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The Forward Exchange Rate Unbiasedness Hypothesis: A Single Break Unit Root and Cointegration Analysis

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ABSTRACT

In an age of globalized finance, Forex market efficiency is particularly relevant as agents engage in arbitrage opportunities across international markets. This study tests the forward exchange rate unbiasedness hypothesis using more powerful tests such as the Zivot-Andrews single-break unit root and the KPSS stationarity (no unit root) tests to confirm that the USD/EUR spot and three-month forward rates are I(1) in nature. The study successfully employs the Engle-Granger cointegration analysis which identifies a stable long-run relationship between the spot and forward rates and generates an ECM model that is used to forecast the in-sample (historical) data. The study's findings refute past conclusions that fail to identify the data's I(1) nature and suggest that market efficiency is present in the long run but not necessarily in the short run.

Keywords: Cointegration Analysis; Error-Correction Model (ECM); Forward Exchange Rate Unbiasedness Hypothesis (FRUH); KPSS No Unit Root Test; Unexploited Profits; Zivot-Andrews Single Break Unit Root Test

1. Introduction

This paper investigates the validity of the forward exchange rate unbiasedness hypothesis (FRUH) which is indicative of efficiency in the foreign exchange market using more powerful unit root and no unit root tests. The study employs the single break unit root and cointegration analysis to determine whether a stable long-run relationship between the USD/EUR spot and forward exchange rates exits, and generates an error correction model to examine further the dynamics of market efficiency. The paper is organized as follows. First, a brief discussion of the relevant literature and a conceptual framework of analyses are presented. Next, the nature of the data and variables is discussed. The third section presents and analyzes the results, while the last section summarizes the main findings in the paper.

2. Conceptual Framework

A multitude of econometric studies have explored the FRUH which suggests that the forward foreign exchange rate serves as an unbiased predictor of the future spot rate. A review of the economic literature surrounding foreign exchange market efficiency yields largely contradictory results with both rejections and confirmations of the hypothesis. By and large, methodological and empirical challenges are at the root of the contradictory results surrounding this important topic in international finance. While early studies disproportionately accepted the FRUH, the findings are increasingly passé for failure to consider the non-stationary nature of the economic data (see [1,2]). Recent studies that use unit-root and cointegration analysis increasingly reject the null hypothesis that the forward rate is an unbiased predictor of future spot rate (see [3-6]).

Given the equation $s_t = \alpha + \beta f_{t-3} + e_t$, confirmation of the FRUH requires that the future spot and forward rates are cointegrated with a vector of (1, −1) and the coefficient $\alpha = 0$ and $\beta = 0$. Under market efficiency, the expected mean of the error term should equal zero and be independently identically distributed as a white-noise error term. Using the spot and three month forward rates, the same criteria must be met to satisfy the efficiency hypothesis. Although studies since Hakkio and Rush [7] generally consider the cointegrating relationship between s_t and f_{t-n} to explore the efficiency and accuracy of the forward in predicting the spot rate, Zivot [8] also suggests that the non-lagged variables should also share a cointegrating vector. Zivot argues that the latter model of cointegration more effectively captures the stylized facts of the exchange rate data and may supplement cointegration findings. However, the relationship between the spot and lagged forward rate is most important for this study. Related articles examining efficiency in the foreign exchange market look at changes in the future spot rate influenced by the forward risk premium. These cases primarily concern deficiencies in the rational expectations hypothesis, which are assumed when investigating the FRUH. Additionally, cointegration analysis warrants the exclusion of the risk premium from the model (see [9]).

The market efficiency hypothesis is based on the idea that participants in the FX market have rational expectations and are risk neutral. Expected returns on speculative currency investments should be zero in the long run (see [6]). With much of the growth in global finance driven by the acceleration and integration of short-term capital flows, market participants are significantly more exposed to foreign markets. Increasing engagement in foreign markets and the resulting financial growth are spurred by market liberalization, technological advances, and financial engineering (see [10]). Foreign exchange is an unavoidable facet of transacting in the global marketplace and the rejection of FRHU suggests there are opportunities to realize incremental returns on investments by engaging in FX market arbitrage. In an inefficient market, agents must exert caution in carefully implementing strategies to yield positive profits from speculative bubbles. The prospect of realizing gains in the FX market is equally valid to that of incurring losses (see [11]). By contrast, a failure to reject the null hypothesis in the long run suggests agents have rational expectations and are risk neutral, thus foreign currency holdings are only useful insofar as simplifying the process of purchasing securities abroad. If the market is efficient and all subjects have complete information, foreign exchange transactions should only yield a normal profit.

This study uses single break unit root and cointegration analysis to determine whether there is a stable underlying relationship between the future spot and forward exchange rates. Following the Engel-Granger cointegration framework, an error correction model is used to examine adjustment speed and efficiency in the presence of systemic shocks. The model takes the general form of $s_t = \alpha + \beta f_{t-3} + e_t$ with the \$/€ spot and 3-month forward rates as the economic variables under investigation. Given the first order integration identified in section III, s_t refers to the log of the spot rate and f_{t-3} enotes the log of the three-month forward exchange rate. The USD/EUR rate is ideal for this study since the euro is the second most traded currency behind the US dollar. Additionally, the launch of the euro common currency on January 1, 1999 marked one of the most monumental economic and political endeavors of the century. Eleven national currencies merged overnight to transform the world's currency market and the process of broadening the euro area continues to this day [10]. The eurozone comprises seventeen member states and there is a reasonable amount of data available to study the common currency. The euro spot and three-month forward rates are from the Haver data base which, in turn, obtained the data from the European Central Banks' Eurostat and London's Financial Times' collection. The spot and 3-month forward \$/€ exchange rates are measured as monthly averages for the period January 2000 to March 2013.

