FOREIGN EXCHANGE MARKET EFFICIENCY. EMPIRICAL RESULTS FOR THE USD/EUR MARKET

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Abstract

The aim of the paper is to verify whether the USD/EUR exchange rate market is efficient. The fundamental parity condition for testing foreign exchange market efficiency is represented by the uncovered interest-rate parity (UIP). Therefore, the UIP hypothesis verification accounts for the crucial part of the paper. The efficiency of the USD/EUR market is tested by applying the conventional UIP regression approach and orthogonality test of the forward rate forecast error. The results show that it is hard to say definitely that USD/EUR foreign exchange market is inefficient. The slope coefficient in UIP regression occurs to be negative, which implies the failure of uncovered interest-rate parity. However, there are no foundations to reject the UIP hypotheses in the time of financial crisis of 21st century. Moreover, the article presents that the forward forecast error is not orthogonal to both its lagged value and the interest rate differential. Thus, the semi-strong foreign exchange market efficiency hypothesis is rejected for the USD/EUR market.

Introduction

Efficiency has two meanings in the economics and finance literature. The first one is in terms of Pareto optimality, where there is a question whether it is possible to improve the welfare of at least one participant in the economic system without worsening the welfare of any other. The second meaning of efficiency refers to the markets and denotes that the current price fully reflects available information and there is no possibility to obtain extraordinary profit on this market. In the paper the second meaning of efficiency is taken into account. According to Fama (1970) we can distinguish three different form of financial market efficiency. The weak form assumes that the current price incorporates all the information contained in the historical prices. As far as the semi-strong form is concerned it says that the current price reflects all publicly available information (e. g. announcement of Gross Domestic Product, inflation rate, interest rate, etc.). The strong form, in turn, assumes that all possibly known information is incorporated in current price.

The definition statement that in an efficient foreign exchange market prices fully reflects available information has generally no empirical testable implications. Therefore, most of the research concerning the efficiency of foreign exchange market are based on the simple assumption of zero expected profit. The fundamental parity condition for testing foreign exchange

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market efficiency is represented by the uncovered interest-rate parity (UIP) and the failure of UIP is generally interpreted as the opportunity to generate non-zero profit.

The aim of the paper is to verify whether the USD/EUR exchange rate market is efficient. The article is focused mainly on the uncovered interest-rate parity theory. The driving force behind it is that the UIP condition represents the fundamental parity condition for testing foreign exchange market efficiency. The remainder of the paper is organized as follows. Section 2 describes the foreign exchange market efficiency theory and the theory of uncovered interest-rate parity. Moreover, this section contains a brief review of the chosen econometric methods employed in testing foreign exchange market efficiency hypothesis. Section 3 presents empirical research based on the data of spot and forward USD/EUR exchange rates. In this section the efficiency of the analyzed market is verified by applying the conventional UIP regression approach and orthogonality test of the forward rate forecast error. The last section provides conclusions drawn from the empirical research.

Foreign exchange market efficiency and the uncovered interest-rate parity

The simple risk-neutral efficient market hypothesis assumes that foreign exchange market participants are risk-neutral and their expectations are rational. When the risk-neutral efficient market hypothesis holds then the expected profits from holding one currency rather than another should be offset by interest rate differential. The uncovered interest-rate parity (UIP) represents the cornerstone parity condition for testing foreign exchange market efficiency. Assuming investors are risk-neutral, the UIP states that the interest rate differential is equal to the expected change in exchange rates:

$$E_t(s_{t+k}|\Omega_t) - s_t = i_t - i_t^*, \tag{1}$$

where $E_t(s_{t+k}|\Omega_t)$ = logarithm of expected spot exchange rate at time $t+k$, based on information known at time t,

   s_t = logarithm of spot exchange rate (quote currency units per unit of base currency),
   i_t = nominal interest rates of quote currency,
   i_t^* = nominal interest rates of base currency.

Equation (1) is not directly testable because market expectations of future spot exchange rates are hardly observable. Therefore, the UIP 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 is equal the expected spot exchange rate at time $t+k$ plus a white-noise error term which is uncorrelated with information available at time t.

$$s_{t+k} = E_t(s_{t+k}|\Omega_t) + \eta_{t+k}, \tag{2}$$

where $E_t(s_{t+k}|\Omega_t)$ = logarithm of expected spot exchange rate at time $t+k$, based on information known at time t,

   s_{t+k} = logarithm of spot exchange rate at time $t+k$,
   η_{t+k} = white-noise error term.

