

COVERED INTEREST RATE PARITY

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Abstract

The idea of covered interest rate parity (CIP) states that simultaneous purchase and sale of two currencies should not result in profit. This parity condition is examined using error correction model (ECM), descriptive analysis of profitable deviations and impulse response functions from the vector error correction model (VECM). This study on average finds support for the parity condition. However, there is also evidence for some rare but large deviations. Majority of the profitable deviations are small in size. Results for persistence of the profitable deviations are mixed. These results suggests that there is not sufficient evidence for either accepting or rejecting the CIP and efficiency of the market. Thus, this paper is inconclusive regarding the validity of CIP and efficiency of the market.

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1 Introduction

Covered interest rate parity (CIP) states that borrowing funds in one currency, converting these funds in the spot market for a foreign currency, lending the foreign currency, selling it forward at the original time in the open market should not yield positive profit.

This is an important topic because foreign exchange market is central in understanding financial markets, international trade and transactions. This topic is also important in understanding the monetary and fiscal policy. The foreign exchange market has also great implication for monetary - and fiscal policy. The foreign exchange market is the world largest and most liquid financial market. It is a place where a country's imports and exports are priced. A violation of the parity condition here would imply no or weakly efficiency form of the market.

Previous studies have found mixed results regarding the parity condition. Studies that support or partially support the parity are Cosandier and Lang (1981), Skinner and Mason (2011), Taylor (1987, 1989) and Kia (1996). While studies that do not support the idea of parity condition are Stein (1965), Crowder (1995), Wohar and Balke (1998) and Batten (2006, 2011). Studies that have also rationalized on the deviation from parity are Frenkel and Levich (1975, 1977), Deardorf (1979), Callier (1981), Oskooee and Das (1985), Aliber (1973), Stoll (1972), Popper (1993) and Stroble (2011). These studies are more elaborately discussed in the next section.

This article focuses on the three aspects of the CIP condition. First, to assess the average validity of the parity, an error correction model (ECM) is employed. Second, the descriptive nature of the profitable deviations is studied. Finally, profitable deviations (net of transaction costs) are reconciled with market efficiency using impulse response functions from vector error correction model (VECM). To the authors knowledge no previous studies has focused on these three aspects collectively. Furthermore, the data series used here are actually provided by an currency broker, this is also something new.

The remaining outline of the paper is as follows: in section 2 previous studies are briefly discussed. Section 3 and 4 addresses data and statistical method employed, respectively. And section 6 and 7 contains empirical results and conclusion, respectively.

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2 Literature Review

Previous studies can roughly be categorized in three groups. The first group supports or partially supports the idea of CIP. Second group, does not support validity of the CIP. And finally, studies that have rationalized on reasons for deviations from parity. These reasons are the real world frictions such as transaction costs, credit risk, political risk, asset substituteability, capital mobility etc. In short, previous studies have arrived at mixed conclusions regarding the validity of the CIP condition. Nevertheless, there is also little consensus why deviations from parity occur.

Cosandier and Lang (1981) using monthly data find support for euro-pairs, but not for Swiss-pairs. They rationalized on political risk and asset's limited substituteability as causes of deviation from parity condition. Aliber (1973) using weekly data for dollar-pound and dollar-franc interest rates rationalized on the political risk as the source of the deviations from the parity condition. Skinner and Mason using 3 and 5 years data frequency finds support parity for AAA rated economies (Norway and UK) but there is no support for parity for the economies rated less than AAA. Thus, credit risk is the source of the deviations from parity. Also, Hans Stoll 1972 rationalized on risk and return (asset substitute-ability) as the reasons for deviations. However, later work of Crowder (1995) argues that use Euro-currency deposits eliminates the barriers of capital control and political risk. Also, Wohar and Balke (1998) argues that the use of credit risk and political risk since they are offshore securities. Popper (1993), concludes that the capital among euro nations are equally mobile both in the short- and long-run. Thus, these rationales do not carry much support.

Taylor (1987) finds support for the parity (only 3 days of observations) and rationalized on the accuracy and timing of the data series. Data series have 10 minutes frequency over three trading days. Period length is very short with respect to norms of academic research and the author acknowledges this. Taylor argues that the previous studies used data that have not been contemporaneously sampled, and do not therefore represent proper test for CIP condition (those prices did not appeared in the market simultaneously). Taylor (1989) finds support for parity in calm periods (similar to Taylor 1987) and there is evidence for substantial deviations in the turbulent periods¹. Arbitrage opportunities tend to increase in turbulent periods. Thus, volatility perhaps is the reasons for deviations.

¹The 1967 devaluation, 13-24 November 1967. The 1972 flotation of sterling, 19-30 June 1972. The inception of European Monetary System, 15-16 March. The 1979 UK General Election, 30 April to 11 May 1979. The 1984 US Presidential Election, 5-16 November 1984. The 1987 UK General Election, 1-19 June 1987. Otherwise period is considered to be calm - or normal period.

Kia (1996) using daily rates finds support for US dollar and Canadian dollar. It is also concluded that the arbitrage favors those with ability to borrow US dollar. Furthermore, application of mid market rates overestimate deviations from parity.

Stein (1965) using daily, weekly and monthly averages for Sterling, US dollar and Canadian dollar (all indirect quotes ²), do not find support for parity for direct and indirect pairs between US, UK and Canada. The author uses linear regression from OLS for validation of the parity condition. Engel and Granger (1987) showed that application of linear regression (OLS) on co-integrated data series yields spurious regression. As a result conclusion from such methods perhaps may not be valid. This is major drawback for this particular article.

Crowder (1995) concludes that the profitable deviations persist longer than what could be expected from an efficient market. This is true for UK, Germany, Japan and Canada. Daily rates are employed, since the persistence of the deviations is several days, it can be said that the market is "weak form efficiency"³. Also, Wohar and Balke (1998) using daily data finds evidence for substantial deviations from parity. However, the article concludes that the deviations outside transaction bands are less persistent than inside the transaction band.

Batten (2006) using daily data also finds considerable violations of CIP using mid market rates, but calm period after 2000. However, Kia (1995) showed that the use of mid-market rate will overstate deviations from parity. Thus, results perhaps can be both valid and consistent but not practically correct. That is percentage deviations will be overestimated, regardless of how much.