3. Data

The US dollar per euro spot rate is the model's dependent variable. For ease of interpretation, the variables are expressed in logarithmic form, so the estimated results reveal the spot rate's adjustment to systemic shocks as an elasticity. The log of the spot rate (dependent variable) is named USD_EUR and is measured as a monthly average and its first difference is referred to as ds_t.

The independent variable is the three-month forward USD/EUR exchange rate measured as a monthly average for the period 2000M01 to 2013M03. The variable requires a logarithmic transformation for the error correction model. The log of the forward rate is called USD_EUR_3MO and its difference is referred to as df_t. The variable is lagged three periods in the model to explore its causal relationship. The expected coefficient assuming satisfaction of the FRUH is one. Most recent studies, however, have failed to find support for the FRUH (see [5]).

Dummy variables D1 and D2 are used in the error correction model to incorporate the structural breaks found in the data respectively for June of 2003 and September and October of 2008. Essentially, D1 and D2 account for periods of macro-instability that disrupt the currency markets.

4. Estimation Results

The log of the spot rate in level form and first differences is plotted, respectively, in **Figures 1(a)** and **(b)** to provide preliminary insights before unit root and cointegration analysis. The level and first difference graphs clearly reveal the integrated nature of the data. The series exhibit clear positive drift in level form and differencing eliminates many of the data's non-stationary properties. ADF, KPSS, and Zivot-Andrews [12] single break point tests further confirm the nature of this process, but economic theory and time series literature support the expectation of an I(1) process.

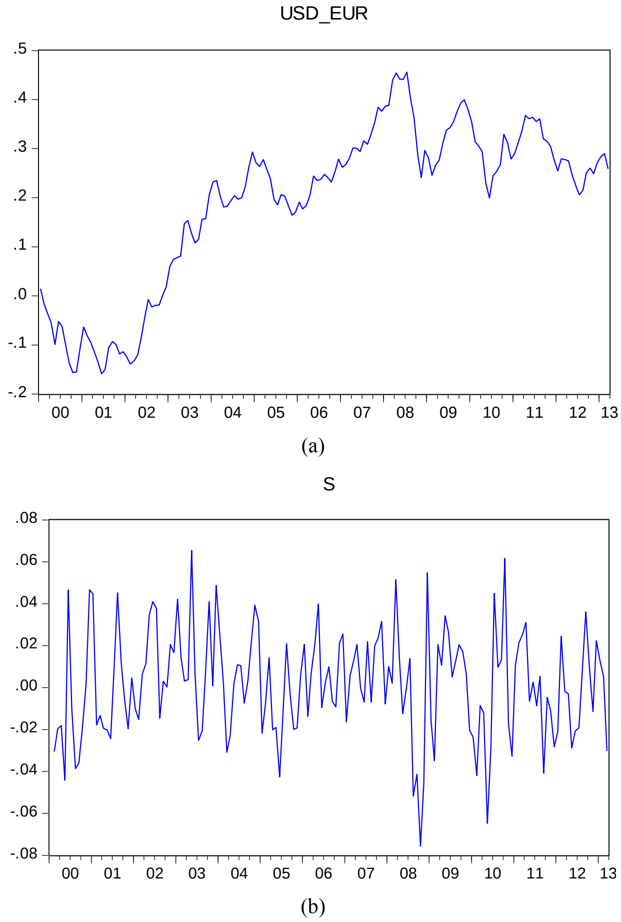


Figure 1. (a) Level Data; (b) Differenced Data.

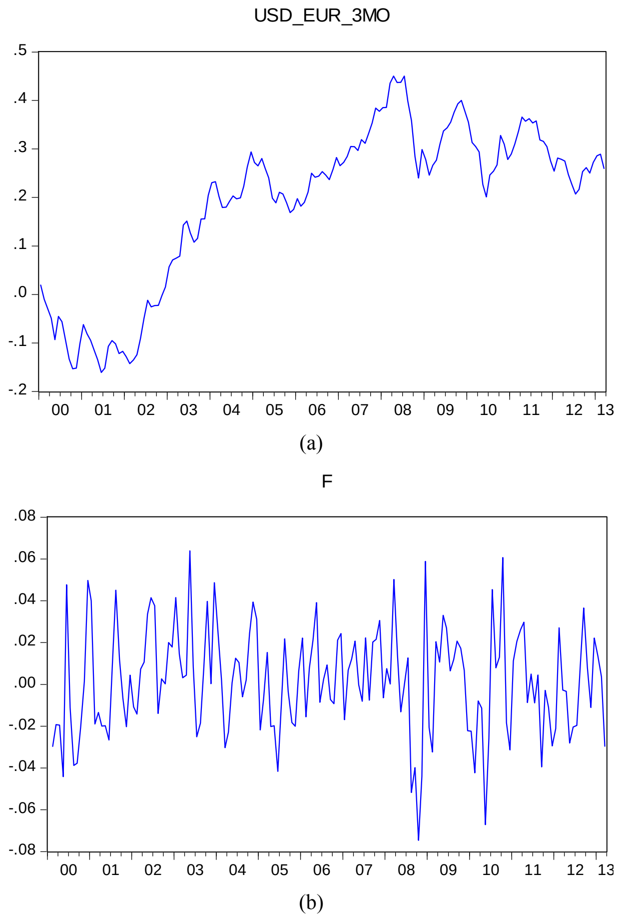


Figure 2. (a) Level Data; (b) Difference Data.

Similar to the spot rate series, the level and first difference plots of the three-month forward rate series visually reveal the integrated nature of the data. Positive drifts in level form are corrected through differencing and the series are rendered more stationary in **Figures 2(a)** and **(b)**.

The admittedly low-powered Augmented Dickey-Fuller test is the first test used to identify a unit root in the spot rate series. The Doldado-Sosvilla methodology suggests an initial test including both a trend and intercept and subsequent tests eliminating insignificant exogenous regressors. The ADF t-statistic for a unit root is (−0.596397) as shown in **Table 1** below. Since the t-stat is insignificant at all levels, the null hypothesis of a unit root cannot be rejected. ADF tests for ds_t, the differenced spot rate, reveal that the ADF *t*-stat (−11.44760) is significantly beyond the 1% level. This permits rejection of the unit root null hypothesis for the differenced series and conclusion that USD_EUR is an I(1) process.