Thus assuming that market participants are endowed with rational expectations and risk-neutral, the UIP states that realized foreign exchange gain from holding one currency rather than another must be offset by interest rate differential. In this case, the uncovered interest-rate parity may be tested by computing the following regression:

$$s_{t+k} - s_t = \alpha + \beta(i_t - i_t^*) + \varepsilon_{t+k}, \qquad\qquad (3)$$

where s_t = logarithm of spot exchange rate at time t,

s_{t+k} = logarithm of spot exchange rate at time $t+k$,

i_t = nominal interest rates of quote currency,

i_t^* = nominal interest rates of base currency,

ε_{t+k} = disturbance term, uncorrelated with information available at time t.

Under the UIP parity condition, the slope parameter β in equation (3) should be equal to unity (β = 1) and the coefficient α should be equal zero (α = 0). In turn, assuming covered interest-rate parity (CIP) holds ($f_t^{(k)} - s_t = i_t - i_t^*$), the UIP can be expressed as follows:

$$E(s_{t+k}|\Omega_t) - s_t = f_t^{(k)} - s_t, \qquad\qquad (4)$$

where $E_t(s_{t+k}|\Omega_t)$ = logarithm of expected spot exchange rate at time $t+k$, based on information known at time t,

s_t = logarithm of spot exchange rate at time t,

$f_t^{(k)}$ = logarithm of the k-period forward exchange rate.

Equation (4) implies directly that the forward exchange rate is equal to the market expectations of the future spot exchange rate.

$$E(s_{t+k}|\Omega_t) = f_t^{(k)}, \qquad\qquad (5)$$

where $E_t(s_{t+k}|\Omega_t)$ = logarithm of expected spot exchange rate at time $t+k$, based on information known at time t,

$f_t^{(k)}$ = logarithm of the k-period forward exchange rate.

Thus, assuming that market participants are endowed with rational expectations, the UIP hypothesis may be tested by following equation.

$$s_{t+k} = \alpha + \beta f_t^{(k)} + \varepsilon_{t+k}, \qquad\qquad (6)$$

where s_{t+k} = logarithm of spot exchange rate at time $t+k$,

$f_t^{(k)}$ = logarithm of the k-period forward exchange rate,

ε_{t+k} = disturbance term, uncorrelated with information available at time t.

K-period forward exchange rate determined at time t is said to be an unbiased predictor of spot exchange rate at time $t+k$ when in equation (6) the coefficients α is equal zero and β is equal unity. However, there are strong evidence that both $f_t^{(k)}$ and s_{t+k} are generated by nonstationary time-series processes, so the equation (6) seems to be inappropriate for the standard linear regression procedure (ordinary least squares, OLS). Therefore, many researchers have tested UIP by using the equation (7). The subtracting s_t from the variables on both sides of equation (6) is ordinarily sufficient to generate stationary variables.

$$s_{t+k} - s_t = \alpha + \beta(f_t^{(k)} - s_t) + \varepsilon_{t+k}, \qquad\qquad (7)$$

where s_t = logarithm of spot exchange rate at time t,

s_{t+k} = logarithm of spot exchange rate at time $t+k$,

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$f_t^{(k)}$ = logarithm of the k-period forward exchange rate,

ε_{t+k} = disturbance term, uncorrelated with information available at time t.

If agent are endowed with rational expectations and risk-neutral, we should expect the slope parameter β to be equal to unity (β = 1) and the coefficient α to be equal zero (α = 0) (equation 7). It is emphasized by McCallum (1994) that although equations (6) and (7) are equivalent under the null hypothesis β = 1, they represent different classes of alternative hypotheses and they give extremely different empirical outcomes. His research results strongly favor the equation (7). Empirical studies based on the estimation of equations (3) and (7) generally rejects the UIP hypothesis. Furthermore, a well-known empirical regularity is that β is significantly less than one, and in fact very often closer to minus unity than plus unity (Froot and Thaler, 1990). Fama (1984), Froot and Frankel (1989), McCallum (1994), among others, have obtained the negative value of the slope coefficient in their calculations. According to Fama (1984), the negativity of the β parameter results from the risk premium required by risk-averse market participants. They demand a higher profit than the interest rate differential in the return for the risk of holding foreign currency. There are, however, the studies which are more favorable to the uncovered interest-rate parity. Alexius (2001) found that UIP may hold better for long interest rates than for short interest rates. The same results obtained Chinn and Meredith (2005). They have found that for long-horizon data, the estimated slope coefficients are generally positive and insignificantly different from the unity. Bansal and Dahlquist (2000) noticed that for emerging economies the slope coefficient β is positive. For developed countries, however, UIP occurred to be violated. They classified developed and emerging economies according to the International Finance Corporation of the World Bank. All exchange rates were denominated in U.S. dollar per unit of foreign currency. Lothian and Wu (2011) studied the validity of uncovered interest-rate parity by constructing ultra-long time series that span two centuries. Their results show that UIP may be violated during a particular short period, but it holds much better over the long period.

