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FOREIGN EXCHANGE RATES IN CENTRAL EUROPEAN ECONOMIES: NONLINEARITIES IN ADJUSTMENT TO INTEREST RATE DIFFERENTIALS

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Abstract: The aim of the paper is to examine the relation between foreign exchange rates and interest rate differentials in Poland, the Czech Republic, and Hungary. The exchange rate equations are inspired by the uncovered interest rate parity (i.e. the UIP condition). The results of empirical studies are usually contrary to the UIP condition. One of the explanations of this puzzle is the existence of certain nonlinearities. The nonlinearities appear because of transaction costs, central bank interventions, limits of speculations, hysteresis, or changes in risk perception. I estimate smooth transition autoregressive models. The threshold variable is an interest rate differential or a level of economic activity. I examine the exchange rates of USD and EUR and 1-, 3- and 6- months and 5- years interest rates. I also test various proxies for risk premium.

Keywords: foreign exchange rates, uncovered interest rate parity, STAR models

INTRODUCTION

The paper concerns the relations between exchange rates and interest rate differentials in Poland, the Czech Republic, and Hungary. The analyzed equations are based on the uncovered interest rate parity (i.e. UIP). According to the UIP condition expected gains from investing in two analogous assets in two different countries should be identical. Thus, the expected change of exchange rate in k-periods should be equal to the difference between domestic and foreign k-period interest rates. The UIP condition postulates that high interest rate currencies should depreciate in relation to low interest rate currencies.

But the results of the empirical studies are inconclusive or reject the UIP condition (see summary of the conducted research in Omer et al. 2012). It is so-called forward premium puzzle. Froot (1990) reports that the average β[1] coefficient for 75 published research equals -0.88. The strong negative correlation between exchange rate and interest rate differential (i.e. β= -1), means that after an increase of domestic interest rate by 1% the exchange rate appreciates by 1% within a year.

There are many explanations of this phenomenon, but their success in practical applications is very limited. Firstly, it is time-varying risk premium. For example, an increase in domestic interest rate could cause an increase in risk aversion to investments in domestic assets and, thus, could have no effect on the exchange rate. Secondly, the investors' expectations might not be rational, because of, for instance, certain expectational errors (learning or peso problems). Thirdly, part of investors slowly reacts for the changes in interest rates, because they have to reconsider their decisions or they cannot react faster. Chinn and Meredith (2005) argue that the negative relation between the exchange rate and interest rates characterizes the short-term data, whereas the positive relation with slope coefficient insignificantly different from unity characterize the long-term data. The authors show that such result is consistent with the standard structural model, in which long-term interest rates react differently on exchange rate shocks than short-term interest rates.

Moreover, the forward premium puzzle can be explained by certain nonlinearities, which I analyze in this paper. The nonlinearities can appear because of transaction costs, central bank interventions[2], limits of speculation, and changes in risk perception. Only when the expected gains from investing in domestic assets are high enough, they will attract speculative capital. The level of risk perception depends on the phase of the business cycle, for instance, during the recent financial crisis high level of risk aversion caused strong depreciation of currencies of Central European economies.

LITERATURE

We can distinguish two groups of studies on nonlinearities in the UIP condition. The first group uses simpler method that allows for discrete switching from one regime to another. Bansal (1997) and Bansal and Dahlquist (2000), using this method, concern a regression of an exchange rate change on a positive and a negative forward premium. Bansal (1997) carries a study for a group of advanced economies[3] and shows that β coefficient is negative for positive interest rate

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[1] β denotes the coefficient of interest rate differential in the exchange rate equation: $\Delta s_{t+k} = \alpha + \beta(i_{t+k} - i^*_{t+k})$, according to UIP conditionα=0, β=1.

[2] in particular these unexpected [Moh et al. 2005]

[3] The author defines the exchange rate as a price of a unit of domestic currency in dollars.

differentials and positive for negative interest rate differentials[4]. In both cases he rejects the hypothesis that $\beta = 1$. Bansal and Dahlquist (2000) do not find similar relation for emerging economies and argue that the results depend on the risk premium and country specific attributes, such as per capita GNP, average inflation rates, inflation volatility, and sovereign ratings.

