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THE APPLICATION OF REGRESSION ANALYSIS IN TESTING UNCOVERED INTEREST RATE PARITY

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Abstract: The aim of the paper is to evaluate and compare two linear regression models proposed by Froot and Frankel (1989) and to show their application in verification of the uncovered interest rate parity (UIP) hypothesis in the selected ten exchange rate markets. The paper shows that both models proposed by Froot and Frankel (1989) are formally equivalent, but they may give different regression results. Many researchers claim that uncovered interest rate parity tends to hold more frequently in emerging markets than in developed economies. The paper is focused on five developed and five emerging economies. It is partly confirmed that developing countries work better in terms of UIP.

Keywords: uncovered interest rate parity, exchange rate, linear regression model

INTRODUCTION

Uncovered interest rate parity (UIP) is a key relationship in international finance. UIP represents the cornerstone parity condition of many fundamental equilibrium exchange rates models such as capital enhanced equilibrium exchange rate model, behavioral equilibrium exchange rate model and monetary model of exchange rate. Uncovered interest rate parity states that high-yield currencies should depreciate and low-yield currencies should appreciate. It needs to be emphasized that UIP parity holds only when investors are risk neutral and have rational expectations. Very often however, we observe the tendency of low interest-yielding currencies to depreciate rather than appreciate as UIP suggests. Deviations from UIP is generally called the forward premium puzzle.

Froot'a and Frankel'a [1989] propose two linear models which may be applied for testing uncovered interest rate parity. The aim of the paper is to assess these models and additionally, to test whether uncovered interest rate parity holds for chosen ten countries. Research is conducted for five developed and five emerging economies. The remainder of the paper is organized as follows. Section UNCOVERED INTEREST RATE PARITY reviews the relevant literature concerning uncovered interest rate parity. Moreover, this section presents two linear models proposed by Froot'a i Frankel'a [1989] for testing uncovered interest rate parity. Section STATISTICAL TESTS FOR REGRESSION MODELS … discusses possible differences in drawing conclusions about UIP on the basis of these two linear models. The empirical results are described in the next section. The last section provides concluding remarks drawn from the empirical research.

UNCOVERED INTEREST RATE PARITY

Covered interest rate parity (CIP) states that the ratio of domestic and foreign interest rates should equal to the ratio of forward and spot exchange rates. CIP can be expressed as follows:

$$\frac{1+r_t}{1+r_t^*} = \frac{F_t^{(k)}}{S_t} \tag{1}$$

where S_t is the price of foreign currency in units of domestic currency in time *t*, $F_t^{(k)}$ is the forward value of exchange rate for a contract agreed in time *t* for an exchange of currencies *k* periods ahead, r_t and r_t^* are domestic and foreign interest rates respectively (with *k* periods to maturity).

Uncovered interest rate parity (UIP) describes the relationship between interest rates and expected exchange rate changes.

$$\frac{1+r_t}{1+r_t^*} = \frac{E(S_{t+k}|\Omega_t)}{S_t} \tag{2}$$

where $E(S_{t+k}|\Omega_t)$ is the expected spot exchange rate at time *t*+*k*, based on information known at time *t*.

Assuming covered interest-rate parity holds the uncovered interest rate parity can be expressed as follows:

$$\frac{E(S_{t+k}|\Omega_t)}{S_t} = \frac{F_t^{(k)}}{S_t} \tag{3}$$

Equation (2) and (3) cannot be directly testable because market expectations of future spot exchange rates are hardly observable. Therefore, uncovered interest rate hypothesis is tested jointly with the assumption of rational expectations in exchange rate market. Under the assumption of rational expectations, the future value of spot exchange rate in time $t+k$ is equal to expected spot exchange rate at time $t+k$ plus a white-noise error term at time $t+k$.

$$S_{t+k} = E_t(S_{t+k}|\Omega_t) + \eta_{t+k} \tag{4}$$

where η_{t+k} is white-noise error term which is uncorrelated with information available at time *t*.

Uncovered interest rate parity hypothesis may be verified by estimating and testing coefficients in two regression models proposed by Froot, Frankel [1989]. The first regression model (5) refers directly to equation (3) and (4).

$$\Delta s_{t+k} = \alpha + \beta \cdot fd_t^k + \eta_{t+k}^k \tag{5}$$

where $\Delta s_{t+k} = s_{t+k} - s_t$, $fd_t^k = f_t^k - s_t$, s_t denotes the logarithm of spot exchange rate at time *t*, s_{t+k} is the logarithm of spot exchange rate at time $t+k$, f_t^k is the logarithm of the *k*-period forward exchange rate. Under the UIP parity condition, the slope parameter β in equation (5) should be equal to unity (β = 1) and the coefficient α should be equal zero (α = 0). It needs to be emphasized that testing uncovered interest rate parity in this form is tantamount to testing the joint hypothesis that market participants are endowed with rational expectations and risk-neutral.