Batten (2011) using daily data finds that deviations occurs but favors those with ability to borrow us dollar. This result is consistent with Kia 1995. However, troubling since Popper (1993), concludes that the capital among euro nations are equally mobile both in the short- and long-run. Thus, it is reasonable to assume that capital is also mobile between US, Canada and Japan because of their bilateral and trilateral trade and lately a greater integration of financial - and capital markets.

Frenkel and Levich (1975, 1977) focus on transaction costs and define the so-called neutral zone band (between transaction band). They find support for deviations outside the neutral zone. Later work of Deardorff (1979), Callier (1981), and Bahmani-Oskooee and Das (1985) reported that the size of the transaction costs was overstated by Frenkel and Levich.

²direct quotes are foreign currency per US dollar and indirect quotes are US dollar per foreign currency.

³Crowder 1995:17

3 Theory

Parity conditions are widely used by economists and academics to explain short and long-term movements in the foreign exchange market. If currencies are allowed to freely float against each other and there are no constraints on capital mobility the expected change in spot exchange rate, interest rate, inflation differential, and the forward premium or discount are proportionally related to each other and mutually determined. Therefore if one variable changes it will normally change all other variables with a feedback on the variable that changes first (Eiteman, Stonehill and Moffet 2010: 183).

CIP relates percentages difference in forward rate premium / discount to interest rate differential between two countries. It can be stated as:

$$S(1 + i^{\$}) = F(1 + i^f) \quad (1)$$

Where S is the spot exchange rate, $i^{\$}$ and i^f is the US and euro (or foreign) interest rates, respectively. F is the forward rate for period N , today. Some additional rearrangements imply the following relationship between forward rate premium / discount and interest rate differential:

$$\frac{F}{S} = \frac{(1 + i^f)^T}{(1 + i^{\$})^T}$$

All terms are the same as in the equation above (1). If the euro is expected to appreciate against US dollar in the future, than the forward rate will be at premium. While if it is expected to depreciate against dollar in the future, then the forward rate will be at discount.

CIP without transaction costs is described by the equation above. The left hand side of the equation is the forward premium (FP) or forward discount, and the right hand-side is the nominal interest rate differential (ID). In the case of transaction costs, a pair of conditions replace the equality in the equation. In the case of where an arbitrageur borrow one currency and lend the other, the trader does not put any money of his / her own. In that the case for an American trader the no arbitrage condition or equation (1) becomes:

$$(1 + r_{\$}^A)^T \geq \frac{S^A}{F^B} (1 + r_f^B)^T \quad (2)$$

where S^A is the spot ask rate, F^B is the forward bid rate, $i_{\A is the US dollar deposit ask rate, and i_f^B is the foreign currency deposit bid rate. While equation (1) must hold for an American trader, a similar condition can be specified for a foreign trader:

$$(1 + r_f^A)^T \geq \frac{S^A}{F^B} (1 + r_{\$}^B)^T \quad (3)$$

Putting these two condition together gives:

$$\frac{S^A (1 + r_f^B)^T}{F^B (1 + r_s^B)^T} \leq 1 \leq \frac{S^B (1 + r_f^A)^T}{F^A (1 + r_s^A)^T}$$

Some additional algebra implies:

$$\begin{aligned} \left[\frac{S^B F^B (1 + r_f^A)^T (1 + r_s^A)^T}{S^A F^A (1 + r_f^B)^T (1 + r_s^B)^T} \right]^{-\frac{1}{2}} &\leq \left[\frac{F^B F^A (1 + r_s^B)^T (1 + r_s^A)^T}{S^B S^A (1 + r_f^B)^T (1 + r_f^A)^T} \right]^{\frac{1}{2}} \\ &\leq \left[\frac{S^B F^B (1 + r_f^A)^T (1 + r_s^A)^T}{S^A F^A (1 + r_f^B)^T (1 + r_s^B)^T} \right]^{\frac{1}{2}} \end{aligned} \quad (4)$$

The middle term in (4) is the covered interest rate parity based on geometric average of the bid/ask prices. While the remaining terms are geometric average of the bid/ask prices and their reciprocals. If the left hand-side of the equation (4) is violated (below the lower band) this implies violation of the equation (1) and it is profitable to borrow dollar and lend foreign currency (euro, yen etc.). If the right hand-side of the equation is violated (above the upper bands), equation (2) is violated and it pays of to borrow foreign currency and lend dollar at the existing bid/ask spread. Applying natural logarithm to equation (4) gives:

$$\Pi^l \leq cip \leq \Pi^u \quad (5)$$

where

$$\begin{aligned} \Pi^l &= -1/2 \ln \left[\frac{S^B F^B (1 + r_f^A)^T (1 + r_s^A)^T}{S^A F^A (1 + r_f^B)^T (1 + r_s^B)^T} \right] \\ cip &= 1/2 \ln \left[\frac{F^B F^A (1 + r_s^B)^T (1 + r_s^A)^T}{S^B S^A (1 + r_f^B)^T (1 + r_f^A)^T} \right] \\ \Pi^u &= 1/2 \ln \left[\frac{S^B F^B (1 + r_f^A)^T (1 + r_s^A)^T}{S^A F^A (1 + r_f^B)^T (1 + r_s^B)^T} \right] \end{aligned}$$

The term *cip* is approximately the percentage deviation from the parity condition based on geometric average of bid/ask prices. The transactions cost band are given by Π^l and Π^u . Note that the arbitrage deviations from CIP fluctuate in a region symmetric around zero (because both traders are assumed to not possess private capital). And this region is solely determined by the bid/ask spread or transaction costs.

4 Data

The choice of the data series is one of the most critical aspects of the empirical research, because attributes (transaction costs, source, length etc.) of the underlying

data series do have an impact on results of analysis. Thus, can seriously affect the conclusion drawn from the study. Especially, the time length of data series is a very debated issue in applied statistics. Previous studies differ substantially from each other in terms of length -, frequency - and source of the data series.

Empirical problem under study requires data series on four variables. That is, spot exchange rate, forward rate, and domestic - and foreign interest rate. Thus, for one currency pair, data on four variables is necessary to test the hypothesis of CIP. This study focuses on euro-dollar and aussie-dollar (EURUSD and AUDUSD).

For each currency pair, transaction costs (ask - and bid rates) are also included. That is, 2 series on spot exchange rate, 2 series on forward rate, 2 series on domestic interest rate and 2 series in foreign interest rate. This is 8 data series for each currency pair and 16 data series in total.

