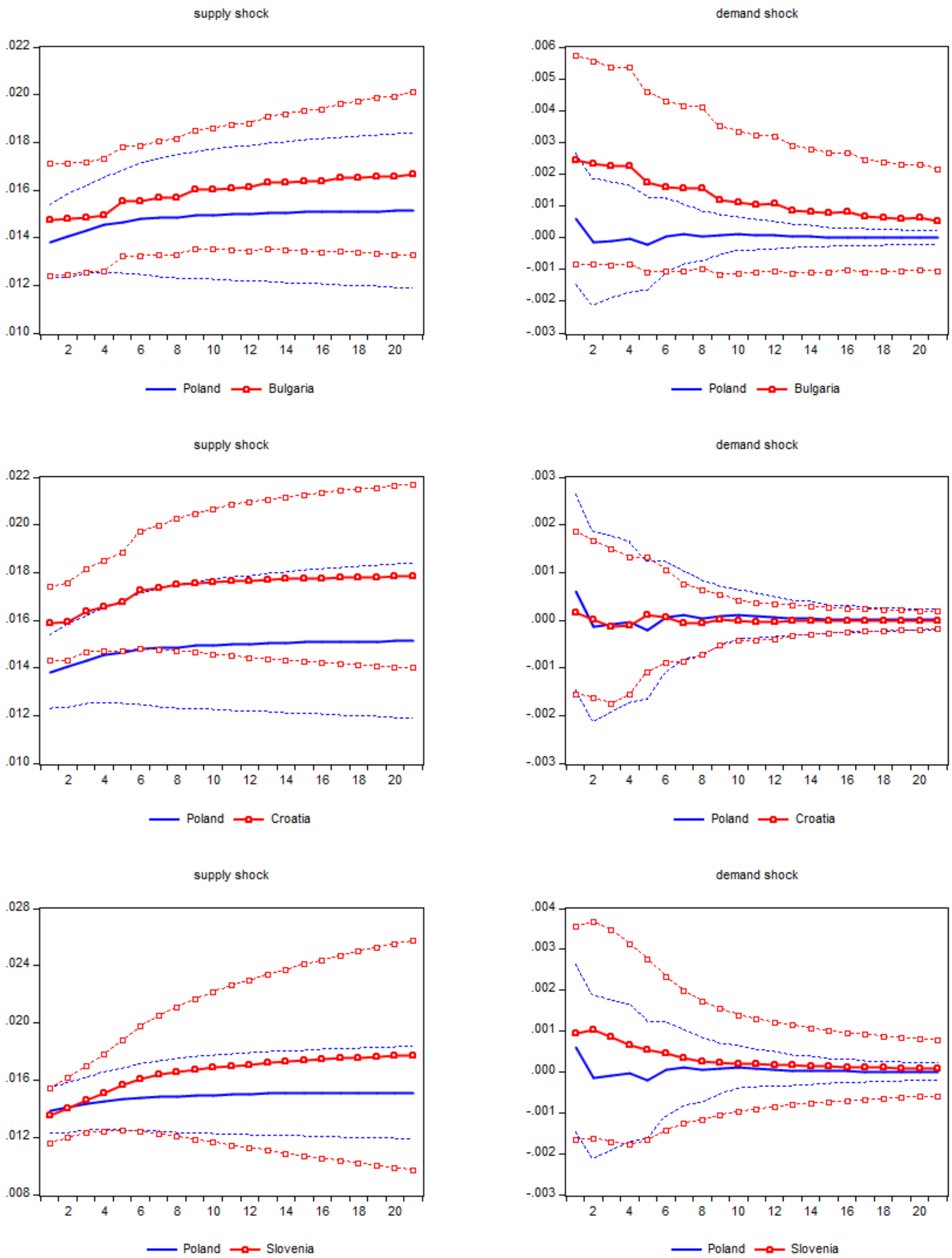


Figure B7: Impulse response functions of the relative output in CEE peggers against Poland

Notes: For Slovakia-Poland pair see Figure 2 in the main text.

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