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CO-INTEGRATION TESTS OF EXCHANGE RATE PARITY CONDITIONS AND A MONETARY MODEL OF EXCHANGE RATE: EVIDENCE FROM THE CZECH REPUBLIC, HUNGARY, POLAND, AND SLOVAKIA[1]

Abstract: *Purchasing power parity and uncovered interest rate parity conditions are both an important building block of any modern approach towards the theory and modelling of exchange rate behaviour. Empirical analyses for these conditions across developed and "stable" economies render mixed results. An interesting question to ask is whether and to what extent the exchange rate behaviour is in accordance with these conditions in emerging foreign exchange markets. In addition to testing the conditions themselves, the paper also tests the relationship between exchange rates on the one hand and interest rates and rates of inflation on the other hand within the context of a basic monetary model of exchange rate. Regarding the time series properties required for testing the parity conditions, co-integration and vector error correction model are acceptable. The focus in this paper is laid on the most developed non-euro (by the end of 2008) countries which entered the European Union in 2004.*

Key words: *co-integration, monetary model, purchasing power parity, uncovered interest rate parity, VECM*

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A substantial number of both pure theoretical or rather empirical models of both nominal and real exchange rate can be found in economic literature. One of the key building locks of most of them is the conditions of purchasing power parity or interest rate parity or both. The paper presents tests of whether the long-term relationships implied by these theories are in compliance with the data. The purchasing power parity and uncovered interest rate parity are also used within traditional monetary models of exchange rate, which is also tested in this paper.

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A large number of papers, further discussed below, report rather mixed results concerning testing the hypotheses based on the parity conditions in the developed economies. The paper focuses on testing these hypotheses in the emerging markets: the Czech Republic, Hungary, Poland, and Slovakia. All these countries entered the EU in 2004, did not use the euro as a domestic currency in the sample period and belong to the most developed countries in the region.

As a method for testing the hypotheses, co-integration and vector error correction models were used. Co-integration is a suitable method for detecting long-run linear relationships among variables, which is a primary goal of this paper. Also, the series used in the analysis are long enough to enable an acceptable use of the method from a technical point of view. However, one must take account of the fact that all the economies for which the hypotheses are tested have been going through substantial structural changes, which, in turn, affects the data series used to test the theories. However, this problem is not unique to transition or post-transition economies. Especially, when testing purchasing power parity with linear methods in the developed economies, extremely long data series are used to overcome the problem of the low power of the tests. This, of course, makes the models exposed to the problem of structural changes in the data as well as in the case of less developed economies with much shorter data series. Co-integration within VAR models is used in this paper. This method is preferable especially when there is no clear distinction between endogenous and exogenous variables, which is necessary when the framework of single equation co-integration is used. Vector error correction models enable to assess the speed with which the dependent variable returns toward the equilibrium value as implied by the co-integration relation. Of course, a common drawback to these methods regardless of any particularities of economies tested is that they are linear. A mounting number of studies imply that the behaviour of the exchange rates may in fact be rather nonlinear at least under certain circumstances: Panos [21], Taylor [26].

Purchasing power parity has been widely tested using co-integration, for example, Edison [8], Corbae [3], Kim [14], Fisher [10], Paya and Peel [22]. The speed of adjustment of the exchange rate toward the long-run value as given by the purchasing power conditions is reported to be low. This, together with the high volatility of both nominal and real exchange rates, poses one of the well-known exchange rate puzzles, Roggoff [24], Taylor and Taylor [27]. One of the relatively new approaches to solving these puzzles departs from using linear model and put models exploiting nonlinearity to use (see above). Other papers rely on nominal rigidities or impact from real variables of the economy.

As well as purchasing power parity, interest rate parity represents an integral part of modern approach toward exchange rates, Obstfeld and Rogoff [20]; however, empirical evidence is as much contradictory as in the case of purchasing power parity. Co-integration has been long used to test this condition, for example Throop [28], Meese [18] or Bjorland [2]. In this paper focus will be placed on the uncovered interest rate parity condition.

Both conditions – purchasing power parity and uncovered interest rate parity are part of monetary models of exchange rate, for example Frenkel [11], Mussa [19], Bilson [1] or a review of traditional exchange rate models in Dornbusch [7], Sarno [25]. In the paper one of the versions of these "ad hoc" models of exchange rate – sticky-price Dornbusch-Frankel model – is tested using the same methodology as in the cases above. A test of two versions of monetary models is given in Hwang [13]. Although he does not find any conclusive evidence, some of the models were able to beat the random walkmodel as far asthe predictive power of the models was concerned.

The paper is structured as follows: the first part describes the data used to test the models. The second part reports the results of the tests and estimated models for purchasing power parity, uncovered interest rate parity and the monetary model for the selected economies. The third part summarizes the key results.

1 Data

Data series for the eurozone, the Czech Republic, Hungary, Poland, and Slovakia were drawn from the Eurostat database. In case of missing values, databases of the respective Central Banks were used. However, the author was unable to find a reliable series of M2 for Slovakia that would cover the sample period. Therefore, Slovakia was excluded from the test of the monetary model.