An Augmented Dickey Fuller test for the three-month forward rate shows that the series has a unit root and is non-stationary in level form without a significant trend or intercept. The ADF test statistic of (−1.593227) in **Table**

Table 1. USD/EUR: Augmented Dickey Fuller unit root tests for stationarity, sample period 2000-2013.

Variables	Levels	First Difference	5% Critical Value	1% Critical Value
S	−0.596	−11.448	−1.943	−2.580
F	−1.593	−9.200	−2.880	−3.472

1 is insignificant and we cannot reject null hypothesis. The differenced series' significant t-statistic of (−9.200284) is significantly beyond the 1% level. Thus, the results reported reject the null hypothesis and suggest the level series is an I(1) process that must be differenced to achieve the stationarity required for modeling.

The Kwiatkowski-Phillips-Schmidt-Shin [13] Lagrange Multiplier unit root test is a more powerful test designed to confirm the finding that the spot rate is an I(1) process. The KPSS test on the level data reports a test-statistic of (0.294096). As shown in **Table 2**. Since the LM-statistic is greater than the 0.216 critical value at the 1% confidence level, the null hypothesis of stationarityis rejected for the level series. This supports the ADF findings of a unit root in level form. The KPSS LM-test results for the differenced series yields insignificant evi-

Table 2. USD/EUR: Kwiatkowski-Phillips-Schmidt-Shin Lagrange Multiplier unit root test, sample period 2000-2013.

Variables	Levels	First Difference	5% Critical Value	1% Critical Value
S	0.294	0.0798	0.146	0.216
F	0.296	0.0831	0.146	0.216

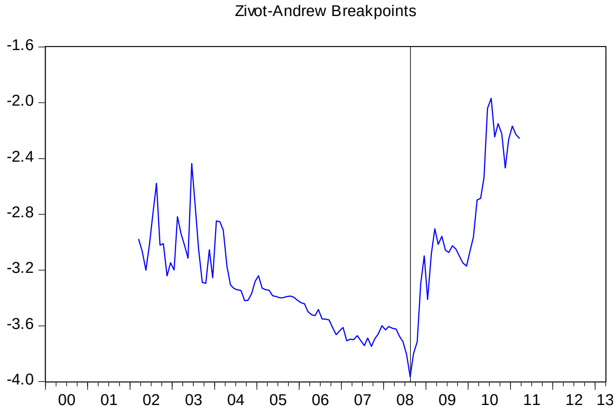
dence to reject the null of stationarity. Again, these findings confirm the ADF results with greater power.

The same high power test is used to confirm that the logged three-month forward exchange rate is an I(1) process as suggested by the ADF. The null hypothesis of stationary in level form can be rejected at the 1% significance level based on the LM-test results represented in **Table 2** and 2.1(b) of the appendix. This finding provides further credibility to support the conclusion from the ADF test that the series has a unit root. A KPSS test of the first difference reveals that df_t is a stationary process. The null hypothesis of stationarity cannot be rejected for the series' first difference, therefore USD_EUR_3MO is an integrated order one process.

The Zivot-Andrew single breakpoint test is another method for detecting unit roots in the presence of a single structural break in the data series. Conventional unit root tests have relatively low power when the stationary alternative is true and a structural break in the data is ignored. In other words, investigators are more likely to conclude incorrectly that the series is non-stationary when a structural break is ignored (see [14]). Following the lead of Perron, most investigators report estimates for either models A and C, but in a relatively recent study Seton [15] has shown that the loss in test power (1-β) is considerable when the correct model is C and researchers erroneously assume that the break-point occurs according to model A. On the other hand, the loss of power is minimal if the break date is correctly characterized by model A but investigators erroneously use model C.

Performing the test on the spot and forward rates using model C reveals significant results. The first tests in **Table 3** and 3.1 of the appendix are significant and do not allow for the rejection of the null hypothesis. This suggests that the series contains both a unit root and a structural break at 2008M08. A break at that point makes logical sense given the start of the US subprime mortgage crisis. The use of model C also provides highly significant results with a failure to reject the presence of a unit root. When using the differenced series for the spot and forward rates, a structural break is also detected at 2003M06 using model C, which coincides with the peak in unemployment following the early 2000's recession and escalating conflict in Iraq. The unexpected cost of rebuilding a stable government capable of self-rule from the rubble of Saddam Hussein's regime was not an out

Table 3. Zivot-Andrews unit root test.



Date: 05/01/13 Time: 02:05

Sample: 2000M01 2013M03

Included observations: 159

Null Hypothesis: USD_EUR has a unit root with a structural break in both the intercept and trend

Chosen lag length: 2 (maximum lags: 4)

Chosen break point: 2008M08

	t-Statistic	Prob. *
Zivot-Andrews test statistic	−3.964702	0.019974
1% critical value:	−5.57	
5% critical value:	−5.08	
10% critical value:	−4.82	

come or obligation the US foresaw.

Dummy variables are therefore incorporated into the model for both of these breaks. Although the financial crisis was already mounting for some time, the unexpected declaration of bankruptcy by Lehman Brothers in September of 2008 marked both the intensification of the U.S. recession and the crisis in world financial markets. Additionally President Bush gave his "Mission Accomplished" speech on the May 1st but by June insurgent attacks were intensifying and it was becoming clear that the mission in Iraq would be far more difficult and costly than ever imagined.