Empirical studies based on the estimation of equation (5) generally reject the UIP hypothesis. Fama [1984], Froot i Frankel [1989], McCallum [1994] show that coefficient β in equation (5) is significantly less than one, and in fact very often closer to minus unity than plus unity. This finding may imply that the forward exchange rate is biased predictor of the spot exchange rate. The violation of uncovered interest rate parity is traditionally called the forward premium puzzle (forward discount bias). Literature provides several explanations of the phenomenon. One possible reason is the existence of a risk premium. Another explanations involve invalidity of the rational expectations hypothesis, peso problems and market inefficiency [Baillie i Bollerslev 2000].

In the second regression model proposed by Froot'a i Frankel'a [1989] forward rate prediction error (a difference between future spot exchange rate s_{t+k} and forward exchange rate f_t^k) is considered to be a dependent variable and forward premium fd_t^k is considered to be an independent variable (6).

$$fd_t^k - \Delta s_{t+k} = \alpha_1 + \beta_1 \cdot fd_t^k + \eta_{t+k}^k \tag{6}$$

where β_1 = 1- β and α_1 = - α. Under the UIP parity condition, both the slope coefficient β_1 and the coefficient α_1 in equation (6) should be equal zero ($\alpha_1 = 0, \beta_1 = 0$).

When coefficients β_1 and α_1 in equation (6) are equal zero and coefficients β and α in equation (5) are equal one and zero respectively, then both regression models proposed by Froot'a i Frankel'a [1989] are equivalent. It needs to be emphasized however, that although these models are formally equivalent they may give different regression results.

STATISTICAL TESTS FOR REGRESSION MODELS WHICH VERIFY THE UIP

Let us consider two regressive models:

$$y_i = \alpha + \beta \cdot x_i + \varepsilon_i \tag{7}$$

$$x_i - y_i = -\alpha + (1 - \beta) \cdot x_i + \eta_i \tag{8}$$

Where y is the endogenous variable, x exogenous variable, α and β are the structural parameters of the model, and $\eta_i = - \varepsilon_i$

After estimating the coefficients of the models we get:

$$\hat{y}_i = a + b \cdot x_i \tag{9}$$

$$x_i - \hat{y}_i = a + (1 - b) \cdot x_i \tag{10}$$

where $\hat{y}_i$ is an estimate of the dependent variable, and a and b are estimates of the structural parameters of model (7).

Let's introduce markings:

$$S_{yy} = \sum_{i=1}^{n} (y_i - \bar{y})^2, S_{xx} = \sum_{i=1}^{n} (x_i - \bar{x})^2, S_{yx} = \sum_{i=1}^{n} (y_i - \bar{y}) \cdot (x_i - \bar{x}),$$
$$SSE = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2, SSR = \sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2 \tag{11}$$

where n is the number of observations.

The basic statistical test based on F statistics, where the number of degrees of freedom for fraction equals 1 and for denominator equals n-2, verifies the existence of a linear relationship between the dependent variable and explanatory variable. We set the null hypothesis which states that the directional coefficient in the regressive model is insignificantly different from 0 (which means no linear relationship between the variables x and y). In the case of model (7) this hypothesis means that coefficient $\beta = 0$ whereas in the model (8) $\beta = 1$. For model (7) test statistic, which we denote as F_1 is:

$$F_1 = \frac{SSR}{SSE} \cdot (n - 2) \tag{12}$$

For the model (8) after translation we obtain statistic F_2:

$$F_2 = F_1 + \frac{S_{xx}}{SSE} \cdot (n-2) - \frac{S_{xy}}{SSE} \cdot 2 \cdot (n-2) \tag{13}$$

F_2 is greater than F_1 if S_{xx} is greater than $2 \cdot S_{xy}$. In this case, the significance of F_1 is greater than the significance of F_2. It may therefore happen that a certain level the significance of the hypothesis about no linear relationship between the variable *x* and *y* cannot be rejected, but you can reject the hypothesis of no linear relationship between the variables *x-y* and *x*.