The sample period starts in January 1998 and ends in November 2008 except for the test of the monetary model, which ends in September 2008.

The series necessary for the test were: nominal spot exchange rates (*S*) expressed as the amount of domestic currency needed for a unit of the foreign currency (the euro being viewed as foreign currency), price levels (*P*) measured by HICP index, one month money market interest rates (*IR*), real GDP (*GDP*) and monetary aggregate M2 (*M2*). All data were seasonally adjusted and except for interest rates enter the models in logs. For the purposes of future analysis, the results of unit root behaviour for interest rate differentials, monetary aggregate differentials, output differentials, year-on-year change in exchange rate and inflation differentials, where inflation was computed as average inflation rate based on HICPindices, are also given.

Co-integration approach is used to test the hypothesis (Johansen method). Co-integration is recovered within VAR model. I choose the lag so that the residuals of VAR do not exhibit autocorrelation and follow normal distribution.

To test whether the series can be used in the co-integration analysis, ADF tests were carried out on their levels and first differences. Linear trend was never used in the test and a constant was added when the graphical analysis of the series suggested it reasonable. The lag was chosen on the basis of AIC criterion (to minimize the criterion). The results of the test are reported in the appendix. They can be summarized as that the series meet the condition necessary for co-integration tests. All series appear to be I(1) (integrated of order 1). A little shadow was cast on the behaviour of logarithmic year-on-year change in exchange rate for Hungary where the null hypothesis of unit root is rejected at 10% level of significance. This will be further commented on below.

2 Empirical Results

The first hypothesis to be tested is the one based on purchasing power parity. It is well known that purchasing power parity in absolute version is a generalization of the law of one price (LOOP):

$$S_{D/F} = \frac{P_D}{P_F} \quad , \tag{4}$$

where *D* and *F* stand for domestic and foreign, respectively.

Taking logarithms of (4), one can readily obtain:

$$s_{D/F} = p_D - p_F \quad , \tag{5}$$

where $s = \log(S)$ and $p = \log(P)$.
If the hypothesis were tested by means of regression (which would pose several problems as the series exhibit unit root behaviour), it might be stated:

$$s_{D/F} = \alpha_0 + \alpha_1 (p_D - p_F) + \varepsilon_t \quad , \tag{6}$$

where α_0 and α_1 are the coefficients being estimated and ε_t is the disturbance term. For the PPP to hold strictly $\alpha_0 = 0$ and $\alpha_1 = 1$ and the disturbance term should be serially uncorrelated. If the differential of logarithmic price level difference increases, the exchange rate should increase (depreciate) proportionately as relatively higher domestic price level leads to commodity arbitrage in the sense that the demand for production abroad is increased, and thus its supply in the domestic economy also increased. Changes in the relative price level occur. This exchange is necessarily linked with the corresponding changes within the supply-demand framework of foreign exchange market. Thus all three variables adjust simultaneously to the original disturbance. Hardly can a distinction between endogenous and exogenous variables be made.

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To test the hypothesis using co-integration, the VAR model for each exchange rate was estimated. Table 1 reports the estimated co-integrating vectors for each exchange rate. Number of chosen lags based on the criteria mentioned above is given (VAR length is the lag given in Table 1 plus 1 as co-integration is performed on first-differenced series). The estimated coefficients and their standard errors are given for each variable.

The reported trace and maximum eigenvalue statistics are given for the null hypothesis of no co-integrating vector. One co-integrating vector which followed the implications given by (5) was detected for each exchange rate, i.e. a rise in domestic price level should give rise to the exchange rate – a positive coefficient and a rise in foreign price level should put a downward pressure on exchange rate – a negative coefficient. However, in the case of Hungary the null of no co-integrating vector could not be rejected using the eigenvalue statistic. The constant may reflect differences in units of measurement, Panos (1997).

For all the four economies the coefficients have the expected signs but some of the estimated coefficients do not show high level of statistical significance.

Following these results, a restriction on the co-integration vector was tested. The restriction was such that the coefficient for domestic price level be 1 and that for foreign price level –1.

The results for one co-integrating vector are given in Table 2. Table 2 reports that the restrictions are found binding in the case of one co-integrating vector.
The imposed restriction was not strictly rejected for the Czech Republic, however, in the case of Hungary and Poland it might be rejected at 10% level of significance and in the case of Slovakia the restriction is rejected at 1% level of significance.