Foreign exchange rate market efficiency may be also tested by carrying out forward-rate forecast error orthogonality test. If market participants are risk neutral, their expectations are rational, cost of transactions are zero and the market is competitive, then the foreign exchange market is efficient in a sense that the expected rate to speculation in the forward exchange rate market is zero. With reference to equation (5) the approximate measure of the rate of return to speculation will equal the difference between spot exchange rate at time $t+k$ and k-period forward exchange rate determined at time t. These difference is also called the forward rate forecast error. Here, we verify market efficiency hypothesis by testing the orthogonality of the forward rate forecast error with respect to a given information set available at time t (Hansen and Hodrick, 1980).

$$s_{t+k} - f_t^{(k)} = \varphi X_t + \varepsilon_{t+k}, \qquad\qquad (8)$$

where $s_{t+k} - f_t^{(k)}$ = forward rate forecast error,

$X_t \subset \Omega_t$ = vector of variables selected from the information set available at time t

ε_{t+k} = disturbance term, uncorrelated with information available at time t.

A weak-form market efficiency test can be reduced to testing hypothesis that φ is equal zero in the regression (8), where X_t contains only the lagged forward rate forecast errors. We can test even a stronger form of market efficiency by adding additional information to the vector of variables X_t. The researches based on the equation (8) generally reject the market efficiency hypothesis. Hansen and Hodrick (1980) reject the null hypothesis that the forward rate forecast error is orthogonal to its lagged values for six out of the seven currencies examined in the 1970s

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and five out of six currencies examined using 1920s data. It means that they reject both the UIP and weak-form market efficiency hypotheses for analyzed currencies.

There are many other econometric methods for testing the simple efficient markets hypothesis like a bivariate vector autoregression model (VAR) comprising time series for spot and forward rates (Hakkio, 1981) or vector error correction model VECM in which the term structure of forward premia plays the part of the equilibrium errors (Clarida and Taylor, 1997). However, a vast majority of researchers report results which reject both UIP and simple efficient market hypothesis. It tends to suggest that there may be failures in the assumptions of rational expectations and of risk-neutrality (Sarno and Taylor, 2002, p. 5-50).

It is worth to emphasize that there are some researches who disagree with the statement that UIP is a cornerstone condition in testing foreign exchange market efficiency. According to Nguyen (2000) the UIP is a sufficient but not necessary condition for exchange rate market efficiency. Moreover, he claims that a departure from interest rate parity does not definitely imply foreign exchange market inefficiency, since there are existed in practice transaction costs and risk premium which should be taken into account. In turn, Olmo and Pilbeam (2011) note that foreign exchange market can be efficient in spite of the fact that conventional regressions rejects the uncovered interest-rate hypothesis. In their opinion UIP holding is neither a sufficient nor a necessary condition for foreign exchange market efficiency. They claim that the proper test of foreign exchange market efficiency should be based on the actual returns of various investment strategies that involve switching between the domestic and foreign currency. However, we need to bear in mind that the failure of UIP is widely interpreted as indicating the potential possibility for generating excess returns. Therefore, testing UIP hypothesis seems to be a proper way for testing the foreign exchange market efficiency.

Testing the USD/EUR market efficiency

As was mentioned before, the UIP is a cornerstone parity condition for testing foreign exchange market efficiency. The UIP hypothesis is tested for USD/EUR market. Quarterly and half-yearly exchange rates of U.S. dollar per euro from January 1999 to December 2010 are applied in the analysis. Spot, 3-month and 6-month forward closing interbank exchange rates come from the Thomson Reuters Datastream. The test of UIP is carried out by using equation (7). The table below presents the obtained results.