Given that both the dependent and independent variables are I(1), the Engle-Granger cointegration test procedure requires an ADF test of the residuals(without intercept and trend) of the Forex equation in level form. An ordinary least squares regression is generated using the log of level series for the equation $s_t = \alpha + \beta f_{t-3} + e_t$ in appendix Table 4.1. As suggested by Zivot [8], the same procedure is conducted for the $s_t = \alpha + \beta ft + e_t$ equation which is represented in Table 4.2. Augmented Dickey-Fuller unit root tests are performed on both sets of residuals in Tables 4.1(b) and 4.2(b) of the appendix. The results for the residuals including the lagged term overwhelmingly support the rejection of the null hypothesis of a unit root for all significance levels. The test in simple form is less significant but the t-statistics are still strong enough to reject the null of a unit root at the 5% level of significance. The stationary nature of the residuals in level form suggests that s_t is cointegrated with both f_{t-3} and f. The identification of a cointegrating vector is important in that it identifies a stable long-run relationship that keeps the variables in proportion over time, and suggests that the market is efficient in the long run. Following the Engle-Granger representation theorem, an error correction model that includes the residuals is generated to reconcile the short and long-run behavior of the underlying relationship between the forward and spot exchange rates.

The final model shown in **Model 1** is significant and with a high degree of explanatory and forecasting power. The error correction model incorporates the forward vaable, error correction term, and two dummy variables: D1 for 2003M06 and D2 for 2008M09-M10 described above. The HAC Newey-West [16] procedure was utiled in estimating the ECM, thus correcting the OLS stanrd errors for both autocorrelation and heteroscedasticity. The Durbin Watson test statistic is 2.1 and suggests that the final model does not suffer from first order serial correlation. All of the terms except for the constant generate high t-statistics and are significant at the 5% significance level. The EC1(−1) term is significant at the 5% level and suggests that a deviation of 10 percent from the long run equilibrium during the current period is corrected in the subsequent period by approximately 0.5 percent. The addition of the D2 term, given that its inclusion makes theoretical sense, increases the Adjusted R squared and enhances the degree of accuracy for the final model.

Model 1. USD/EUR: Error Correction Model; dependent variable is: (S), 2000-2013.

OLS Regressions				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.87E-05	6.93E-05	0.846956	0.3984
F	1.001182	0.003877	258.2166	0.0000
EC1(−1)	−0.046752	0.021973	−2.127676	0.0350
D1	−0.001047	0.000250	−4.182255	0.0000
D2	−0.001122	0.000310	−3.619541	0.0004
AR(1)	−0.288958	0.092038	−3.139549	0.0020
R-squared	0.998	Mean dependent var		0.002
Adjusted R-squared	0.998	S.D. dependent var		0.025
S.E. of regression	0.001	Akaike info criterion		−10.611
Sum squared resid	0.000	Schwarz criterion		−10.495
Log likelihood	838.994	Hannan-Quinn criter.		−10.564
F-statistic	14495.59	Durbin-Watson stat		2.100
Prob(F-statistic)	0.000			

The fact that the constant is not significantly different from zero supports the efficiency hypothesis.

The estimated coefficient for the forward rate is 1.001182 with a *t*-stat of 258.2166. This result is highly significant and since it is close to 1, the model fulfills the FRUH criteria. The failure to reject the null hypothesis serves to support the use of the forward rate as an unbiased estimator of the future spot rate. The evidence for the dollar-euro rate suggests support for market efficiency in the long run but not necessarily in the short run because a disequilibrium exists between the two variables, suggesting that expected returns to speculators are not zero in the short run (see [7]). In general, the results suggest that participants in the foreign exchange market are risk neutral and have little to gain from speculation in the long run.

EC models were also used to track the historical data on the percentage change in the spot rate for the period under review. **Figure 3** below shows that the model was able to track the turning points in the actual series quite well. s refers to the actual series and (sf) denotes the in-sample forecast. In addition, **Figure 4** below shows that the Theil inequality coefficient for this model is 0.02270, which is well below the threshold value of 0.3, and suggests that the predictive power of the model is quite good (see [17]). The Theil coefficients can be decomposed into three major components: the bias, variance, and covariance terms. Ideally, the bias and variance components should equal zero, while the covariance

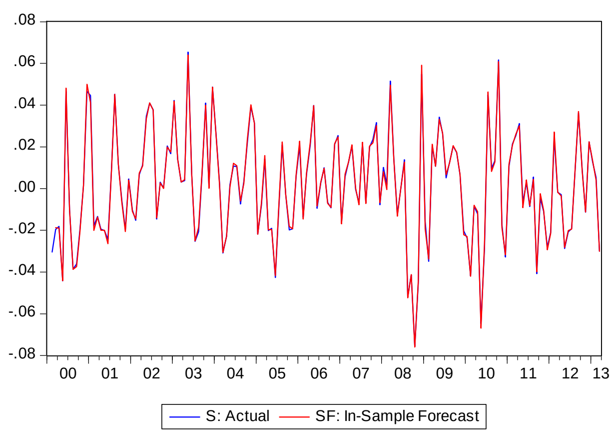


Figure 3. Actual and simulated percentage changes in the spot rate.

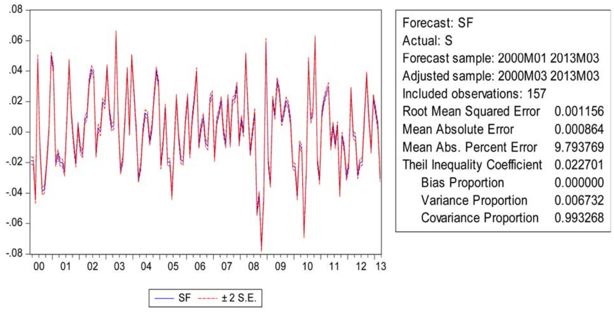


Figure 4. Theil inequality coefficient for in-sample forecast.

proportion should equal one. The reported estimates suggest that all of these ratios are close to their optimum values (bias = 0.0000, variance = 0.0067, and covariance = 0.9932). Sensitivity analysis on the coefficients also revealed that changes in the initial or ending period did not alter the predictive power of the selected models (results are available upon request).