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Tab. 1

Co-integration vectors for PPP (*, **, * rejection of the null at 1%, 5%, 10% level, respectively)**

Czech Republic				
		lag	Trace Statistic	M-E Statistic
Cointegration equation		9	58,72226***	42,79444***
	$ER_{CZK/EUR}$	P_{CZ}	P_{EA}	C
coefficient (standard error)	1	1,353572 (0,85163)	-2,184666 (1,78802)	7,687282 (1,59273)
Hungary				
		lag	Trace Statistic	M-E Statistic
Cointegration equation		11	40,29654**	19,0743
	$ER_{HUF/EUR}$	P_{HU}	P_{EA}	C
coefficient (standard error)	1	2,046521 (0,58027)	-4,488099 (1,47499)	16,91733 (4,20083)
Poland				
		lag	Trace Statistic	M-E Statistic
Cointegration equation		12	40,41268**	21,38778*
	$ER_{PLN/EUR}$	P_{PL}	P_{EA}	C
coefficient (standard error)	1	3,032631 (1,24151)	-4,548128 (1,38729)	8,750770 (3,41614)
Slovakia				
		lag	Trace Statistic	M-E Statistic
Cointegration equation		12	47,77914***	30,18797***
	$ER_{SKK/EUR}$	P_{SK}	P_{EA}	C
coefficient (standard error)	1	1,070448 (0,13364)	-4,395714 (0,33231)	19,01500 (1,02220)

Tab. 2

Tests of restriction on co-integrating vectors (*, **, * rejection of the null at 1%, 5%, 10% level, respectively)**

Czech Republic		Poland	
Number of CE	LR statistic	Number of CE	LR statistic
1	0,268516	1	3,816596*
Hungary		**Slovakia**	
Number of CE	LR statistic	Number of CE	LR statistic
1	2,948466*	1	14,46650***

Taking account of the results of the co-integration analysis, VECM was formed for each exchange rate to assess the stability of the model and to capture the forecasting power of PPP hypothesis. VECMs are not fully presented regarding their lengths. The adjustment coefficient to the co-integrating vector is given as well as the basic diagnostic of the model. Serial correlation of residuals, remaining heteroskedasticity or the Jarque Bera test for normal distribution of the residuals are not reported. Given the way the models were built, the condition is satisfied.

Tab. 3

VECMs for PPP

Czech Republic		Poland	
Error Correction Term		Error Correction Term	
coefficient (standard error) [t-statistic]	-0,018182 (0,01060) [-1,71577]	coefficient (standard error) [t-statistic]	-0,015514 (0,02154) [-0,72460]
Adj. R	0,116781	Adj. R	0,177057
F-statistic	1,592552	F-statistic	1,699238
AIC	-5,681418	AIC	-4,683304
Hungary		**Slovakia**	
Error Correction Term		Error Correction Term	
coefficient (standard error) [t-statistic]	-0,025438 (0,03457) [-0,73585]	coefficient (standard error) [t-statistic]	-0,002501 (0,00272) [-0,91854]
Adj. R	0,03893	Adj. R	0,100211
F-statistic	1,146069	F-statistic	1,246766
AIC	-5,09924	AIC	-5,864792

Table 3 reports that the forecasting capacity of the models is very low. Morever, the adjustment coefficients are not statistically significant. The probable reason for the contradictory results of the co-integration tests and VECM's may stem from the fact that the time series used are not long enough to tackle the problem of structural shocks and the fact that, generally, it takes a long time for the exchange rates to adjust to the equilibrium as given by PPP.

Chocholatá [5] is not able to find enough support for the PPP for Slovakia, and this result is line with hers. For discussion of problems connected with testing the PPP condition see for example Mandel and Tomšík [16]. More other factors are used to model (real) exchange rate as PPP is not sufficient. For discussion of real exchange rate modelling see Egert and Halpern [9].

The second theory put to test was the uncovered interest rate parity (UIP). Comparing domestic return with expected foreign return and assuming the principal equals 1, the idea behind UIP may be expressed:

$$1+\boldsymbol{R}_t^D = E_t\left[\frac{S_{t+1}}{S_t}\left(1+\boldsymbol{R}_t^F\right)\right] \quad , \tag{7}$$

where E denotes the expectation operator. The condition reflects the fact that the return on domestic assets represented by the domestic interest rate should equal to the return on foreign asset given by the foreign interest rate and the relationship between current and expected future spot exchange rate, which must be considered because one must use the foreign currency to invest in the foreign asset market.
Taking logarithms of (7) and approximating log *(1+IR)* by *IR*, the condition may be restated as follows:

$$\boldsymbol{R}_t^D = \boldsymbol{R}_t^F + E_t\Delta s_{t+1} \Leftrightarrow E_t\Delta s_{t+1} = \boldsymbol{R}_t^D - \boldsymbol{R}_t^F \quad \text{or} \tag{8}$$

$$E_t s_{t+1} = s_t + \boldsymbol{R}_t^D - \boldsymbol{R}_t^F \tag{8a}$$

Equation (8a) may re-written as a forward looking difference equation for s:

$$s_t = E_t s_{t+1} + \boldsymbol{R}_t^F - \boldsymbol{R}_t^D \tag{9}$$

The solution to (9) is:

$$s_t = \sum_{k=0}^{\infty} E_t\left(\boldsymbol{R}_{t+k}^F - \boldsymbol{R}_{t+k}^D\right) \tag{10}$$

The short-run and long-run implications of UIP are obvious from (9) and (8), respectively. Assuming the expected spot exchange rate is higher than the current spot exchange rate (the domestic currency is expected to depreciate) then in the short run a rise in domestic interest rate tends to lower (appreciate) the exchange rate as the demand for domestic assets rises. This is captured by equation (9). However, by equation (8) the spot appreciation given the expected spot exchange rate means higher future depreciation of domestic currency. This is the long-run implication of the UIP condition.