The second group of studies uses smooth transition models, which allow for a smooth transition from one regime to another. Investors in different periods make their decisions. Only when the potential profits are high enough, the investors will change their assets' portfolio. While when the potential profits are relatively low, less investors will be willing to trade. Also the investors might need time to observe the profitable trading possibility and assess information and transaction costs.

Sarno et al. (2005) study nonlinearities in the UIP condition concerning five major US dollar exchange rates in period from 1985 to 2002. The authors use exponential smooth transition function. The results indicate that β coefficient is negative when small deviations from UIP appear, and it is positive when large deviations appear. Precisely, they argue that when Sharpe ratios[5] are small than the deviation from market efficiency is statistically significant and persistent, however, too small economically to attract speculative capital. On the other hand, when Sharpe ratios are large, they attract speculative capital, and then the spot forward regression satisfies the UIP condition.

Similar study for ten currencies from 1978 to 2002 is conducted by Baillie and Kiliç (2006). The authors apply, in contrast to Sarno et al. (2005), a logistic smooth transition function. Their results also show that only relatively high level of interest rate differential generates the results consistent with the UIP condition.

METHODOLOGY

The no-arbitrage condition might be written as:

$$(1+i_{t+k}) = (1+i^{*}_{t+k})\frac{E(S_{t+k}\,|\,F)}{S_t}, \qquad (1)$$

where i_{t+k} and i^{*}_{t+k} are domestic and foreign nominal interest rates between t and t+k, S_t is the nominal exchange rate (the price of foreign currency in units of domestic currency), $E(S_{t+k}\,|F)$ is the expected exchange rate in t+k given the information set F at time t. Assuming that $\log(1+x) \approx x$, for x close to zero, and rational expectations, I logarithm the equation (1) and obtain:

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[4] Similar results for an absolute value of interest rate differential are obtained by Bilson (1981).

[5] We can interpret Sharpe ratio as the expected excess return from the strategy per unit of risk.

$$i_{t+k} = i^{*}_{t+k} + \log(S_{t+k}) - \log(S_t), \qquad (2)$$

I then denote the natural logarithms as the variables in lowercase letters and obtain the regression usually tested in the literature (so-called Fama regression):

$$\Delta s_{t+k} = \alpha + \beta(i_{t+k} - i^{*}_{t+k}) + \varepsilon_{t+k}. \qquad (3)$$

In the paper I also estimate the following exchange rate equation, which has better statistical properties than equation (3), i.e.:

$$s_{t+k} = \varphi s_t + \alpha + \beta(i_{t+k} - i^{*}_{t+k}) + \varepsilon_{t+k}. \qquad (4)$$

Next I test if adding a proxy for risk premium helps to obtain results that are consistent with UIP condition:

$$s_{t+k} = \varphi s_t + \alpha + \beta(i_{t+k} - i^{*}_{t+k}) + \gamma(risk\_premium) + \varepsilon_{t+k}. \qquad (5)$$

Similarly to Sarno et al. (2005) and Baillie and Kiliç (2006) I estimate the smooth transition models:

$$s_{t+k} = \varphi s_t + \alpha + \beta_1(i_{t+k} - i^{*}_{t+k}) + \beta_2(i_{t+k} - i^{*}_{t+k})F(z_t, \gamma, c) + \varepsilon_{t+k}, \qquad (6)$$

where in case of logistic transition function:

$$F(z_t, \gamma, c) = \frac{1}{1 + \exp(-\gamma(z_t - c)/\sigma(z_t))}, \qquad \gamma > 0, \qquad (7)$$

or in case of exponential transition function:

$$F(z_t, \gamma, c) = 1 - \exp(-\gamma(z_t - c)^2), \qquad \gamma > 0, \qquad (8)$$

z_t is a transition variable, namely it is a differential between domestic and foreign interest rates or a level of economic activity, γ is a slope parameter, c is a location parameter, $\sigma(z_t)$ is a standard deviation of z_t. All parameters are estimated using constrained maximum likelihood method.