5. Conclusion

Efficiency in the foreign exchange market is especially relevant in the world of globalized finance since market agents are frequently and increasingly transacting both at home and abroad. This study shows that the spot and three-month forward exchange rates are I(1) processes using the more powerful KPPS stationarity test and the Zivot Andrews single break unit root test. Following the Engle-Granger cointegration analysis framework, a long-run stable relationship between the three-month forward exchange rate and the future spot rate is identified which suggests that the forward rate contains useful information about the spot rate; in other words, it supports market efficiency in the long run. Insofar as the error correction model is concerned, it provided further support for the forward exchange rate unbiasedness hypothesis. With a high degree of power, the results of the model fulfill the final two criteria for market efficiency, viz., a constant equal to 0 and a coefficient of 1. However, the results also suggest that there is a disequilibrium in the short run that is only partially corrected in subsequent periods, suggesting that, in the short run, there might be unexploited profit opportunities for speculators and/or a time-varying risk premium. Needless to say, economists have debated the issue of exchange market efficiency since the 70's and this study, although supportive of market efficiency in the long run, will by no means settle the controversy. Finally, the endogenously determined structural breaks in the data indicate that, since the common currency's inception, volatility and disruption of the Forex market have been generated by both the un-expected costs associated with the war in Iraq and the 2008 global financial crisis.

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Appendix:

ADF Tests:

Table 1.1.

Null Hypothesis: USD_EUR has a unit root

Exogenous: Constant, Linear Trend

Lag Length: 1 (Automatic-based on SIC, maxlag = 13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−1.879977	0.6602
Test critical values:	1% level	−4.017568	
	5% level	−3.438700	
	10% level	−3.143666	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable: D(USD_EUR)

Method: Least Squares

Date: 04/30/13 Time: 23:55

Sample (adjusted): 2000M03 2013M03

Included observations: 157 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
USD_EUR (−1)	−0.037629	0.020016	−1.879977	0.0620
D(USD_EUR (−1))	0.322964	0.076939	4.197673	0.0000
C	0.001599	0.004044	0.395337	0.6931
@TREND(2000M01	8.38E − 05	7.31E − 05	1.146264	0.2535
R-squared	0.114862	Mean dependent var		0.001760
Adjusted R-squared	0.097506	S.D. dependent var		0.025432
S.E. of regression	0.024161	Akaike info criterion		−4.583039
Sum squared resid	0.089311	Schwarz criterion		−4.505172
Log likelihood	363.7685	Hannan-Quinn criter.		−4.551414
F-statistic	6.618140	Durbin-Watson stat		1.906269
Prob (F-statistic)	0.000311			

Table 1.2.

Null Hypothesis: USD_EUR has a unit root

Exogenous: Constant

Lag Length: 1 (Automatic-based on SIC, maxlag = 13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−1.627012	0.4664
Test critical values:	1% level	−3.472259	
	5% level	−2.879846	
	10% level	−2.576610	

Continued

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable: D(USD_EUR)

Method: Least Squares

Date: 05/01/13 Time: 00:03

Sample (adjusted): 2000M03 2013M03

Included observations: 157 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
USD_EUR (−1)	−0.018971	0.011660	−1.627012	0.1058
D(USD_EUR (−1))	0.310732	0.076273	4.073951	0.0001
C	0.004800	0.002927	1.640082	0.1030

R-squared	0.107261	Mean dependent var	0.001760
Adjusted R-squared	0.095667	S.D. dependent var	0.025432
S.E. of regression	0.024185	Akaike info criterion	−4.587226
Sum squared resid	0.090078	Schwarz criterion	−4.528827
Log likelihood	363.0973	Hannan-Quinn criter.	−4.563508
F-statistic	9.251392	Durbin-Watson stat	1.906204
Prob (F-statistic)	0.000161		

Table 1.3.

Null Hypothesis: USD_EUR has a unit root

Exogenous: None

Lag Length: 1 (Automatic-based on SIC, maxlag = 13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−0.596397	0.4576
Test critical values:	1% level	−2.579774	
	5% level	−1.942869	
	10% level	−1.615359	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable: D(USD_EUR)

Method: Least Squares

Date: 04/30/13 Time: 23:56

Sample (adjusted): 2000M03 2013M03

Included observations: 157 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
USD_EUR (−1)	-0.004622	0.007750	−0.596397	0.5518
D(USD_EUR (−1))	0.310701	0.076687	4.051526	0.0001

Continued

R-squared	0.091668	Mean dependent var	0.001760
Adjusted R-squared	0.085807	S.D. dependent var	0.025432
S.E. of regression	0.024317	Akaike info criterion	−4.582649
Sum squared resid	0.091652	Schwarz criterion	−4.543716
Log likelihood	361.7380	Hannan-Quinn criter.	−4.566837
Durbin-Watson stat	1.901715		

Table 1.4.

Null Hypothesis: S has a unit root

Exogenous: Constant, Linear Trend

Lag Length: 0 (Automatic-based on SIC, maxlag = 13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−9.104497	0.0000
Test critical values:	1% level	−4.017568	
	5% level	−3.438700	
	10% level	−3.143666	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable: D(S)

Method: Least Squares

Date: 05/01/13 Time: 00:19

Sample (adjusted): 2000M03 2013M03

Included observations: 157 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
S (−1)	−0.698449	0.076715	−9.104497	0.0000
C	0.003469	0.003952	0.877802	0.3814
@TREND(2000M01)	−2.80E − 05	4.29E − 05	−0.652052	0.5153
R-squared	0.350275	Mean dependent var		2.12E-06
Adjusted R-squared	0.341837	S.D. dependent var		0.030025
S.E. of regression	0.024359	Akaike info criterion		−4.572940
Sum squared resid	0.091375	Schwarz criterion		−4.514540
Log likelihood	361.9758	Hannan-Quinn criter.		−4.549222
F-statistic	41.51164	Durbin-Watson stat		1.901343
Prob (F-statistic)	0.000000			

Table 1.5.