The implications may be further complicated by assuming rational expectations and more periods. Then it is not just the current movements in interest rates but also all the future movements as perceived by the agents. Thus, an expected future change in interest rates can have no impact on the future spot exchange rate as the change is already part of the current information set known to the agents and, thus, influences the exchange rate long before it actually happens. The long-run implication is straightforward and given by (10).

The test of the UIP condition focuses on the long-run "traditional" implication of the hypothesis, given by equation (9). A rise in interest rate differential increases the expected rate of depreciation.

Current logarithmic year-on-year changes in exchange rates are related to differentials based on one-month money market interest rates. Monthly changes were also examined for the purpose of the analysis; however, their volatility is substantially higher than those based on yearly changes, which leads to the rejection of unit root behaviour on their levels. Thus they cannot be considered I(1) thus integrated of the same order as the other variables entering this part of the analysis. For regression analysis the hypothesis might be stated equivalently to the case of PPP (6) with the exception that the constant may be nonzero reflecting risk premium:

$$\Delta s_{D/F} = \alpha_0 + \alpha_1 \left(R_D - R_F \right) + \varepsilon_t \quad , \tag{6}$$

where α_0 and α_1 are the coefficients being estimated and ε_t is the disturbance term, $\Delta s_{D/F}$ is the logarithmic year-on-year change in exchange rate and *IR* is the one-month money market rate, domestic or foreign.

Table 4 reports the results of co-integration tests. Trace statistic and maximum eigenvalue statistic did not reject the null of no co-integration vector in any of the cases; however, in the cases of the Czech Republic and Hungary the null is rejected only at 10% level of statistical significance by the trace statistic. In all the cases the estimated relationship follows the one implied by the UIP. The VAR lags are a little higher than in the case of PPP testing but still they are a ceptable regarding the research on this topic using data with relatively higher frequency.

Tab. 4

Co-integration vectors for UIP (*, **, * rejection of the null at 1%, 5%, 10% level, respectively)**

Czech Republic				
		lag	**Trace Statistic**	**M-E Statistic**
Cointegration equation		15	18,58309*	13,33211
	$\mathbf{ER_{CZK/EUR}}$	$\mathbf{IR_{CZ} - IR_{EA}}$		**C**
coefficient (standard error)	1	0,156731 (0,10843)		-0,003269 (0,00083)
Hungary				
		lag	**Trace Statistic**	**M-E Statistic**
Cointegration equation		10	19,66254*	11,39169
	$\mathbf{ER_{HUF/EUR}}$	$\mathbf{IR_{HU} - IR_{EA}}$		**C**
coefficient (standard error)	1	0,013776 (0,04430)		-0,001102 (0,00287)
Poland				
		lag	**Trace Statistic**	**M-E Statistic**
Cointegration equation		14	50,11529***	40,65343***
	$\mathbf{ER_{PLN/EUR}}$	$\mathbf{IR_{PL} - IR_{EA}}$		**C**
coefficient (standard error)	1	0,155707 (0,03034)		-0,010225 (0,00211)
Slovakia				
		lag	**Trace Statistic**	**M-E Statistic**
Cointegration equation		11	31,30310***	24,00829***
	$\mathbf{ER_{SKK/EUR}}$	$\mathbf{IR_{SK} - IR_{EA}}$		**C**
coefficient (standard error)	1	0,154652 (0,01642)		- 0,006512 (0,00049)

The constants presented in Table 4 may be both negative and positive even though one would expect them to be negative reflecting the assets outside the eurozone may be viewed as riskier.

The restrictions on the co-integration vector were tested, i.e. the coefficient of the differential is 1. The restrictions were found to be nonbinding in presence of one co-integrating vector. The results are thus not presented. Table 5 presents VECMs for the four exchange rates.

The VECMs are stable and the speed of adjustment to the long-run given by UIP condition is much higher than in the case of PPP, and also they show higher statistical significance. The models explain between 16 – 35 % of exchange rate variability.

The adjustment coefficients are statistically significant: at 1% level for Hungary and at 5% level for the rest of the economies. The half-life of a shock to the equilibrium is the shortest in the case of Slovakia (app. 3 months) and longest in the case of Poland (app. 9 months). As shown in Pošta (2009), nonlinear models of adjustment can lead to superior results.