The hypothesis formulated above can also be verified by means of *t* statistic. For model (7) this statistic is determined by the formula:

$$t_1^{\beta} = \frac{b}{S(b)} = \frac{\dfrac{S_{xy}}{S_{xx}}}{\sqrt{\dfrac{SSE}{S_{xx}} \cdot \dfrac{1}{n-2}}} = \frac{S_{xy}}{\sqrt{\dfrac{S_{xx} \cdot SSE}{n-2}}} \tag{14}$$

where *S* (*b*) is the estimation error of coefficient *b*.

t statistics for model (8) is equal to:

$$t_2^{1-\beta} = \frac{1-b}{S(1-b)} = \frac{1 - \dfrac{S_{xy}}{S_{xx}}}{\sqrt{\dfrac{SSE}{S_{xx}} \cdot \dfrac{1}{n-2}}} = \sqrt{\frac{S_{xx}}{SSE} \cdot (n-2)} - t_1 \tag{15}$$

Statistics t_1^{β} can verify the hypothesis that β parameter is significantly different from zero whereas $t_2^{1-\beta}$ that β parameter is significantly different from *1*. The test based on *F* statistics is equivalent to the test based on *t* statistics are the following equalities are met:

significance F_1 = significance t_1^{β}, significance F_2 = significance $t_2^{1-\beta}$ (16)

If model (7) uses $t_2^{1-\beta}$ statistics (which enables the verification of the hypothesis that β coefficient is significantly different from *1*) it is also necessary to use F_2statistics, rather than F_1, because the F_1 significance will differ from $t_2^{1-\beta}$ significance.

For the tests which verify the significance of intercept α, they are equivalent for both models, except that the empirical values for *t* test have different signs.

If we want to verify the hypothesis of uncovered interest rate parity, first we must verify the hypothesis that the parameter $\beta = 1$, and the parameter $\alpha = 0$. It is better than to use model (8)[1], as the standard regression analysis enables us to determine the value of the relevant statistics. If we use model (7) the results must be transformed according to formulas (13) and (15). In addition, if S_{xx} is greater than $2 \cdot S_{xy}$, it may be that for a certain level of significance, we cannot reject the hypothesis that the coefficient β in model (7) is insignificantly different from zero, while in model (8) we find that β is significantly different from 1.

EMPIRICAL RESULTS

Several explanations for the UIP failure have been put forward in the literature. Flood and Rose [2002] have shown that uncovered interest rate parity works systematically better for countries in crisis, whose exchange rates are considerably more volatile. Clarida et al. [2009] have obtained consistent results. In their opinion the sign of slope coefficient β depends on market volatility. In high volatility regimes, coefficient β occurs to be positive. Bansal and Dahlquist [2000] have noticed that UIP performs better in developing compared to developed countries. Similar researches have been conducted by Ito and Chinn [2007], Frankel and Poonawala [2010]. According to Bansal and Dahlquist [2000] country-specific attributes such as per capita income, interest rates, inflation and country risk rating are important in explaining deviations form uncovered interest rate parity.

The aim of the paper is to test uncovered interest rate parity hypothesis for chosen five developed and five emerging economies and additionally to check whether results are similar to those obtained by Bansal and Dahlquist [2000]. The UIP hypothesis is verified on the basis of regression models (5) and (6) proposed by Froot'a i Frankel'a [1989]. The models are built for ten exchange rates: USD/GBP, USD/AUD, JPY/USD, CAD/USD, CHF/USD, BRL/USD, MXN/USD, MYR/USD, THB/USD, RUB/USD. Countries were selected on the basis of Ghoshray'a and Morley'a [2012]. The uncovered interest rate parity hypothesis is verified for five developed economies such as United Kingdom (British Pound, GBP), Australia (Australian Dollar, AUD), Japan (Japanese Yen, JPY), Canada (Canadian Dollar, CAD), Switzerland (Swiss Franc, CHF) and for five emerging economies such as Brazil (Brazilian Real, BRL), Mexico (Mexican Peso, MXN), Malaysia (Malaysian Ringgit, MYR), Thailand (Thai Baht, THB), Russia (Russian Ruble, RUB). We use monthly data from Bloomberg on spot exchange rates (s_t) and forward exchange rates (f_t^k) for USD/GBP, JPY/USD, CAD/USD, CHF/USD from January 1995 to December 2012, for THB/USD from September 1995 to December 2012, for MXN/USD from November 1997 to December 2012, for BRL/USD from February 1999 to December 2012, for USD/AUD from September

[1] In this model the dependent variable y_i is $fd_t^k - \Delta s_{t+k}$, while the independent x_i is fd_t^k

2000 to December 2012, for RUB/USD from August 2001 to December 2012 and for MYR/USD from April 2005 to December 2012. Time periods for exchange rates are different because of data limitations.