For equation (4) I test linearity against smooth transition models, applying two tests [see van Dijk et al. 2000] LM1 and LM2. These tests are based on estimating auxiliary regressions, which have simpler form than logistic or exponential functions. In order to derive LM1 test one uses a first-order Taylor approximation, and to derive LM2 test a second-order Taylor approximation. When the linearity hypothesis is rejected, smooth transition models are estimated. I choose logistic or exponential function depending on the p-value of LM1 and LM2 tests. If LM1 test has smaller p-value I choose a logistic transition function, and if LM2 test has smaller p-value I choose an exponential transition function.

Additionally, I test if the equation (4) is nonlinear according to differential between interest rates using the following simple threshold regression:

$$s_{t+k} = \varphi s_t + \alpha + \beta_1(i_{t+k} - i^{*}_{t+k})I_{t+k}^{+} + \beta_2(i_{t+k} - i^{*}_{t+k})I_{t+k}^{-} + \varepsilon_{t+k}, \qquad (9)$$

$$I_{t+k}{}^{+} = \begin{cases} 1 & when \quad (i_{t+k} - i^{*}_{t+k}) \geq \tau, \\ 0 & otherwise, \end{cases} \quad I_{t+k}{}^{-} = \begin{cases} 1 & when \quad (i_{t+k} - i^{*}_{t+k}) < \tau, \\ 0 & otherwise. \end{cases}$$

DATA

I use monthly data. The analysis is for Poland, the Czech Republic, and Hungary. There is dual currency system in these countries. The euro plays a central role in trade, and the dollar in financial transactions. The exchange rate is the price of USD or EUR in units of domestic currency (PLN, CZK, HUF).

When USD exchange rates are used, there are different starting dates for each country. Thus, the sample starts when the floating exchange regime was implemented, for Poland in April 2000 and for the Czech Republic in June 1997, or when the widening of the band to +/-15% occurred, for Hungary in May 2001.

When EUR exchange rates are used, the sample starts in January 2004, when all three countries joined the European Union. Marcinkowska et al. (2009) indicate this date as the date when the structural change appeared, and the dollar was replaced by the euro as the base currency for foreign currency transactions. The sample ends in December 2012.

I use 1-, 3-, 6- month money market rates, namely WIBOR, PRIBOR, BUBOR, and LIBOR and EURIBOR, as well as 5- year government bonds. The level of economic activity is measured as an output gap, that is the difference between logarithms of seasonally adjusted GDP and its trend. The quarterly data were disaggregated to monthly frequencies using the Fernandez method. I also use the other method of calculating the output gap using industrial production index. As a proxy of risk premium I apply: output gap, returns on stock market indices (WIG 20 index, PX index, BUX index), the difference between the returns on domestic and foreign (S&P 500, Euro Stoxx 50) stock market indices, the ratio of gross government debt to GDP, and the ratio of current account to GDP. The data were obtained from the webpages of the relevant central banks, OECD, and IMF.

RESULTS

Table 1 shows the results of estimating symmetric models (see equations (3), (4), and (5)). In case of the equation (3) β coefficients of interest rate differential are statistically insignificant for Poland and the Czech Republic, and they are negative and statistically significant for short-term interest rates for Hungary. This models seems to fit the data worst (c.f. high values of sums of the squared errors - SSR). In case of the equations (4) and (5) for Poland β coefficients are positive and statistically significant for dollar and 1-month interest rate for euro.

These positive β coefficients are consistent with the UIP condition. The coefficients on interest rate differentials for the Czech Republic and Hungary are statistically insignificant or, in a few cases when euro exchange rate is considered, statistically significant and negative.

The equation 5 includes some proxies for risk premium. I have chosen the variables that are statistically significant and fit the data best. In case of Poland these are: the output gap calculated using industrial production index and returns on WIG20 index, in case of the Czech Republic these are: the ratio of current account balance to GDP and output gap, and in case of Hungary these are: returns on BUX index and the ratio of gross government debt to GDP. Nevertheless, the addition of these variables does not help to obtain the results consistent with the UIP condition. Still, the results of estimating the equation 5 give positive β coefficients only in case of Poland.