The data series employed have daily frequency and starts on June 7, 2006 and ends March 21, 2014. That gives 2033 observations on 16 data series. The data series are obtained from Thomson Reuters Datastream and provided by Tullet Prebon⁴.

Most part of the research and analysis is performed using statistical software R. However, Microsoft Excel is also used to make some minor data preparations. This includes naming columns and converting the data format such that it compatible with R software.

4.1 Data Diagnostics

It is commonly known that time series data typically are non-stationary. A stationary or weak stationary process can be defined as a stochastic process with constant mean, variance and covariance structure. It is important that these conditions are satisfied in order to make statistical inference about the analysis conducted on theses data series. Furthermore, properties of the data series are also important in choice of an appropriate statistical method.

It is shown that (Engel and Granger, 1987) a linear regression from OLS on non-stationary variable(s) will yield spurious regressions. That is inflated t -values, low standard errors of the parameter estimated and high values of model fit. As a result conclusion based on such analysis may not statistically be valid.

⁴Thomson Reuters Datastream collects data from many sources. However, Tullet Prebon is the only source which is a broker itself. Therefore, data from this source is assumed to be closest to tradeable data. However, it is no way to confirm whether it was actually market clearing quotes/data.

4.1.1 Stationarity and Integration

There are several popular statistical tests to assess stationarity of data series. Here the Augmented Dicky Fuller (ADF) test for unit root is applied. This test can be applied particularly when the u_t is autocorrelated. Using p-lags of the dependent variable the model can be stated as:

$$\Delta y_t = \psi y_{t-1} + \sum_{i=1}^p \alpha_i \Delta y_{t-i} + u_t \quad (6)$$

Here ψ is expected to be 0. The null hypothesis is; series contains a unit root vs. series is stationary. The test statistics is calculated as:

$$test\ statistics = \frac{\hat{\psi}}{\hat{SE}(\hat{\psi})}$$

ADF "soak up" the dynamic structure in y_t , to ensure that u_t is not autocorrelated. The test is still applied on ψ , using the same critical values for DF table as used before. The test statistics do not follow a usual a t -distribution. Instead DF critical values are used. The lag length, p , can be either determined using frequency of the data or an information criterion. Here only significant lags were taken. If the test statistics is more negative than the critical value, the unit root hypothesis is rejected and it is concluded that the series is stationary (Brooks 2010:329).

If a variable become stationary with difference, d , then the variable is said to be difference stationary (DS) or integrated of order d . ADF test is applied the same way as before. The only difference is that variables are first differentiated once and then the test is applied. Conclusions are also made the same way as before. In our case all variables became stationary with first difference, i.e. integrated of order (I).

Table 1 and 2 presents results for aussie-dollar and euro-dollar. The conclusion is that all variables are integrated of order (I).

4.1.2 Cointegration

A set of variables is defined as cointegrated if a linear combination of non-stationary variables is stationary. Many time series are non-stationary but <<move together>> over time, that is, there exist some influence on the series (for example, market force), which imply that the two series are bound by some relationship in the long run (Brooks 2008:336).

The OLS residual-based approach is applied here to test the cointegrating regression, even though several other approaches are available, including DW test statistic, PP approach or CRDW framework. The test for cointegration is performed by first

Table 1: Augmented Dicky Fuller test for the AUDUSD pair

Variable	Deterministic terms	Lags	Test value	Critical value		
				1%	5%	10%
spot bid	constant, trend	3	-1.80	-3.96	-3.41	-3.12
Δ spot bid		0	-37.20	-2.58	-1.95	-1.62
spot ask	constant, trend	3	-1.80	-3.96	-3.41	-3.12
Δ spot ask		0	-37.24	-2.58	-1.95	-1.62
forward bid	constant, trend	3	-1.80	-3.96	-3.41	-3.12
Δ forward bid		0	-37.20	-2.58	-1.95	-1.62
forward ask	constant, trend	3	-1.80	-3.96	-3.41	-3.12
Δ forward ask		0	-37.24	-2.58	-1.95	-1.62
$i_{\$}$	constant, trend	6	-1.36	-3.96	-3.41	-3.12
$\Delta i_{\$}$		0	-41.07	-2.58	-1.95	-1.62
i_{aud}	constant, trend	12	-2.30	-3.96	-3.41	-3.12
Δi_{aud}		0	-47.69	-2.58	-1.95	-1.62

Table 2: Augmented Dicky Fuller test for the data EURUSD pair

Variable	Deterministic terms	Lags	Test value	Critical value		
				1%	5%	10%
spot bid	constant, trend	2	-2.81	-3.96	-3.41	-3.12
Δ spot bid		0	-39.15	-2.58	-1.95	-1.62
spot ask	constant, trend	2	-2.81	-3.96	-3.41	-3.12
Δ spot ask		0	-37.14	-2.58	-1.95	-1.62
forward bid	constant, trend	2	-2.99	-3.96	-3.41	-3.12
Δ forward bid		0	-42.23	-2.58	-1.95	-1.62
forward ask	constant, trend	2	-2.99	-3.96	-3.41	-3.12
Δ forward ask		0	-42.23	-2.58	-1.95	-1.62
$i_{\$}$	constant, trend	6	-1.36	-3.96	-3.41	-3.12
$\Delta i_{\$}$		0	-41.07	-2.58	-1.95	-1.62
i_{eur}	constant, trend	8	-1.29	-3.96	-3.41	-3.12
Δi_{eur}		0	-39.04	-2.58	-1.95	-1.62

estimating the cointegrating variables using OLS and obtain residuals. Econometrically, estimate first a linear model of the form:

$$y_t = \beta_1 + \beta_2 x_{2t} + \beta_3 x_{3t} + \dots + \beta_k x_{kt} + u_t \quad (7)$$