Tab. 5

VECMs for UIP

Czech Republic		Poland	
Error Correction Term		Error Correction Term	
coefficient (standard error) [t-statistic]	-0,143978 (0,06008) [-2,39644]	coefficient (standard error) [t-statistic]	-0,075784 (0,03408) [-2,22375]
Adj. R	0,263338	Adj. R	0,351464
F-statistic	2,215414	F-statistic	2,993543
AIC	-10,27259	AIC	-9,201934
Hungary		**Slovakia**	
Error Correction Term		Error Correction Term	
coefficient (standard error) [t-statistic]	-0,203210 (0,06606) [-3,07592]	coefficient (standard error) [t-statistic]	-0,223766 (0,08540) [-2,62017]
Adj. R	0,159065	Adj. R	0,277241
F-statistic	2,011964	F-statistic	2,84819
AIC	-9,578913	AIC	-10,46345

The third model to be tested is one of the basic monetary models. Here the so-called sticky-price Dornbusch-Frankel model will be tested. First, a short introduction to monetary models and their implications in general is given.

Monetary models assume flexible prices and exogenous money and output. In what follows money demand is defined by:

$$MD = Ye^{-\lambda IR} \quad , \tag{11}$$

where *MD* is money demand (equal to supply in equilibrium), *Y* is real output and λ is semi-elasticity of money demand with respect to interest rate. In equilibrium the money demand (11) equals real money supply:

$$\frac{M}{P} = Ye^{-\lambda IR} \quad , \tag{12}$$

Taking logarithms of (12):

$$m = p + y - \lambda R \quad , \tag{12}$$

where p, m and y are the logs of P, M and Y, respectively. The demand function (11) may be stated for both domestic and foreign economy. The difference between domestic and foreign money supply is:

$$m_D - m_F = (p_D - p_F) + (y_D - y_F) - \lambda(R_D - R_F) \quad , \tag{13}$$

assuming equal domestic and foreign semi-elasticities.
Making use of PPP and UIP conditions (5) and (8), equation (13) may be restated:

$$s_t = \frac{\lambda}{1+\lambda}[\tilde{m}_t - \tilde{y}_t] + \frac{\lambda}{1+\lambda} E_t s_{t+1} \ , \tag{14}$$

where variables with tilde denote differences between domestic and foreign values. As in the case of UIP condition, the solution when assuming more periods and rational expectations will be also given for the purpose of completeness. Equation (14) can be expressed as a forward looking difference equation:

$$s_t = \frac{1}{1+\lambda}[\tilde{m}_t - \tilde{y}_t] + \frac{\lambda}{1+\lambda} E_t s_{t+1} \quad , \tag{15}$$

Assuming the following condition holds to rule out speculative bubbles, that is:

$$\lim_{n\to\infty} \frac{\lambda}{1+\lambda} E_t s_{t+n} = 0$$

the solution of (15) is:

$$s_t = \frac{1}{1+\lambda} \sum_{i=0}^{\infty} \left(\frac{\lambda}{1+\lambda}\right)^i E_t [\tilde{m}_{t+i} - \tilde{y}_{t+i}] \quad . \tag{16}$$

Thus, the current spot exchange is influenced by current and expected changes in money supply and output differentials. It is also influenced by current and expected interest rate differentials; however, the interest rate differential is an endogenous parameter in the monetary models rather than exogenous as in the UIP condition.

A simpler approach is taken to testing the monetary model. The testing is based on earlier formulation of monetary models without using rational expectations, see Meese and Rogoff [17].

The sticky-price Dornbusch-Frankel model, in the fashion of the flexible-price monetary model (13), is stated as follows:

$$s_t = \alpha\left(m_t^D - m_t^F\right) + \beta\left(y_t^D - y_t^F\right) + \gamma\left(R_t^D - R_t^F\right) + \delta\left(p_t^D - p_t^F\right) \quad , \quad (17)$$

where β and γ are expected to be negative and α and δ are expected to be positive. The model will be tested within the same framework as the previous hypotheses. Due to the reason stated in part 2, Slovakia was excluded from the test. Table 6 reports the co-integration equations detected for the Czech Republic, Hungary and Poland.

The quarterly series of real GDP were transformed into monthly series using quadratic polynomial (to transform the quarterly series into monthly series, quadratic polynomial is fit for each set of three consecutive points from the quarterly series and then used to fill in the missing points in the monthly series for that period so that the average of the interpolated high frequency points matches the actual low frequency values).

Tab. 6

Cointegration vectors for a monetary model
(*, **, * rejection of the null at 1%, 5%, 10% level, respectively)**