Table 1. Symmetric models

			Equation (3)			Equation (4)			Equation (5)		
			β	Wald test	SSR	β	Wald test	SSR	β	Wald test	SSR
Poland	USD	1M	0,64	0,61	0,195	2,97*	0,16	0,184	3,24*	0,09	0,179
		3M	0,55	0,53	0,195	2,70*	0,20	0,186	3,03*	0,11	0,180
		6M	0,49	0,49	0,195	2,57*	0,25	0,186	3,02*	0,13	0,181
		5Y	0,33	0,58	0,195	2,43	0,47	0,190	3,62*	0,19	0,184
	EUR	1M	-0,54	0,39	0,062	3,58*	0,22	0,058	3,46*	0,23	0,056
		3M	-1,01	0,27	0,062	3,12	0,31	0,058	3,05	0,32	0,056
		6M	-1,49	0,19	0,062	2,64	0,48	0,059	2,46	0,51	0,057
		5Y	-3,31	0,20	0,061	-1,52	0,45	0,059	-1,80	0,38	0,057
Czech Republic	USD	1M	0,68	0,65	0,191	0,95	0,94	0,190	0,91	0,92	0,188
		3M	0,54	0,54	0,191	0,80	0,80	0,190	0,75	0,78	0,189
		6M	0,44	0,47	0,191	0,70	0,72	0,190	0,64	0,70	0,189
		5Y	-0,07	0,72	0,162	-0,15	0,70	0,161	1,31	0,93	0,158
	EUR	1M	0,18	0,74	0,024	-0,66	0,52	0,023	-6,36*	0,02	0,021
		3M	0,20	0,75	0,024	-0,36	0,59	0,023	-5,27*	0,03	0,021
		6M	-0,02	0,68	0,024	-0,55	0,53	0,023	-4,98*	0,03	0,021
		5Y	-2,16	0,11	0,023	-0,33	0,61	0,023	-2,03	0,27	0,022
Hungary	USD	1M	-1,42	0,03	0,184	-0,38	0,30	0,176	-0,06	0,35	0,167
		3M	-1,78	0,01	0,183	-0,69	0,21	0,176	-0,41	0,23	0,167
		6M	-2,05*	0,01	0,182	-0,90	0,17	0,176	-0,71	0,17	0,167
		5Y	0,89	0,97	0,185	0,83	0,94	0,176	-0,49	0,47	0,167
	EUR	1M	-2,31*	0,01	0,050	-2,06*	0,01	0,049	-0,65	0,25	0,044
		3M	-2,61*	0,00	0,049	-2,35*	0,00	0,049	-0,75	0,23	0,044
		6M	-2,95*	0,00	0,049	-2,68*	0,00	0,048	-0,86	0,23	0,044
		5Y	-1,67	0,30	0,051	-1,19	0,44	0,050	0,44	0,83	0,044

Source: own calculations;

Wald test denotes p-value of Wald test for the null hypothesis β = 1;

* denotes statistical significance of the parameter

Now, I concentrate only on the equations 4 and 5. I carried out similar analysis for the equation 3, but in no case the obtain results showed positive relation between the change of exchange rate and interest rate differential.

I, next, estimate the models in the form of equation 9 to test if dividing the sample into two subsamples depending on the value of interest rate differential helps to obtain positive and statistically significant β coefficients. Various thresholds τ from the set of values of interest rate differential were tested. Table 2 presents the results for τ equal to 0.9 quantile.

The asymmetric effects are detected only in case of Poland. The Wald test rejects the null hypothesis of $\beta_1 = \beta_2$ for euro exchange rate in case of 1-, 3-, and 6-months interest rates, and for dollar exchange rate in case of 1-month interest rate. The interest rate differential seems to have larger impact on the exchange rate when it is relatively low ($\beta_2 > \beta_1$).