Table 1 presents the obtained results of the UIP test on the basis of regression model (5). Models are marked as M1 (USD/GBP), M2 (USD/AUD), M3 (JPY/USD), M4 (CAD/USD), M5 (CHF/USD), M6 (BRL/USD), M7 (MXN/USD), M8 (MYR/USD), M9 (THB/USD) and M10 (RUB/USD). Table 1 displays coefficients, their standard errors, test statistics and their corresponding significance levels.

Table 1. OLS estimation results of equation (5) for ten exchange rates

Model	b S(b)	a S(a)	F_1	Sig. F_1	t_1^{β}	t^{α}	Sig. t^{α}
M1 - USD/GBP	-1,252 (1,784)	-0,0008 (0,0022)	0,493	0,483	-0,702	-0,391	0,696
M2 - USD/AUD	0,477 (2,681)	0,0056 (0,0072)	0,032	0,859	0,178	0,770	0,443
M3 - JPY/USD	-1,175 (1,240)	-0,0038 (0,0040)	0,898	0,345	-0,948	-0,948	0,344
M4 - CAD/USD	-2,858 (1,854)	-0,0017 (0,0017)	2,376	0,125	-1,541	-1,047	0,297
M5 - CHF/USD	-2,831 (1,675)	-0,0067 (0,0037)	2,858	0,093	-1,691	-1,792	0,075
M6 – BRL/USD	0,523 (0,805)	-0,0047 (0,0083)	0,422	0,517	0,649	-0,560	0,577
M7 - MXN/USD	-0,045 (0,419)	0,0028 (0,0035)	0,012	0,915	-0,107	0,798	0,426
M8 - MYR/USD	0,339 (0,918)	-0,0024 (0,0020)	0,136	0,713	0,369	-1,187	0,239
M9 - THB/USD	1,780 (0,489)	-0,0038 (0,0027)	13,253	0,0003	3,641	-1,397	0,164
M10 - RUB/USD	1,592 (0,299)	-0,0069 (0,0027)	28,376	4,1E-07	5,327	-2,525	0,013

Source: own estimations

The slope coefficient is significantly different from zero in models M5, M9 and M10 with at least 90 percent level of confidence. Furthermore, only in M5 and M10 estimates for α are significantly different from zero. For exchange rates USD/GBP, USD/AUD, JPY/USD, CAD/USD, BRL/USD, MXN/USD and MYR/USD both slope coefficient β and intercept coefficient α are insignificant. Only for CHF/USD, THB/USD and RUB/USD slope coefficient β is significant, which implies that there is linear relationship between dependent variable (Δs_{t+k}) and independent variable (fd_t^k). For CHF/USD coefficient β equals -2,8313, for THB/USD β equals 1,7796 and for RUB/USD β equals 1,59919. These results confirm the findings of Bansal and Dahlquist [2000]. The slope coefficients for emerging economies (Thailand and Russia) are positive and for developed economies (Switzerland) negative. As was mentioned before, UIP is satisfied if the parameter β in the first model (5) is positive, and unsatisfied when β is negative. The estimation signs of β coefficients confirm the results obtained by Bansal and Dahlquist [2000]. For the currencies of emerging countries (Brazil, Malaysia, Thailand, and Russia) parameters β are positive, while for developed countries (United Kingdom, Japan, Canada and Switzerland) negative. Only for Australia and Mexico Bansal and Dahlquist's [2000] thesis has not been confirmed. It needs to be emphasized, however, that for most of the models coefficient β was insignificant. It suggests that presented findings should be treated with some caution.

Table 2 displays regression results of equation (6). Models are marked as M1′ (USD/GBP), M2′ (USD/AUD), M3′ (JPY/USD), M4′ (CAD/USD), M5′ (CHF/USD), M6′ (BRL/USD), M7′ (MXN/USD), M8′ (MYR/USD), M9′ (THB/USD) and M10′ (RUB/USD). The table below contains slope coefficient estimates, standard errors, test statistics and their corresponding significance levels (p-value). Moreover, the value of S_{xx}, S_{xy} and *SEE* are provided, which enable to apply formulas (13) and (15).