Czech Republic						
		lag	**Trace Statistic**		**M-E Statistic**	
Cointegration equation		5	103,0438***		33,12623*	
	$ER_{CZK/EUR}$	**GDP_{CZ} - GDP_{EA}**	**$M2_{CZ}$ - $M2_{EA}$**	**IR_{CZ} - IR_{EA}**	fi_{CZ} - fi_{EA}	**C**
coefficient (standard error)	1	-5,527706 (0,79907)	-3,940770 (1,13732)	-31,99050 (6,45812)	3,075290 (1,74056)	-53,83419 (11,2509)
Hungary						
		lag	**Trace Statistic**		**M-E Statistic**	
Cointegration equation		6	254,7271***		100,2773***	
	$ER_{HUF/EUR}$	**GDP_{HU} - GDP_{EA}**	**$M2_{HU}$ - $M2_{EA}$**	**IR_{HU} - IR_{EA}**	fi_{HU} - fi_{EA}	**C**
coefficient (standard error)	1	-0,415399 (0,87584)	0,413984 (0,36023)	0,252879 (0,36410)	1,004889 (0,74408)	6,149495 (2,14719)
Poland						
		lag	**Trace Statistic**		**M-E Statistic**	
Cointegration equation		4	154,9819***		53,81759***	
	$ER_{PLN/EUR}$	**GDP_{PL} - GDP_{EA}**	**$M2_{PL}$ - $M2_{EA}$**	**IR_{PL} - IR_{EA}**	fi_{PL} - fi_{EA}	**C**
coefficient (standard error)	1	-9,966341 (-4,73865)	2,228722 (2,19073)	-9,874922 (-2,57142)	5,410706 (3,092343)	27,53692 (4,68160)

One co-integrating vector following the implications of the sticky-price Dornbush-Frankel model was found for Poland. The co-integrating vector for the Czech Republic and Hungary does not meet the implications with respect to monetary supply differential and interest rate differential, respectively.

VECMs were set up for the Czech Republic, Hungary and Poland, the results are given in Table 7.

Tab. 7

VECMs for a monetary model

Czech Republic		Poland	
Error Correction Term		Error Correction Term	
coefficient (standard error) [t-statistic]	-0,063363 (0,01236) [-5,12605]	coefficient (standard error) [t-statistic]	-0,020790 (0,01053) [-1,97443]
Adj. R	0,34701	Adj. R	0,146539
F-statistic	3,104414	F-statistic	2,121769
AIC	-6,174994	AIC	-4,894092

Hungary	
Error Correction Term	
coefficient (standard error) [t-statistic]	-0,113389 (0,06714) [-1,68896]
Adj. R	0,12935
F-statistic	1,485318
AIC	-5,226193

All the three models imply return to equilibrium; however, only for the cases of the Czech Republic and Poland are the adjustment coefficients statistically significant (at 1% and 10% level, respectively).

As even the sticky-price monetary model rests to some extent on the purchasing power parity, the very low statistical significance of the VECMs related to PPP as shown previously may be the main reason behind a rather lower significance of the monetary model tests.

3 Conclusion

In the paper co-integration tests of the absolute version of purchasing power parity, uncovered interest rate parity and sticky-price Dornbusch-Frankel model were run.

For all the countries examined, one co-integration vector was found when testing PPP. The estimated vectors followed the implication given by the PPP condition. Generally, the adjustment to the equilibrium as given by PPP was extremely slow, and the adjustment coefficients are not statistically significant. This paper reports the half-life of a shock to PPP condition to last for up to 4 years (disregarding the unsound estimate for Slovakia). Given the high volatility of exchange rates, it is just a typical example of one of the so-called exchange rate puzzles. It is also necessary to take account of the fact that co-integration is a test of a linear relationship between variables, while the adjustment of the exchange rate may be nonlinear as some of the papers indicate. This line of reasoning, of course, is valid for the following conclusions as well.

Next, the long-run implication of the uncovered interest rate parity was tested. Again statistically significant co-integration vectors were found for all the four economies, and in addition the estimated coefficients of the co-integrating vectors were supportive of the theory. Vector error correction models constructed in the case of UIP displayed stability and a rather low speed of adjustment toward equilibrium regarding the context of financial markets. The estimated length of the adjustment process takes from 3 up to 9 months.

Third, a sticky-price Dornbusch-Frankel variant of a monetary model of exchange rate was tested. A reasonable co-integrating vector was found for Poland. The estimated co-integrating vectors for the Czech Republic and Hungary violated the implication of the theory in some respect. However, the error correction model set up for Poland exhibits little explanatory power.

On the whole the condition of uncovered interest rate parity finds some support in data. The fact that the estimated lengths of adjustment are quite long is in line with most of the papers using similar testing strategies. The data do not seem to be in line with purchasing power parity. Estimates of extremely slow adjustments are common when using linear methods. In addition the transitive/post-transitive nature of the economies tested and shorter time series (in context of purchasing power parity) may bring in additional distortion. Hence the tests of the sticky-price monetary model are probably negatively influenced by the inclusion of purchasing power parity condition.

Of course, when interpreting the results of the analysis, one must bear in mind that regarding the length of the series and intensity of the structural changes of the economies examined in this paper, the results of the tests are rather sensitive to the exact sample period taken. Lower power of the tests may also bring up some problems when assessing the co-integrating relationships. This may be seen when examining the co-integrating relationships from the point of view of significance of the estimated coefficients and significance of the estimated speed of adjustment connected with the particular co-integrating relationship. However, the problem of lower power of tests and structural changes is not unique to the transition/post-transition economies.

References

[1] BILSON, J. F.O. The Monetary Approach to Exchange Rate: Some Empirical Evidence. [IMF Staff Papers], 1978. pp. 48-75.