Table 2. Threshold model – Equation (9)

			β_1	β_2	Wald test	SSR
Poland	USD	1M	2,39*	4,73*	0,02	0,180
		3M	2,52*	3,16*	0,55	0,185
		6M	2,22*	3,44*	0,32	0,185
		5Y	2,27	3,02	0,64	0,190
	EUR	1M	1,91	7,52*	0,00	0,055
		3M	1,40	6,50*	0,01	0,056
		6M	1,40	5,67*	0,03	0,057
		5Y	-3,17	0,93	0,08	0,058
Czech Republic	USD	1M	0,72	2,09	0,53	0,189
		3M	0,59	1,70	0,61	0,190
		6M	0,46	1,59	0,60	0,190
		5Y	-2,75	0,90	0,57	0,160
	EUR	1M	-4,40	0,73	0,40	0,022
		3M	-3,61	0,64	0,45	0,023
		6M	-3,45	0,27	0,57	0,023
		5Y	0,25	-0,42	0,92	0,023
Hungary	USD	1M	-0,33	-0,57	0,88	0,176
		3M	-1,25	1,18	0,16	0,173
		6M	-1,14	-0,03	0,40	0,175
		5Y	0,93	-0,30	0,55	0,176
	EUR	1M	-1,93	-0,79	0,39	0,049
		3M	-2,13*	-0,65	0,23	0,048
		6M	-2,49*	-1,25	0,37	0,048
		5Y	-1,18	-1,15	0,98	0,050

Source: own calculations;

Wald test denotes p-value of Wald test for the null hypothesis $\beta_1 = \beta_2$;

* denotes statistical significance of the parameter

Then, linearity of the exchange rate equations against smooth transition models is tested. The threshold variables is an interest rate differential or a level of economic activity. Table 3 presents p-values of LM1 and LM2 tests. The tests indicate strong nonlinearity of euro exchange rate equations in Poland. Dollar exchange rate equations in the Czech Republic and Hungary seem to be nonlinear according to the level of economic activity. Also the euro exchange rate equation for 5-year government bonds in the Czech Republic appears to be nonlinear. Smooth transition models (i.e. STAR models) are estimated for the equations for which LM-type tests show nonlinearity. Table 3 presents the results of estimating the STAR models.

Table 3. LM-type tests for STAR nonlinearity

			USD			EUR		
Equation:			(4)	(5)	(4)	(4)	(5)	(4)
Threshold variable:			differential	differential	output gap	differential	differential	output gap
Poland	1M	LM1	0,23	0,54	0,46	0,07*	0,09*	0,00*
		LM2	0,10*	0,17	0,63	0,07*	0,07*	0,00*
	3M	LM1	0,31	0,72	0,44	0,03*	0,03*	0,00*
		LM2	0,20	0,38	0,71	0,05*	0,05*	0,00*
	6M	LM1	0,35	0,80	0,54	0,04*	0,05*	0,00*
		LM2	0,26	0,46	0,83	0,03*	0,03*	0,00*
	5Y	LM1	0,61	0,97	0,34	0,13	0,09*	0,09*
		LM2	0,50	0,38	0,25	0,31	0,25	0,14
Czech Republic	1M	LM1	0,53	0,52	0,11	0,94	0,20	0,13
		LM2	0,37	0,21	0,07*	0,81	0,28	0,13
	3M	LM1	0,63	0,69	0,12	0,91	0,39	0,17
		LM2	0,35	0,19	0,09*	0,78	0,40	0,21
	6M	LM1	0,87	0,98	0,22	0,46	0,78	0,28
		LM2	0,36	0,18	0,12	0,36	0,21	0,37
	5Y	LM1	0,64	0,40	0,04*	0,21	0,05*	0,85
		LM2	0,87	0,70	0,07*	0,34	0,12	0,02*
Hungary	1M	LM1	0,15	0,22	0,07*	0,17	0,23	0,30
		LM2	0,28	0,40	0,13	0,35	0,47	0,26
	3M	LM1	0,14	0,24	0,05*	0,25	0,25	0,33
		LM2	0,28	0,44	0,13	0,43	0,49	0,35
	6M	LM1	0,19	0,32	0,07*	0,47	0,34	0,48
		LM2	0,38	0,56	0,18	0,39	0,62	0,58
	5Y	LM1	0,86	0,96	0,27	0,59	0,83	0,97
		LM2	0,87	0,71	0,44	0,77	0,97	0,61

Source: own calculations;
differential means interest rate differential;
* denotes p-value less than 0.1

The estimation of logistic smooth transition models for Poland for euro exchange rate shows, similarly as the estimation of equation 9, that higher level of interest rate differential or higher level of economic growth generate the regimes where the difference between domestic and foreign interest rate has weaker impact on the exchange rate ($\beta_1+\beta_2 < \beta_1$). Interestingly, for the Czech koruna – dollar exchange rate in case of 5-years bonds the positive relation between the exchange rate and interest rate differential ($\beta_1+\beta_2>0$) is found for the time periods where the level of economic activity is relatively high. βcoefficients for Hungary are always negative and their absolute value is higher in the time periods where the interest rate differential is relatively high.