Null Hypothesis: D(S) has a unit root				
Exogenous: Constant				
Lag Length: 2 (Automatic-based on SIC, maxlag = 13)				
			t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic			−11.41115	0.0000
Test critical values:	1% level		−3.473096	
	5% level		−2.880211	
	10% level		−2.576805	
*MacKinnon (1996) one-sided p-values.				
Augmented Dickey-Fuller Test Equation				
Dependent Variable: D(S,2)				
Method: Least Squares				
Date: 05/01/13 Time: 00:30				
Sample (adjusted): 2000M06 2013M03				
Included observations: 154 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D (S(−1))	−2.059546	0.180485	−11.41115	0.0000
D (S(−1),2)	0.647650	0.130722	4.954415	0.0000
D (S(−2),2)	0.214490	0.080233	2.673330	0.0083
C	0.000320	0.002176	0.147022	0.8833
R-squared	0.685197	Mean dependent var		−5.97E-05
Adjusted R-squared	0.678901	S.D. dependent var		0.047635
S.E. of regression	0.026993	Akaike info criterion		−4.360876
Sum squared resid	0.109290	Schwarz criterion		−4.281994
Log likelihood	339.7874	Hannan-Quinn criter.		−4.328834
F-statistic	108.8297	Durbin-Watson stat		1.958890
Prob (F-statistic)	0.000000			

Table 1.6.

Null Hypothesis: D(S) has a unit root			
Exogenous: None			
Lag Length: 2 (Automatic-based on SIC, maxlag = 13)			
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−11.44760	0.0000
Test critical values:	1% level	−2.580065	
	5% level	−1.942910	
	10% level	−1.615334	

Continued

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable: D(S,2)

Method: Least Squares

Date: 05/01/13 Time: 00:31

Sample (adjusted): 2000M06 2013M03

Included observations: 154 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D (S(−1))	−2.059028	0.179865	−11.44760	0.0000
D (S(−1),2)	0.647283	0.130274	4.968635	0.0000
D (S(−2),2)	0.214285	0.079961	2.679881	0.0082
R-squared	0.685152	Mean dependent var		−5.97E − 05
Adjusted R-squared	0.680982	S.D. dependent var		0.047635
S.E. of regression	0.026905	Akaike info criterion		−4.373718
Sum squared resid	0.109306	Schwarz criterion		−4.314557
Log likelihood	339.7763	Hannan-Quinn criter.		−4.349687
Durbin-Watson stat	1.958836			

Table 1.1(b)

Null Hypothesis: USD_EUR_3MO has a unit root

Exogenous: Constant, Linear Trend

Lag Length: 1 (Automatic-based on SIC, maxlag = 13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−1.853265	0.6738
Test critical values:	1% level	−4.017568	
	5% level	−3.438700	
	10% level	−3.143666	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable: D(USD_EUR_3MO)

Method: Least Squares

Date: 05/01/13 Time: 01:15

Sample (adjusted): 2000M03 2013M03

Included observations: 157 after adjustments

Variable	Coefficien	Std. Error	t-Statistic	Prob.
USD_EUR_3MO(−1)	−0.037143	0.020042	−1.853265	0.0658
D(USD_EUR_3MO(−1))	0.312895	0.077209	4.052590	0.0001
C	0.001563	0.004049	0.385970	0.7001

Continued

@TREND(2000M01)	8.32E − 05	7.32E − 05	1.136803	0.2574
R-squared	0.108380	Mean dependent var		0.001721
Adjusted R-squared	0.090898	S.D. dependent var		0.025400
S.E. of regression	0.024218	Akaike info criterion		−4.578301
Sum squared resid	0.089736	Schwarz criterion		−4.500435
Log likelihood	363.3967	Hannan-Quinn criter.		−4.546677
F-statistic	6.199278	Durbin-Watson stat		1.907224
Prob (F-statistic)	0.000530			

Table 1.2(b)

Null Hypothesis: USD_EUR_3MO has a unit root

Exogenous: Constant

Lag Length: 1 (Automatic-based on SIC, maxlag = 13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−1.593227	0.4837
Test critical values:	1% level	−3.472259	
	5% level	−2.879846	
	10% level	−2.576610	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable: D(USD_EUR_3MO)

Method: Least Squares

Date: 05/01/13 Time: 01:16

Sample (adjusted): 2000M03 2013M03

Included observations: 157 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
USD_EUR_3MO(−1)	−0.018630	0.011693	−1.593227	0.1132
D(USD_EUR_3MO(−1))	0.300906	0.076558	3.930450	0.0001
C	0.004733	0.002938	1.610995	0.1092
R-squared	0.100849	Mean dependent var		0.001721
Adjusted R-squared	0.089172	S.D. dependent var		0.025400
S.E. of regression	0.024241	Akaike info criterion		−4.582629
Sum squared resid	0.090494	Schwarz criterion		−4.524229
Log likelihood	362.7364	Hannan-Quinn criter.		−4.558911
F-statistic	8.636363	Durbin-Watson stat		1.907614
Prob(F-statistic)	0.000279			

Table 1.3(b)

Null Hypothesis: USD_EUR_3MO has a unit root

Exogenous: Constant

Lag Length: 1 (Automatic-based on SIC, maxlag = 13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−1.593227	0.4837
Test critical values:	1% level	−3.472259	
	5% level	−2.879846	
	10% level	−2.576610	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable: D(USD_EUR_3MO)