[2] BJORLAND, H. C. – HUNGNES, H. The Importance of Interest Rates for Forecasting the Exchange Rate. In: *Journal of Forecasting*, 2006, vol. 25, no. 3, pp. 209-221.

[3] CORBAE, D. – OULIARIS, S. Cointegration and Tests of Purchasing Power Parity. In: *The Review of Economics and Statistics*, 1988, vol. 70, no. 3, pp. 508-511.

[4] CUMBY, R.E. – OBSTFELD, M. A Note on Exchange-Rate Expectations and Nominal Interest Differentials: A Test of the Fisher Hypothesis. In: *Journal of Finance*, 1981, vol. 36, no. 3, pp. 697-703.

[5] CHOCHOLATÁ, M. Aplikácia Johansenovej kointegračnej metódy pri testovaní platnosti parity kúpnej sily na Slovensku. In: *Ekonomické rozhľady*, 2009, vol. 38, no. 4, pp. 481-495.

[6] DORNBUSCH, R. Expectations and Exchange Rate Dynamics. *Journal of Political Economy*, 1976, vol. 84, no. 6, pp. 1161-1176.

[7] DORNBUSCH, R. Real Exchange Rates and Macroeconomics: A Selective Survey. In: *Scandinavian Journal of Economics*, 1989, vol. 91, no. 2, pp. 401-432.

[8] EDISON, H. J. Purchasing Power Parity in the Long Run: A Test of the Dollar/Pound Exchange Rate (1890-1978). In: *Journal of Money, Credit and Banking*, 1987, vol. 19, no. 3, pp. 376-387.

[9] EGERT, B. – HALPERN, L. Equilibrium Exchange Rates in Central and Eastern Europe: A Meta-Regression Analysis. BOFIT Discussion Paper No. 4/2005.

[10] FISHER, E. O. – PARK, J. Y. Testing Purchasing Power Parity under the Null Hypothsis of Cointegration. In: *Economic Journal*, 1991, vol. 101, no. 409, pp.1476-1484.

[11] FRENKEL, J. A. A Monetary Approach to the Exchange Rate: Doctrinal Aspects and Empirical Evidence. In: *Scandinavian Journal of Economics*, 1976, vol. 78, no. 2, pp. 200-224.

[12] FROOT, K.A. – ROGOFF, K. Perspectives on PPP and Long-Run Real Exchange Rates. [NBER Working Paper Series, WP no. 4952], 1994.

[13] HWANG, J. K. Dynamic Forecasting of Monetary Exchange Rate Models: Evidence from Cointegration. In: *International Advances in Economic Research*, 2001, vol. 7, no. 1, pp. 51-64.

[14] KIM, Y. Purchasing Power Parity in the Long Run: A Cointegration Approach. In: *Journal of Money, Credit and Banking*, 1990, vol. 22, no. 4, pp. 491-503.

[15] LUTKEPOHL, H. *New Introduction to Multiple Time Series Analysis*. Firenze. Springer, 2007, ISBN 978-3-540-26239-8

[16] MANDEL, M. – TOMŠÍK, V. Relativní verze parity kupní síly: problémy empirické verifikace. (Relative Version of Purchasing Power Parity: Problems of Empirical Verification). In: *Politická ekonomie*, 2008, vol. 56, no. 6, pp. 723 -738.

[17] MEESE, R. – ROGOFF, K. Empirical Exchange Rate Models of the Seventies: Do They Fit out of Sample?In: *Journal of International Economics*, 1983, vol. 14, no. 1-2, pp. 3-24.

[18] MEESE, R. – ROGOFF, K. Was it Real? The Exchange Rate-Interest Differential Relation over the Modern Floating-Rate Period. In: *Journal of Finance*, 1988, vol. 43, no. 4, pp. 933-948.

[19] MUSSA, M. The exchange rate, the balance of payments, and monetary and fiscal policy under a regime of controlled floating. In: *Scandinavian Journal of Economics*, 1976, vol. 78, no. 2, pp. 229 – 248.

[20] OBSTFELD, M. – ROGOFF, K. Exchange Rate Dynamics Redux. In: *Journal of Political Economy*, 1995, vol. 103, no. 3, pp. 624-660.

[21] PANOS, M. – NOBAY, R. A. – PEEL, D.A. Transaction Costs and Nonlinear Adjustment in Real Exchange Rates: An Empirical Investigation. In: *Journal of Political Economy*, 1997, vol. 105, no. 4, pp. 862-879.

[22] PAYA, I. – PEEL, D. A. On the Relationship between Nominal Exchange Rates and Domestic and Foreign Prices. In: *Applied Financial Economics*, 2007, vol. 17, no. 2, pp. 105-117.