Obtain the residuals from the model and perform an ADF test

$$\Delta \hat{u}_t = \hat{u}_{t-1} + v_t \quad (8)$$

where v_t is iid error term. The hypothesis on the cointegrating regression takes the form: $H_0 : \hat{u}_t I(1)$ vs. $H_A : \hat{u}_t I(0)$. If the null is rejected then it is concluded that a stationary combination of the non-stationary variables has been found. Therefore the variables will be classified as cointegrated. Critical values are now modified values of DF, since the test is performed in residuals of a model. It is now appropriate

to apply an error correction model. In our case we solve equation (1) with respect to F^A and obtain

$$F^B \geq S^A \frac{(1 + r_f^B)^T}{(1 + r_s^A)^T} \quad (9)$$

Replacing the term on the right-hand side with $\overline{S^A}$ and taking natural logarithms yields, $\ln(F^B) \geq \ln(\overline{S^A})$. Finally putting in linear regression term:

$$\ln(F_t^B) \geq c + \beta 1 \ln(\overline{S^A}_{1t}) + u_t \quad (10)$$

Note that the right hand-side of the inequality implies that if $\ln(\overline{S^A})$ is greater than 1, covered interest rate parity on average (in- and outside the transaction band) does not hold. Therefore, $\ln(\overline{S^A})$ is expected to be equal to or less than 1. This condition will be tested using an error correction model in <<Empirical Results>> section. Table 3 presents test results for aussie-dollar and euro-dollar pairs. It

Table 3: Conintegration test for AUDUSD - EURUSD pair

Variable	Deterministic terms	Lags	Test value	Critical value		
				1%	5%	10%
Δu_t^{aud}	constant, trend	1	-14.65	-3.96	-3.41	-3.12
Δu_t^{eur}	constant, trend	0	-45.19	-3.96	-3.41	-3.12

must be concluded that the variables are cointegrated. This is an expected result since the theoretical framework for CIP requires a long-run relationship between exchange rate and forward rate. In short, the relationship between exchange rates and forward rates converge to its long-run equilibrium. The appropriate application of an econometric model in this case is an error correction model.

5 Method

The linear relationship between spot and forward exchange rates should not be analyzed using standard OLS, even though it has been the case in some previous studies. When OLS is applied on non-stationary variables the parameter estimates will be consistent but biased. Standard error of the parameters will be very low yielding to high values for t statistics and R square. As a result, valid conclusions cannot be drawn from those results (Engel and Granger 1987). This has also been documented by Jansen (2009).

Fortunately, the error correction model or equilibrium correction model (Engel and Granger 1987) can overcome this problem using combinations of first differenced and lagged level of co-integrated variables. The model can be stated as:

$$\Delta y_t = \alpha + \beta_1 \Delta x_t + \beta_2 (y_{t-1} - \gamma x_{t-1}) + u_t \quad (11)$$

The term $y_{t-1} - \gamma x_{t-1}$ on the right hand side of the equation (11) is known as the error correction term. If y_t and x_t are cointegrated with coefficient γ , then $y_{t-1} - \gamma x_{t-1}$ will be $I(0)$, even though the y_t and x_t are $I(1)$. It is now possible to use OLS and the standard procedure for statistical inference. An intercept is introduced in the model, α , and this is based on the theoretical requirements which is expected to be 0.

The dependent variable in (11) is expected to change between $t - 1$ and t , as a result of changes in the values of the independent variable, x , between $t - 1$ and t , and it also partially expected to correct any disequilibrium that existed during the previous period. The lagged value of the error correction term, $y_{t-1} - \gamma x_{t-1}$, reflect the changes in y between $t - 1$ and t in response to a disequilibrium between time $t - 1$ and t . The short-run relationship between y and x is captured by the coefficient β_1 , while the γ captures the long-run relationship. The coefficient β_2 captures the last period's equilibrium that is corrected in the current period. It can also be interpreted as the speed of adjustment in (y and x) back to equilibrium (Brooks 2008:338).

5.1 Parameter estimation in ECM

ECM is performed using residuals from the OLS regression. Equation (12) illustrates this:

$$\Delta y_t = \alpha + \beta_1 \Delta x_t + \beta_2 (\hat{u}_{t-1}) + v_t \quad (12)$$

where $\hat{u}_{t-1} = y_{t-1} - \hat{\tau} x_{t-1}$. The linear combination of the non-stationary variables that makes the equation stationary is known as the co-integrating vector. In this case it would be $[1 - \hat{\tau}]$. It is now valid to perform inference concerning the parameters β_1 and β_2 .

The equation for ECM estimation can be stated using the equation (6) in the first difference and in regression form or ECM form:

$$\Delta \ln(F_t^B) \geq c + \beta_1 \Delta \ln(\overline{S^A}_{1t}) + \beta_2 (\hat{u}_{t-1}) + v_t \quad (13)$$

5.2 The Case for ECM

There are several reasons to prefer ECM among other relevant models. First, the theoretical foundation of the problem under study requires a long-run relationship. That is, a long-term relationship between the spot - and the forward market. Secondly, the non-stationary feature of the time series data requires a method of parameter estimation that takes this aspect into account. Finally, the ECM is much

simpler to estimate and easier to interpret compared to a variety of competing models.

The three most prominent critiques of the Engel-Granger 2-step method (ECM) is as follows; first, it has a limited power in unit root and co-integration test. Secondly, the simultaneous equation bias if the causality between y and x runs in both directions. Finally, it is not possible to perform hypothesis test about the actual co-integrating relationship estimated at stage 1.

The first point is not an issue since the underlying sample is large, both in terms of observations (2033) and the length of the time period (roughly 8 years). Second, simultaneous equation bias is also not a concern. The theoretical framework requires that spot market together with money market (interest rates) determine the forward market. The other way around would for example imply that the forward market causes the money market, which is not likely since interest rates are exogenous, determined by the central banks. Finally, since we have only two variables that mean only one co-integrating relationship. In this case hypothesis on co-integrating relationship is not a problem, which could be if there was more than two variables in the model.

6 Empirical results

Results are divided in three parts. First sections contains results for ECM, where <<on average>> validity of the parity conditions is tested. In sections two, descriptive nature of the profitable deviations are studied. The third section, impulse response functions, contains results for persistence of the profitable deviations.

6.1 Error correction model

Table 4 contains results from ECM estimation for the both currency pairs. Panel A contains results for the aussie-dollar while panel B contains results euro-dollar.