Similarly, the exponential smooth transition models for Poland show that higher absolute value of interest rate differential, generates the regimes where the differential does not affect the exchange rate (β_2 statistically insignificant). While for the Czech koruna – dollar exchange rate and short term interest rates the results show positive and statistically significant relation between the exchange rate and interest rate differential in the time periods in which the absolute value of the level of economic activity is relatively high.

Table 4. Smooth transition models– Equation (6)

			Equation	Threshold variable	β_1	β_2	c	SSR
Logistic smooth transition models								
Poland	EUR	1M	(4)	output gap	3,95*	-29,09*	0,025	0,051
Poland	EUR	3M	(4)	differential	10,17*	-6,68*	0,003	0,054
Poland	EUR	3M	(5)	differential	9,65*	-6,31*	0,003	0,052
Poland	EUR	3M	(4)	output gap	3,58*	-31,86*	0,025	0,052
Poland	EUR	6M	(4)	output gap	3,68*	-28,28*	0,025	0,052
Poland	EUR	5Y	(5)	differential	29,19	-34,00	0,001	0,052
Poland	EUR	5Y	(4)	output gap	0,43	-18,38*	0,025	0,053
Czech Republic	USD	5Y	(4)	output gap	-13,07*	19,73*	-0,005	0,154
Czech Republic	EUR	5Y	(5)	differential	1,89	-0,08*	-0,003	0,021
Hungary	USD	1M	(4)	output gap	-0,14	-11,98*	0,056	0,164
Hungary	USD	3M	(4)	output gap	-0,31	-11,82*	0,057	0,164
Hungary	USD	6M	(4)	output gap	-0,36	-11,62*	0,058	0,164

Table 4. -continuation

			Equation	Threshold variable	β_1	β_2	c	SSR
Exponential smooth transition model								
Poland	USD	1M	(4)	differential	5,15*	-30,96	0,005	0,182
Poland	EUR	1M	(4)	differential	7,64	-628,78	0,002	0,056
Poland	EUR	6M	(4)	differential	7,82*	-475,10	0,002	0,057
Poland	EUR	1M	(5)	differential	7,71	-637,23	0,002	0,054
Poland	EUR	6M	(5)	differential	7,45*	-431,95	0,002	0,055
Czech Republic	USD	1M	(4)	output gap	-1,05	5,41*	-0,014	0,187
Czech Republic	USD	3M	(4)	output gap	-1,33	5,21*	-0,014	0,187
Czech Republic	USD	6M	(4)	output gap	-1,42	5,42*	-0,015	0,188
Czech Republic	EUR	5Y	(4)	output gap	-7,09	8,11	-0,036	0,022

Source: own calculations;
differential means interest rate differential;
* denotes statistical significance of the parameter

CONCLUSIONS

The study concerns the relationship between an exchange rate and an interest rate differential in Poland, the Czech Republic, and Hungary. The main aim of the paper is to test whether allowing for certain nonlinear effects enables to obtain results consistent with the UIP condition, i.e. a positive relation between an exchange rate and an interest rate differential.

The results show that the Polish zloty – euro exchange rate equations and the Polish zloty – dollar exchange rate equation for 1-month interest rate are nonlinear. Precisely, in the periods where the level of interest rate differential or the level of economic growth is relatively high, the interest rate differential has weaker impact on the exchange rate. In case of the Czech koruna – dollar exchange rate allowing for nonlinear effects gives positive β coefficients in the periods where the level or the absolute level of economic activity is relatively high. In case of the Czech koruna – euro and the Hungarian forint – euro or –dollar exchange rates the results point to, difficult to explain, negative relation between the exchange rate and the interest rate differential. Additionally, including certain proxies for risk premium does not change the results.

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