[23] POŠTA, V. Nonlinear Dynamics under Uncovered Interest Rate Parity. In: *Ekonomické rozhľady*, 2009, vol. 38, no. 4, pp. 496-514.
[24] ROGOFF, K. The Purchasing Power Parity Puzzle. In: *Journal of Economic Literature*, 1996, vol. 34, no. 2, pp. 647-668.
[25] SARNO, L. – TAYLOR, M. P. *The Economics of Exchange Rates*. Cambridge. Cambridge University Press, 2002, ISBN 0-521-48584-3.
[26] TAYLOR, M. P. – PEEL, D. A. – SARNO, L. Nonlinear Mean-Reversion in Real Exchange Rates: Toward a Solution to the Purchasing Power Parity Puzzles. In: *International Economic Review*, 2001, vol. 42, no. 4, pp. 1015-1042.
[27] TAYLOR, A. M. – TAYLOR, M. P. The Purchasing Power Parity Debate. *Journal of Economic Perspectives*, 2004, vol. 18, no. 4, pp. 135-158.
[28] THROOP, A.W. A Generalized Uncovered Interest Parity Model of Exchange Rates. [Economic Review – Federal Reserve Bank of San Francisco]. Federal Reserve Bank of San Francisco, 1993, pp. 3-16.

Appendix 1

Tab. 1

ADF for levels (left side) and first differences (right side)
(*,**,* indicates rejection of the null at 1%, 5%, 10% level of significance, respectively)**

Variable	t-statistic
logs of exchange rates	
$ER_{CZK/EUR}$	-0,789284
$ER_{HUF/EUR}$	0,540789
$ER_{PLN/EUR}$	0,054681
$ER_{SKK/EUR}$	0,54545
logaritmic exchange rate yoy changes	
$ER_{CZK/EUR}$	-1,283013
$ER_{HUF/EUR}$	-3,153994*
$ER_{PLN/EUR}$	-2,078541
$ER_{SKK/EUR}$	-0,498883
logs of price levels	
P_{CZ}	-0,462978
P_{EA}	0,299574
P_{HU}	-2,183564
P_{PL}	-2,439576
P_{SK}	-2,501185
interest rate differentials	
IR_{CZ} - IR_{EA}	-2,469707
IR_{HU} - IR_{EA}	-2,368131
IR_{PL} - IR_{EA}	-1,995819
IR_{SK} - IR_{EA}	-1,895479
inflation differentials	
⊠$_{CZ}$ - ⊠$_{EA}$	-1,322073
⊠$_{HU}$ - ⊠$_{EA}$	-2,05378
⊠$_{PL}$ - ⊠$_{EA}$	-2,547961
⊠$_{SK}$ - ⊠$_{EA}$	-1,694712
logs of GDP differentials	
GDP_{CZ} - GDP_{EA}	1,479283
GDP_{HU} - GDP_{EA}	-1,329923
GDP_{PL} - GDP_{EA}	0,976323
GDP_{SK} - GDP_{EA}	1,651345
logs of M2 differentials	
$M2_{CZ}$ - $M2_{EA}$	-2,566931
$M2_{HU}$ - $M2_{EA}$	-2,371575
$M2_{PL}$ - $M2_{EA}$	-1,623547
$M2_{SK}$ - $M2_{EA}$	-1,787529

Variable	t-statistic
logs of exchange rates	
$ER_{CZK/EUR}$	-3,851309***
$ER_{HUF/EUR}$	-5,05404***
$ER_{PLN/EUR}$	-4,788146***
$ER_{SKK/EUR}$	-4,656391***
logaritmic exchange rate yoy changes	
$ER_{CZK/EUR}$	-3,330547***
$ER_{HUF/EUR}$	-4,549730***
$ER_{PLN/EUR}$	-4,802579***
$ER_{SKK/EUR}$	-5,549254***
logs of price levels	
P_{CZ}	-3,813349***
P_{EA}	-3,150341***
P_{HU}	-2,666258***
P_{PL}	-2,746828***
P_{SK}	-3,169696***
interest rate differentials	
IR_{CZ} - IR_{EA}	-2,600777***
IR_{HU} - IR_{EA}	-3,931256***
IR_{PL} - IR_{EA}	-3,003242***
IR_{SK} - IR_{EA}	-7,408188***
inflation differentials	
⊠$_{CZ}$ - ⊠$_{EA}$	-2,657322***
⊠$_{HU}$ - ⊠$_{EA}$	-2,999519***
⊠$_{PL}$ - ⊠$_{EA}$	-2,614683***
⊠$_{SK}$ - ⊠$_{EA}$	-3,539045***
logs of GDP differentials	
GDP_{CZ} - GDP_{EA}	-2,652896***
GDP_{HU} - GDP_{EA}	-3,235895***
GDP_{PL} - GDP_{EA}	-3,82239***
GDP_{SK} - GDP_{EA}	-3,71997***
logs of M2 differentials	
$M2_{CZ}$ - $M2_{EA}$	-5,756646***
$M2_{HU}$ - $M2_{EA}$	-4,319944***
$M2_{PL}$ - $M2_{EA}$	-4,001902***
$M2_{SK}$ - $M2_{EA}$	-6,121187***

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