The slope coefficient is insignificantly different from zero in models M1′, M2′, M6′, M8′ i M9 with at least 10% significance level. This is equivalent with statement that β in equation (5) is insignificantly different from one, which implies that UIP hypothesis cannot be rejected. In other models slope coefficient is significant which means that forward rate prediction error $\Delta s_{t+k} - fd_t^k$ can be explained by forward premium fd_t^k. Moreover, when we increase the significance level to 0,115, the coefficient β in model M9′ will be also significant.

Estimation results imply that for JPY/USD, CAD/USD, CHF/USD, MXN/USD and RUB/USD exchange rates, uncovered interest rate hypothesis is rejected. However, there are no foundations to reject $\beta_1 = 0$ null hypothesis for USD/GBP, USD/AUD, BRL/USD, MYR/USD and THB/USD with at least 10% significance level.

Table 2. OLS estimation results of equation (6) for ten exchange rates

Model	b S(b)	F_2	sig. F_2	$t_2^{\beta_1}$	S_{xx}	S_{xy}	SEE
M1′ - USD/GBP	2,252 (1,784)	1,595	0,208	1,263	0,0002	-0,0002	0,126
M2′ - USD/AUD	0,523 (2,681)	0,038	0,846	0,195	0,0002	0,0001	0,232
M3′ - JPY/USD	2,175 (1,240)	3,077	0,081	1,754	0,0007	-0,0008	0,228
M4′ - CAD/USD	3,859 (1,854)	4,330	0,039	2,081	0,0002	-0,0005	0,125
M5′ - CHF/USD	3,832 (1,675)	5,234	0,023	2,288	0,0004	-0,0010	0,221
M6′ – BRL/USD	0,478 (0,805)	0,352	0,554	0,594	0,0043	0,0022	0,456
M7′ - MXN/USD	1,045 (0,419)	6,230	0,014	2,496	0,0051	-0,0002	0,161
M8′ - MYR/USD	0,661 (0,918)	0,519	0,473	0,720	0,0004	0,0002	0,034
M9′ - THB/USD	-0,780 (0,489)	2,354	0,112	-1,595	0,0050	0,0088	0,243
M10′ - RUB/USD	-0,592 (0,299)	3,923	0,050	-1,981	0,0087	0,0138	0,104

Source: own estimations

Estimations of equation (6) do not provide unambiguous results. Uncovered interest rate parity holds for two developed economies (United Kingdom and Australia) and two emerging economies (Brazil and Malaysia). However, the UIP hypothesis is rejected for three developed countries (Japan, Canada and Switzerland) and for three developing countries (Mexico, Thailand and Russia). The conclusions were drawn on the basis of evaluation of slope coefficient β_1. The intercept coefficient α has been insignificantly different from zero for United Kingdom, Australia, Japan, Canada, Brazil, Mexico, Malaysia and Thailand. It may imply the existence of transaction costs or non-zero risk premium. Only for Switzerland and Russia α has occurred to be significant.

From a statistical point of view, model (6) seems to be better than model (5). In the first regression model, most slope coefficients β was insignificantly different from zero. Hence, it was not sensible to test whether it is different from 1. The estimation of equation (6) gives insignificant slope coefficient only in four cases. A difference in significance of F-test statistics in models (5) and (6) results from the test structure. This is because the probability distribution of the test statistic is determined by the null hypothesis but not by real variable's distribution.

SUMMARY

The paper verifies the hypothesis of uncovered interest rate parity for the currencies of five developed and five developing countries. The results do not give a clear confirmation or denial of the UIP theory. Bansal and Dahlquist [2000] have found that the UIP works systematically better for developing countries while for developed countries the UIP hypothesis is generally rejected. The parity is satisfied if the parameter β in the first model (5) is positive, and unsatisfied when β is negative.

The estimation signs of β parameter in the first model confirm the results obtained by Bansal and Dahlquist [2000]. For the currencies of developing countries (Brazil, Malaysia, Thailand, and Russia), parameter β has positive values, while for developed countries (United Kingdom, Japan, Canada and Switzerland) negative. Only for the exchange rate of Australian and Mexican currency Bansal and Dahlquist's thesis has not been confirmed. It should be noted, however, that parameter β is insignificantly different from zero for most of the models, which suggests that these findings should be treated with some caution.

The results of calculations presented in the paper confirm the advantage of the second regression model (6) over the first model (5). The first model shows that for most exchange rates parameter β is insignificantly different from 0, and therefore it is not advisable to test whether it is different from 1. However, the results of calculations on the basis of the second model, show that this parameter is insignificantly different from 1 only in four cases.

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