Table 1: OLS estimation results of equation $s_{t+k} - s_t = \alpha + \beta(f_t^{(k)} - s_t) + \varepsilon_{t+k}$
for k = 3,6 months

USD/EUR	quarterly data, k = 3		half-yearly data, k = 6	
	α	β	α	β
estimated coefficient	0,006	-2,445*	0,000	-2,177
t-ratio (p-value)	0,903 (0,37)	-1,896 (0,06)	0,006 (0,99)	-1,225 (0,23)
R²	0,04		0,032	
number of observations	47		23	
LM (p-value)	1,86 (0,14)		2,38 (0,12)	
LM-ARCH (p-value)	0,40 (0,98)		4,04 (0,13)	

Note: The t-statistic and p-value are constructed based on the hypothesis: α = 0 and β = 1;
*marginal significance level < 0,1.

Source: Own estimations on the basis of the data from Thomson Reuters Datastream

The results reported in Table 1 are in line with the findings from majority of previous published research. The slope coefficient is negative and for quarterly data statistically significantly different from unity. Statistically significant deviation from $\beta = 1$ null hypothesis is denoted by asterix (*). Furthermore, none of the intercept estimates for α are significantly different from zero. Both the ARCH effects and autocorrelation are not evidenced in the analyzed data.

The negativity of the slope coefficient and the rejection of the null hypothesis $\beta = 1$ is associated with the rejection of UIP hypothesis. Therefore, on the basis of the above results, we can conclude that the USD/EUR foreign exchange market is inefficient. We can draw such conclusions mainly on the basis of the quarterly data of exchange rates. The analysis of half-yearly data, however, does not provide such a clear conclusion.

In order to investigate the robustness of the results, we can divide the sample into subperiods. Flood and Rose (2002) found out that UIP works systematically better in the time of crisis. Thus, we split the sample and perform an analysis within two subperiods. The first subperiod embraces the time before financial crisis of 21st century (01.1999 – 08.2007). The second subperiod, in turn, includes the time of crisis (08.2007 - 12.2010). The analysis is carried out on the basis of the quarterly data. The results are shown in the Table 2.

Table 2: Subperiod OLS estimation results of equation $s_{t+k} - s_t = \alpha + \beta(f_t^{(k)} - s_t) + \varepsilon_{t+k}$
for k = 3 months, quarterly data

USD/EUR	I.1999 - II.2007		III.2007 - III.2010	
	α	β	α	β
estimated coefficient	0,0128*	-4,6536*	0,0119	15,0116
t-ratio	1,97	-3,61	0,73	1,82
(p-value)	(0,06)	(0,00)	(0,48)	(0,11)
R²	0,22		0,26	
number of observations	34		13	
LM (p-value)	0,49 (0,74)		2,95 (0,11)	
LM-ARCH (p-value)	3,5 (0,48)		4,25 (0,37)	

Note: The t-statistics and p-value are constructed based on the hypothesis: $\alpha = 0$ and $\beta = 1$; *marginal significance level < 0,1.

Source: Own estimations on the basis of the data from Thomson Reuters Datastream

The slope estimates for the subperiod regressions exhibit large fluctuations. In the first subperiod, the slope coefficient β is negative and statistically significantly different from unity. Moreover, the intercept estimate for α is significantly different from zero. Hence, we can infer that the UIP hypothesis is rejected for the data covering the period before financial crisis of 21st century. It means, that the USD/EUR exchange rate market was not efficient during this time. However, the regression slope estimates vary dramatically in two analyzed subperiods. For the second period, the coefficient β is positive and insignificantly different from unity. The intercept coefficient α is also insignificantly different from zero. Therefore, we can conclude that there are no foundations to reject the $\alpha = 0$ and $\beta = 1$ null hypotheses in the time of crisis. Above conclusions are in line with the results obtained by Flood and Rose (2002). We find that UIP works better on average in the time of crisis than in previous time in the sense that the slope coefficient from a regression is positive and insignificantly different from unity. However, we need to bear

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in mind that the second subperiod may be too short to provide robust results. There is a potential danger of drawing wrong conclusions based on a short sample.