For aussie-dollar the intercept is very small and not statistically different from zero. β_1 is equal to 1.001 with correct sign (positive) and is statistically significant. Since both the dependent and independent variable is presented in natural logarithms, the value of the coefficients must be interpreted as percentages⁵. Thus, 1 percent change in the spot rate is associated with 1.001 percent change in the forward rate, all else equal. The error correction term, \hat{u}_{t-1} , is -0.4269 with correct sign (negative) and is statistically significant. Error correction term implies that

⁵ β 's are the elasticity of the dependent variable, Y , wrt. independent variables, X 's

Table 4: Estimates from Error Correction Model for AUDUSD - EURUSD pair

Panel A: AUDUSD					
Coefficients	Estimate	Std. error	<i>t</i> -value	Adj. <i>R</i> ²	N
				0.9994	2033
Intercept	-2.245e-07	7.273e-06	-0.031		
$\Delta \ln(\overline{S^A}_{1t})$	1.001	5.564e-04	1799.713***		
\hat{u}_{t-1}	-0.4269	1.816e-02	-23.501***		
Panel B: EURUSD					
Coefficients	Estimate	Std. error	<i>t</i> -value	Adj. <i>R</i> ²	N
				0.8225	2033
Intercept	8.407e-06	8.991e-05	0.094		
$\Delta \ln(\overline{S^A}_{1t})$	0.7697	9.344e-03	82.376***		
\hat{u}_{t-1}	-0.9980	1.951e-02	-51.144***		

about 43 percent of disequilibrium from previous day is corrected by the following day, all else equal.

A *t*-test⁶ on the size of the coefficients in the regression reveals that both β_1 and β_2 are individually equal to or less than 1. The *t*-statistics for β_1 and β_2 are 1.80⁷ and -78.57⁸, respectively. None of the *t*-statistics exceeds the critical value of 1.96. A combined *t*-test on $\beta_1 + \beta_2$ yields a *t*-statistics of -22.76⁹ which is not greater than the critical value of 1.96. Thus, the null that the right hand-side of the model is equal to or less than 1 cannot be rejected at 95 (or 99) confidence level. The conclusion is that on average the covered interest rate parity condition holds for the aussie-dollar.

For euro-dollar the intercept is small and not statistically significant. Both slope coefficients, β_1 and β_2 , have the correct sign, positive and negative, respectively. The value for β_1 is 0.7697 and β_2 is -0.9980, and both coefficients are significant. Also here, both dependent and independent variables are presented with natural logarithms. Therefore the values for coefficients will be interpreted as percentages. Thus, 1 percentage change in the spot rate is associated with 0.7697 percent change in the forward rate, all else equal. Error correction term, \hat{u}_{t-1} , implies that 99.80 percent of the disequilibrium from previous day is corrected today. That is a very high rate of correction to equilibrium.

⁶Residuals for both pairs are not normally distributed. Histograms and normal probability plots revealed a few outliers. However, a further inspection wrt. leverage points revealed that outliers are not influential points. Thus, considering a large sample size, a slight deviation from normality is not assumed to be a serious problem.

⁷ $(1.001-1)/0.0005564 = 1.80$

⁸ $(-0.4269-1)/0.01816 = -78.57$

⁹ $(1.001-0.4269-1)/(0.0005564+0.01816) = -22.76$

A t -test on the slope coefficients in the model reveals that both β_1 and β_2 , are not individually significantly greater than 1. The t -statistics for β_1 and β_2 are -24.65¹⁰ and -102.40¹¹, respectively. None of the t -statistics exceeds the critical value of 1.96. A combined t -test on $\beta_1 + \beta_2$ yields the t -statistic of -42.7¹², which is obviously not greater than the critical value of 1.96. Also for this pair, the null that the right-hand side of equation is less or equal to 1, cannot be rejected. The conclusion is that on average covered interest rate parity holds for the euro-dollar pair.

6.2 Descriptive analysis of profitable deviations

Figures 1 and 2 show the natural logarithms of forward premium at geometric averages for bid - and ask spread, natural logarithms of the interest rate differential, also calculated at geometric averages for both currency pairs. CIP and profitable deviations from CIP for both currency pairs calculated at geometric average.

For aussie-dollar (Figure 1) the forward premium and deviation from covered interest rate parity are quite stable over time. While the interest rate differential even though small in size, fluctuate relatively more. The last plot in Figure 1, <<Profitable deviations from CIP>> shows deviations net of transactions costs (from equation 5). The largest three spikes (deviations) occurred before 2008. Otherwise, the deviations are quite small but have a tendency to be below zero. It is also obvious from the plot some moderate concentration of deviations during a few months after 2008 (perhaps due to financial turmoil). It is interesting that from the first quarter of 2009 to 2011 and after first quarter of 2013 there is not a single deviation net of transaction costs.

Figure 2 shows results for euro-dollar¹³. Also for this pair forward premium and CIP is quite stable over time. Pattern of euro-dollar interest rate differential closely resembles interest rate differential for aussie-dollar, but is much smaller in size. The last plot in figure 2 <<Profitable deviations from CIP >> shows deviations from CIP net of transactions costs (also from equation 5). Also for this pair the three largest spikes occurred before 2008 and one in late 2009. Otherwise the deviations are quite small in size, but have a tendency to be more above zero than below zero. It is noticeable the deviations before 2008 are predominately above zero. While after 2008 they are predominately below zero. However, there is not a single profitable deviation after the second quarter of 2009.

¹⁰ $(0.7697-1)/0.009344 = -24.65$

¹¹ $(-0.9980-1)/0.01951 = -102.40$

¹² $(0.7697-0.998-1)/(0.009344+0.01951) = -42.7$

¹³Note that because of readability the scale of the figure is set to 0.002. Therefore some spikes are beyond the upper frame of the figure.