Method: Least Squares

Date: 05/01/13 Time: 01:16

Sample (adjusted): 2000M03 2013M03

Included observations: 157 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
USD_EUR_3MO(-1)	−0.018630	0.011693	−1.593227	0.1132
D(USD_EUR_3MO(-1))	0.300906	0.076558	3.930450	0.0001
C	0.004733	0.002938	1.610995	0.1092
R-squared	0.100849	Mean dependent var		0.001721
Adjusted R-squared	0.089172	S.D. dependent var		0.025400
S.E. of regression	0.024241	Akaike info criterion		−4.582629
Sum squared resid	0.090494	Schwarz criterion		−4.524229
Log likelihood	362.7364	Hannan-Quinn criter.		−4.558911
F-statistic	8.636363	Durbin-Watson stat		1.907614
Prob (F-statistic)	0.000279			

Table 1.4(b)

Null Hypothesis: F has a unit root

Exogenous: Constant, Linear Trend

Lag Length: 0 (Automatic-based on SIC, maxlag = 13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−9.200100	0.0000
Test critical values:	1% level	−4.017568	
	5% level	−3.438700	
	10% level	−3.143666	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Continued

Dependent Variable: D(F)

Method: Least Squares

Date: 05/01/13 Time: 01:24

Sample (adjusted): 2000M03 2013M03

Included observations: 157 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
F(-1)	−0.708141	0.076971	−9.200100	0.0000
C	0.003380	0.003959	0.853816	0.3945
@TREND(2000M01)	−2.70E − 05	4.30E − 05	−0.628238	0.5308
R-squared	0.355022	Mean dependent var		6.96E-07
Adjusted R-squared	0.346645	S.D. dependent var		0.030197
S.E. of regression	0.024409	Akaike info criterion		−4.568840
Sum squared resid	0.091750	Schwarz criterion		−4.510441
Log likelihood	361.6539	Hannan-Quinn criter.		−4.545122
F-statistic	42.38388	Durbin-Watson stat		1.903271
Prob (F-statistic)	0.000000			

Table 1.5(b)

Null Hypothesis: F has a unit root

Exogenous: Constant

Lag Length: 0 (Automatic-based on SIC, maxlag = 13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−9.203471	0.0000
Test critical values:	1% level	−3.472259	
	5% level	−2.879846	
	10% level	−2.576610	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable: D(F)

Method: Least Squares

Date: 05/01/13 Time: 01:27

Sample (adjusted): 2000M03 2013M03

Included observations: 157 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
F(−1)	−0.706704	0.076787	−9.203471	0.0000
C	0.001217	0.001949	0.624309	0.5333
R-squared	0.353369	Mean dependent var		6.96E-07
Adjusted R-squared	0.349197	S.D. dependent var		0.030197
S.E. of regression	0.024361	Akaike info criterion		−4.579019
Sum squared resid	0.091985	Schwarz criterion		−4.540086
Log likelihood	361.4530	Hannan-Quinn criter.		−4.563207
F-statistic	84.70387	Durbin-Watson stat		1.900803
Prob (F-statistic)	0.000000			

Table 1.6(b)

Null Hypothesis: F has a unit root				
Exogenous: None				
Lag Length: 0 (Automatic-based on SIC, maxlag = 13)				
			t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic			−9.200284	0.0000
Test critical values:	1% level		−2.579774	
	5% level		−1.942869	
	10% level		−1.615359	
*MacKinnon (1996) one-sided p-values.				
Augmented Dickey-Fuller Test Equation				
Dependent Variable: D(F)				
Method: Least Squares				
Date: 05/01/13 Time: 01:28				
Sample (adjusted): 2000M03 2013M03				
Included observations: 157 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
F(−1)	−0.703454	0.076460	−9.200284	0.0000
R-squared	0.351743	Mean dependent var		6.96E − 07
Adjusted R-squared	0.351743	S.D. dependent var		0.030197
S.E. of regression	0.024313	Akaike info criterion		−4.589247
Sum squared resid	0.092216	Schwarz criterion		−4.569780
Log likelihood	361.2559	Hannan-Quinn criter.		−4.581341
Durbin-Watson stat	1.901439			

KPSS tests:

Table 2.1.

Null Hypothesis: USD_EUR is stationary		
Exogenous: Constant, Linear Trend		
Bandwidth: 10 (Newey-West automatic) using Bartlett kernel		
		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.294096
Asymptotic critical values*:	1% level	0.216000
	5% level	0.146000
	10% level	0.119000
*Kwiatkowski-Phillips-Schmidt-Shin (1992, **Table 1**)		
Residual variance (no correction)		0.009552
HAC corrected variance (Bartlett kernel)		0.085235
KPSS Test Equation		

Continued

Dependent Variable: USD_EUR				
Method: Least Squares				
Date: 05/01/13 Time: 01:33				
Sample: 2000M01 2013M03				
Included observations: 159				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	−0.041448	0.015527	−2.669403	0.0084
@TREND(2000M01)	0.002909	0.000170	17.11939	0.0000
R-squared	0.651168	Mean dependent var		0.188391
Adjusted R-squared	0.648946	S.D. dependent var		0.166004
S.E. of regression	0.098357	Akaike info criterion		−1.787927
Sum squared resid	1.518834	Schwarz criterion		−1.749324
Log likelihood	144.1402	Hannan-Quinn criter.		−1.772251
F-statistic	293.0734	Durbin-Watson stat		0.067298
Prob (F-statistic)	0.000000			

Table 2.2.

Null Hypothesis: S is stationary				
Exogenous: Constant, Linear Trend				
Bandwidth: 1 (Newey-West automatic) using Bartlett kernel				
				LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic				0.079840
Asymptotic critical values*:	1% level			0.216000
	5% level			0.146000
	10% level			0.119000
*Kwiatkowski-Phillips-Schmidt-Shin (1992, **Table 1**)				
Residual variance (no correction)				0.000644
HAC corrected variance (Bartlett kernel)				0.000836
KPSS Test Equation				
Dependent Variable: S				
Method: Least Squares				
Date: 05/01/13 Time: 01:51				
Sample (adjusted): 2000M02 2013M03				
Included observations: 158 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.003549	0.004082	0.869288	0.3860
@TREND(2000M01)	−2.51E-05	4.45E-05	−0.562515	0.5746
R-squared	0.002024	Mean dependent var		0.001557
Adjusted R-squared	−0.004373	S.D. dependent var		0.025480
S.E. of regression	0.025535	Akaike info criterion		−4.484941
Sum squared resid	0.101719	Schwarz criterion		−4.446174
Log likelihood	356.3103	Hannan-Quinn criter.		−4.469197
F-statistic	0.316423	Durbin-Watson stat		1.382589
Prob (F-statistic)	0.574573			

Table 2.3.