Foreign exchange rate market efficiency may be also tested by carrying out orthogonality tests of the forward rate forecast error ($s_{t+k} - f_t^{(k)}$) with respect to a given information set available at time t (equation 8). In the paper the X_t vector of variables contains the lagged forward rate forecast error ($s_t - f_{t-k}^{(k)}$) and interest rate differential ($i_t - i_t^*$). Therefore, we test here the so-called semi-strong form of market efficiency, which assumes that the current price reflects all publicly available information (herein e.g. interest rate differential) and the historical prices. The analysis is based on quarterly data of spot and 3-month forward exchange rates plus 3-month USD Libor and 3-month EUR Libor interbank interest rates. Table 3 presents the results of a study.

Table 3: Orthogonality test of the forward rate forecast error. Results for equation
$$s_{t+k} - f_t^{(k)} = \varphi_1(s_t - f_{t-k}^{(k)}) + \varphi_2(i_t - i_t^*) + \varepsilon_{t+k} \text{, for k = 3 months, quarterly data}$$

	quarterly data, k=3	
	φ_1	φ_2
estimated coefficient	0,300*	-0,01
t-ratio	0,15	0,01
(p-value)	(0,049)	(0,43)
F-statistics	3,33	
(p-value)	(0,05)	
R²	0,12	
number of observations	46	
LM (p-value)	1,24 (0,31)	
LM-ARCH (p-value)	0,69 (0,95)	

Note: The F-statistics is constructed based on the hypothesis $\varphi_1 = \varphi_2 = 0$, the t-statistics is constructed based on the hypothesis: $\varphi_1 = 0$ and $\varphi_2 = 0$; *marginal significance level < 0,1.

Source: Own estimations on the basis of the data from Thomson Reuters Datastream

The results in the table above are constructed for the exchange rate USD/EUR, where EUR is a base currency and USD is a quote currency. Therefore, the interest rate differential is the difference between US interest rates (USD Libor) and European interest rates (EUR Libor). Since, we used the quarterly data of 3-month forward contracts, we can assume that data do not overlap. Thus, under the assumption of rational expectations, we could apply ordinary least squares (OLS) analysis in the orthogonality test. On the basis of the results presented in the table 3 we reject the null hypothesis that φ is equal zero in the equation (8) (H$_0$: $\varphi = 0$). Hence, we reject the null hypothesis that the forward forecast error is orthogonal to both its lagged value and the interest rate differential. It means that the semi-strong foreign exchange market efficiency hypothesis is rejected for the USD/EUR market. Consequently, we can conclude that the USD/EUR market is not efficient. The obtained results are in line with the outcomes of the conventional UIP regression approach for quarterly data and the pre-crisis subperiod analysis. However, the regression analysis in the time of crisis do not provide such conclusions. Thus, it is hard to say definitely that the USD/EUR market is inefficient. Moreover, as Sarno and Taylor (2002, p. 5-50) suggested, the rejection of foreign exchange market efficiency hypothesis may result from the wrong assumptions of rational expectations and of risk-neutrality. Now then, it is worth to take into consideration the re-examination of this traditional economic assumptions.

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Conclusions

The efficiency of financial markets is one of the most controversial issues in international finance. The preceding analysis can be summarized as follows:

1. The Uncovered Interest Rate Parity (UIP) represents the cornerstone parity condition for testing foreign exchange market efficiency. The results obtained for USD/EUR market imply the rejection of UIP hypothesis. The slope coefficient β is negative and additional for quarterly data statistically significantly different from unity. Therefore, on the basis of the conventional UIP regression analysis, we can conclude that the USD/EUR market is not efficient in a sense that its participants are not risk-neutral or/and their expectations are irrational.

2. On the basis of the subperiod analysis we can draw conclusions that UIP works systematically better in the time of crisis. The regression slope estimates vary dramatically in two analyzed subperiods. In the pre-crisis period, the slope coefficient β is negative and statistically significantly different from unity. In turn, during the time of crisis, the coefficient β is positive and insignificantly different from unity.

3. The semi-strong foreign exchange market efficiency hypothesis is rejected for the USD/EUR market. On the basis of orthogonality tests of the forward rate forecast error, the null hypothesis that the forward forecast error is orthogonal to both its lagged value and the interest rate differential have been rejected.

4. One of the interesting findings is that the rejection of foreign exchange market efficiency hypothesis may result from the wrong assumptions that market participants are risk-neutral and that their expectations are rational. Thus, the re-examination of this fundamental economic assumptions should be taken into account in further research concerning foreign exchange market efficiency.

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