Figure 1: AUDUSD

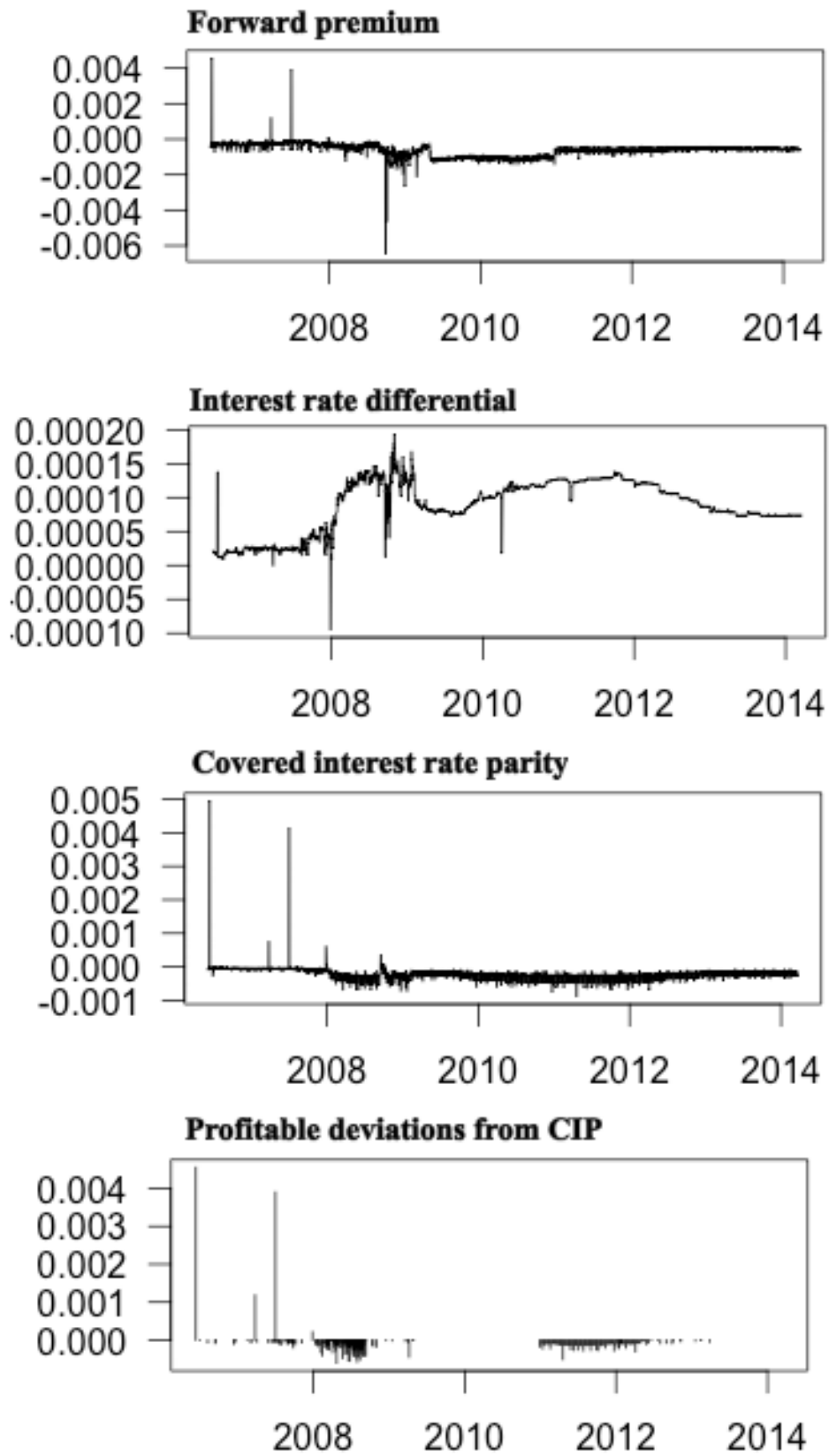


Figure 2: EURUSD

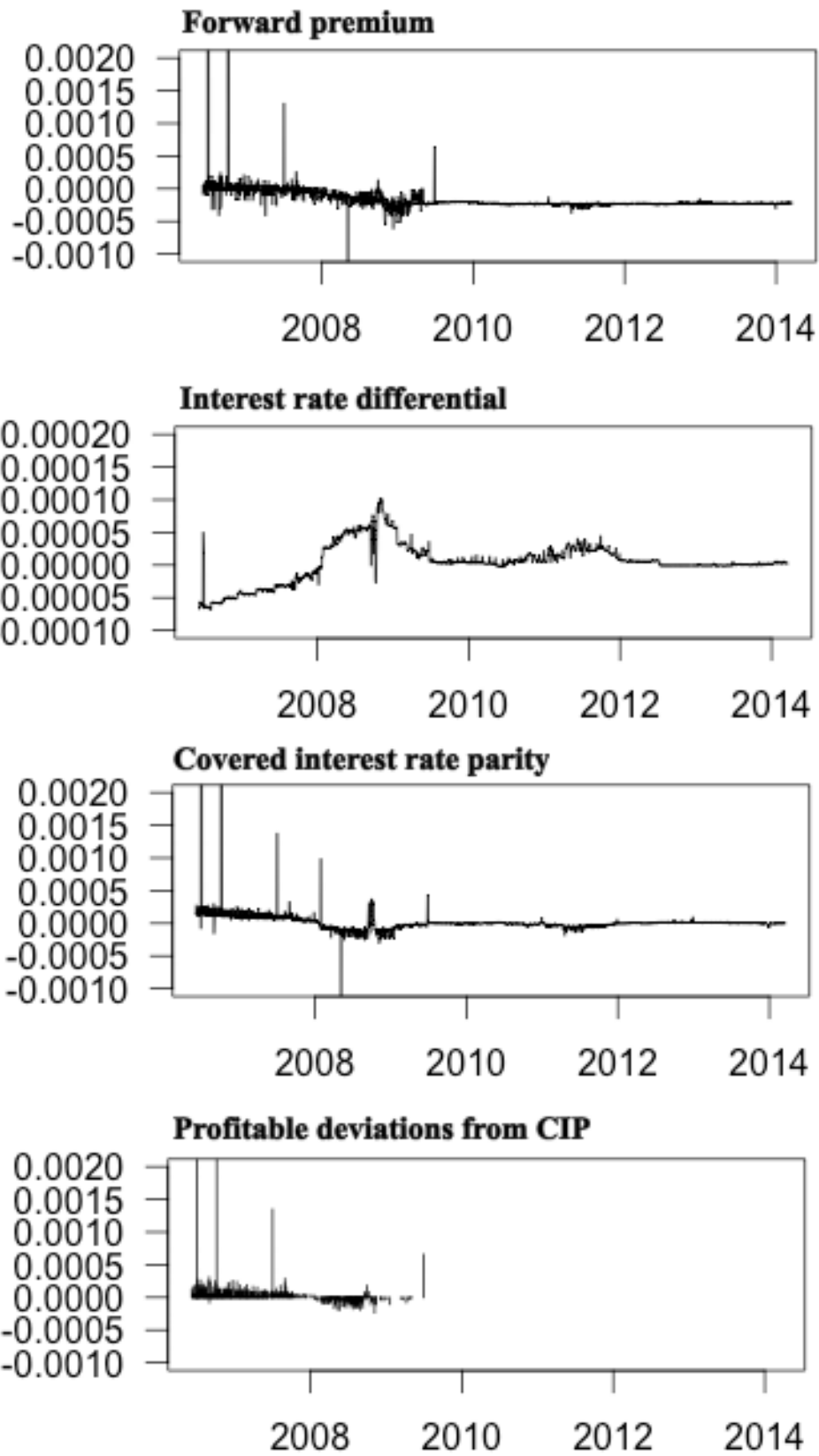


Table 5 presents the number of observations exceeding upper and lower transaction band for both pairs. For aussie-dollar 4 observations exceeds the upper-band and 250 observations exceeds the lower-band. This gives a total fraction of deviations exceeding the transactions band of 14.6 percent. The euro-dollar exceeds upper-band 292 times while the lower band is violated 136 times. This gives a total fraction of observations violating the transactions costs band of 19 percent. These deviations must be considered as substantial. The larger percentage deviations for euro-dollar perhaps are due to a greater integration of the Europe's financial markets to US financial market compared to Australian financial market to US market. Therefore financial crisis in the US are more likely to impact these two markets disproportionately.

Table 5: Deviations from covered interest rate parity

	AUDUSD	EURUSD
Deviations above up-band	4 (0.2)	292 (12.3)
Deviations below low-band	250 (14.4)	136 (6.7)
Sample size	2033	2033

Number in parenthesis are percentages

Table 6 presents mean, median and standard deviation for the upper-band, CIP and lower-band for both pairs. For Aussie-dollar the median and mean for CIP is statistically different from zero¹⁴. That means that despite of symmetric transaction costs the CIP for aussie-dollar deviated in negative direction. However, the median for transaction costs is 0.04 percent, which is smaller than what is reported by Wohar and Balke (0.08). Since, median of CIP is much smaller then median of the

Table 6: Medians, Means and standard deviations

	AUDUSD			EURUSD		
	median	μ	σ	median	μ	σ
Π^u	0.000389	0.000482	0.000322	0.000212	0.000175	0.000093
CIP_i	-0.000196	-0.000201	0.000200	-0.0000002	0.000110	0.004605
Π^l	-0.000389	-0.000482	0.000322	-0.000212	-0.000175	-0.000093

transaction band, it can be concluded that one could not on average make profitable arbitrage by randomly engaging in trading aussie-dollar.

Table 6, column 5, 6 and 7 presents results for the euro-dollar. For this pair the median and the mean is not significantly different from zero¹⁵. This implies

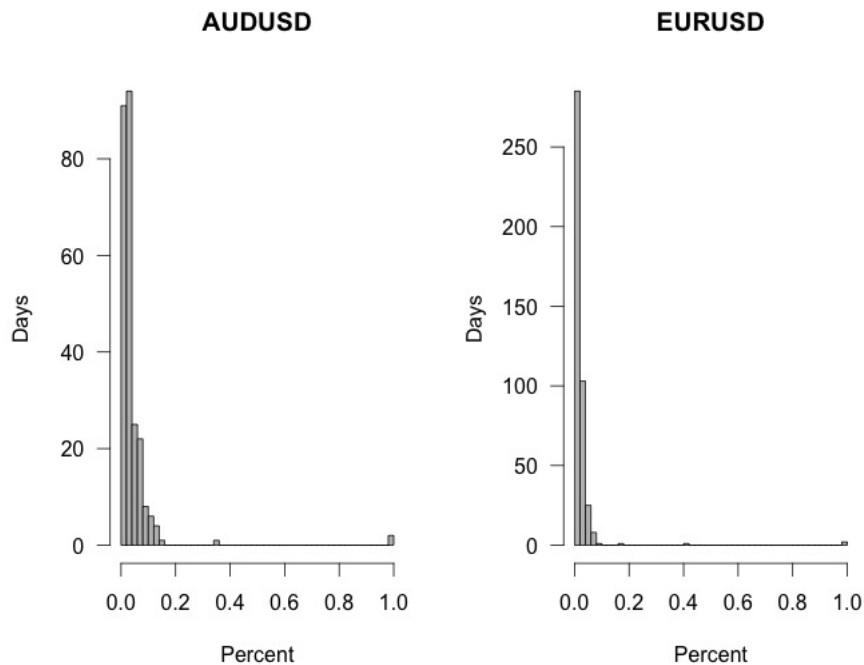
¹⁴ t -statistics = -45.4141

¹⁵ t -statistic=1.0818

that the euro-dollar systematically stayed around zero. Also median and mean for the CIP is smaller than mean and median for transactions costs. That means, one could not on average make profitable arbitrage by randomly engaging in trading euro-dollar. Notice that the median for CIP is much smaller than mean of the CIP. This is because of some large positive deviations.

Figure 5 presents annualized¹⁶ profitable deviations for both currency pairs. It is clear from figure that most of the profitable opportunities are very small on annual basis. For aussie-dollar the median and mean are 2.6 - and 4.2 percent, respectively. Only 2 observations are greater than 100 percent. For the euro-dollar the size of the

Figure 3: Annualized profitable deviations (1=100 percent)



annualized profitable deviations are even smaller, median and mean are 1.2 percent and 2.3 percent, respectively. Only two observations are greater than 100 percent. This is a comforting result since this pair is much larger in terms of daily trading volume. And the trade of goods and service between euro-block and the US is much larger than between US and Australia.

This result suggests that the magnitude of systematic profits is very small. When the entire sample is taken into account the mean annualized profits for aussie-dollar

¹⁶ann.profit dev. $= (1 + dev.)^{250} - 1$. It is assumed 250 trading days within a year. It is also assumed that profitable deviations are equally distributed over the course of the year. Also for readability of the figure and practical reasons, annualized deviations greater than 100 percent are set to 1 (100 percent).

and euro-dollar are reduced to 0.52 percent and 0.47 percent, respectively. These returns must be considered to be marginal.

In the next section it will be focused on the persistence of profitable deviation.

6.3 Impulse response functions

To study the dynamic relationship between profitable deviations, forward premium and the interest rate differential a vector error correction model (VECM) was estimated. Impulse response functions are obtained from VECM to see the impact of innovations in the forward premium and interest rate differential on profitable deviations.

In the cointegrating relation profitable deviation was entered first, then forward premium and finally, interest rate differential. The chosen lag length is 2-lags for both aussie-dollar and euro-dollar¹⁷. The cointegration rank, r , from Johansen's procedure¹⁸ is 1 for aussie-dollar and 2 for euro-dollar. Interest rate differential are treated as exogenous, as also suggested by Engel and Granger (1987).

The restriction in short run and long run matrices are imposed such that shocks in interest rate differential affects both interest rate differential and forward premium contemporaneously, but shocks in forward premium only affects the forward premium contemporaneously. Thus, in the long run impact matrix, ΞB , elements (2,3), (3,2) and (3,3) are set to zero. In the short run impact matrix, B , (3,3) are set to zero.

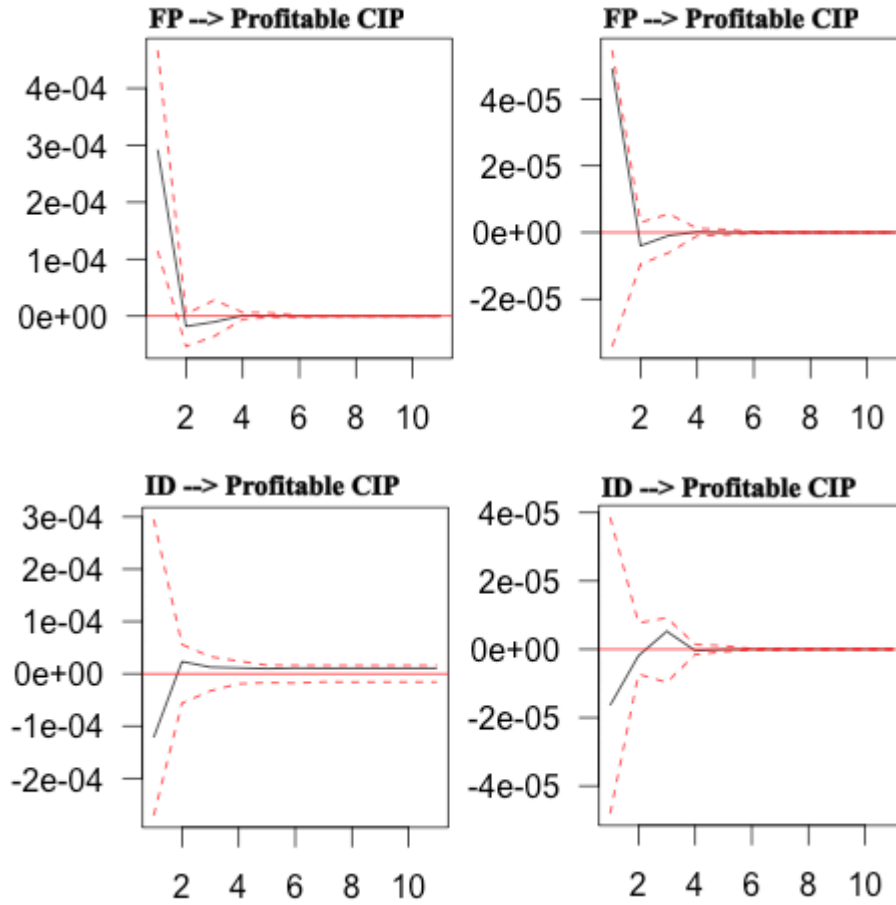
Figures 4 plots the impulse response of profitable CIP deviations to innovations in interest rate differentials and forward premium along with the 95 percent confidence interval around each response. First column contains result for aussie-dollar while the second column contains results for euro-dollar. For aussie-dollar innovations in forward premium are quickly restored to equilibrium. While innovations in interest rate differential appear to move the system to a new equilibrium (shocks persist in the system). For euro-dollar, profitable deviations quickly restore to equilibrium after innovations in the forward premium. While innovations in interest rate differential restore to equilibrium but persist longer than innovations in forward premium.

Table 7 presents normalized impulse response of profitable deviations from shocks in forward premium and interest rate differential. For aussie-dollar most of the innovations in the forward premium are restored to equilibrium within the same day. However, innovations in the interest differential seems to persist in the system indefi-

¹⁷Aussie-dollar AIC:3, HQ:2, SC:2, FPE:3 and Euro-dollar AIC:3, HQ:2, SC:1, FPE:3

¹⁸Trace test

Figure 4: Impulse Response Functions for aussie-dollar and euro-dollar



nitely. Perhaps an interest differential shock moves the system to a new equilibrium. Results for euro-dollar are quite similar to aussie-dollar regarding innovations in forward premium. However, innovations in interest differentials persist only for up to 4 days, rather than persisting indefinitely as in the aussie-dollar system.

Table 7: Normalized Impulse responses of profitable deviations (1=100 percent)

Days	AUDUSD		EURUSD	
	FP*	ID*	FP*	ID*
1	0,91	-0,53	0,91	-0,68
2	-0,06	0,10	-0,07	-0,08
3	-0,03	0,05	-0,02	0,22
4	-0,00	0,05	-0,00	-0,02
5	0,00	0,04	0,00	0,00
6	0,00	0,05	0,00	0,00
7	0,00	0,05	0,00	0,00
10	0,00	0,05	0,00	0,00

asterisks (*) donates innovation

7 Conclusion

Analysis from ECM support that the parity conditions on average holds for both pairs. However, there is also evidence for some large deviations, even though the majority of the deviations are small for both pairs. The final part of the analysis, impulse responses, shows that market participants react efficiently to shocks in forward premium, but at a slower rate to interest rate differential. The contradicting results arrives perhaps due to results in ECM section are average results. Since most part of the period is free of profitable deviations, this period is also likely to overshadow the period with profitable deviations.

Two important issues need to be mentioned here. First, data series under study contains a period of financial crisis (subprime crisis in US). This event is likely to increase volatility and thereby likelihood of the profitable deviations. This rational is consistent with Taylor (1989) where he argues that frequency of the profitable deviations increase in turbulent periods. This point is further strengthened by plots of both pairs, where majority of the deviations are up to and little after 2008 and thereby ceases after for euro-dollar and for two years for aussie-dollar. Second, accuracy and timing of the data series. This issue raised by Taylor (1987, 1989) can seriously challenge the validity of any conclusion drawn from this paper. The authors are completely aware of this fact and admit that even though the data is obtained from a reliable source there is no guarantee that the data series actually reflect market clearing quotes on which trade took place.

These results suggest that there is not sufficient evidence for either accepting or rejecting the CIP and efficiency of the market. Thus, this study is inconclusive regarding the validity of the CIP and efficiency of the market.

Further studies can focus exactly on this aspect and apply market clearing data. This is perhaps the only way to gain a greater consensus regarding the validity of the covered interest rate parity.

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