Null Hypothesis: S is stationary				
Exogenous: Constant				
Bandwidth: 2 (Newey-West automatic) using Bartlett kernel				
				LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic				0.116265
Asymptotic critical values*:		1% level		0.739000
		5% level		0.463000
		10% level		0.347000
*Kwiatkowski-Phillips-Schmidt-Shin (1992, **Table 1**)				
Residual variance (no correction)				0.000645
HAC corrected variance (Bartlett kernel)				0.000881
KPSS Test Equation				
Dependent Variable: S				
Method: Least Squares				
Date: 05/01/13 Time: 01:52				
Sample (adjusted): 2000M02 2013M03				
Included observations: 158 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.001557	0.002027	0.768046	0.4436
R-squared	0.000000	Mean dependent var		0.001557
Adjusted R-squared	0.000000	S.D. dependent var		0.025480
S.E. of regression	0.025480	Akaike info criterion		−4.495573
Sum squared resid	0.101926	Schwarz criterion		−4.476189
Log likelihood	356.1503	Hannan-Quinn criter.		−4.487701
Durbin-Watson stat	1.379790			

Table 2.1(b)

Null Hypothesis: USD_EUR_3MO is stationary		
Exogenous: Constant, Linear Trend		
Bandwidth: 10 (Newey-West automatic) using Bartlett kernel		
		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.295846
Asymptotic critical values*:	1% level	0.216000
	5% level	0.146000
	10% level	0.119000
*Kwiatkowski-Phillips-Schmidt-Shin (1992, **Table 1**)		
Residual variance (no correction)		0.009573
HAC corrected variance (Bartlett kernel)		0.085773

Continued

KPSS Test Equation
Dependent Variable: USD_EUR_3MO
Method: Least Squares
Date: 05/01/13 Time: 02:02
Sample: 2000M01 2013M03
Included observations: 159

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	−0.040650	0.015544	−2.615208	0.0098
@TREND(2000M01)	0.002905	0.000170	17.07396	0.0000
R-squared	0.649960	Mean dependent var		0.188823
Adjusted R-squared	0.647730	S. D. dependent var		0.165893
S.E. of regression	0.098461	Akaike info criterion		−1.785808
Sum squared resid	1.522056	Schwarz criterion		−1.747205
Log likelihood	143.9717	Hannan-Quinn criter.		−1.770132
F-statistic	291.5201	Durbin-Watson stat		0.066965
Prob (F-statistic)	0.000000			

Table 2.2(b)

Null Hypothesis: F is stationary
Exogenous: Constant, Linear Trend
Bandwidth: 1 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.083098
Asymptotic critical values*:	1% level	0.216000
	5% level	0.146000
	10% level	0.119000

*Kwiatkowski-Phillips-Schmidt-Shin (1992, **Table 1**)

Residual variance (no correction)	0.000642
HAC corrected variance (Bartlett kernel)	0.000828

KPSS Test Equation
Dependent Variable: F
Method: Least Squares
Date: 05/01/13 Time: 02:10
Sample (adjusted): 2000M02 2013M03
Included observations: 158 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.003412	0.004077	0.836966	0.4039
@TREND(2000M01)	−2.38E-05	4.45E-05	−0.534336	0.5939
R-squared	0.001827	Mean dependent var		0.001523
Adjusted R-squared	−0.004572	S. D. dependent var		0.025442
S.E. of regression	0.025500	Akaike info criterion		−4.487725
Sum squared resid	0.101436	Schwarz criterion		−4.448958
Log likelihood	356.5303	Hannan-Quinn criter.		−4.471981
F-statistic	0.285515	Durbin-Watson stat		1.402386
Prob (F-statistic)	0.593870			

Table 2.3(b)

Null Hypothesis: F is stationary				
Exogenous: Constant				
Bandwidth: 1 (Newey-West automatic) using Bartlett kernel				
				LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic				0.122854
Asymptotic critical values*:		1% level		0.739000
		5% level		0.463000
		10% level		0.347000
*Kwiatkowski-Phillips-Schmidt-Shin (1992, **Table 1**)				
Residual variance (no correction)				0.000643
HAC corrected variance (Bartlett kernel)				0.000830
KPSS Test Equation				
Dependent Variable: F				
Method: Least Squares				
Date: 05/01/13 Time: 02:12				
Sample (adjusted): 2000M02 2013M03				
Included observations: 158 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.001523	0.002024	0.752250	0.4530
R-squared	0.000000	Mean dependent var		0.001523
Adjusted R-squared	0.000000	S.D. dependent var		0.025442
S.E. of regression	0.025442	Akaike info criterion		−4.498554
Sum squared resid	0.101622	Schwarz criterion		−4.479171
Log likelihood	356.3858	Hannan-Quinn criter.		−4.490683
Durbin-Watson stat	1.399823			

Zivot-Andrews Break Point Tests:

Table 3.1.

Zivot-Andrews Unit Root Test		
Date: 05/01/13 Time: 03:05		
Sample: 2000M01 2013M03		
Included observations: 159		
Null Hypothesis: USD_EUR has a unit root with a structural break in both the intercept and trend		
Chosen lag length: 2 (maximum lags: 4)		
Chosen break point: 2008M08		
	t-Statistic	Prob.*
Zivot-Andrews test statistic	−3.991058	0.016963
1% critical value:	−5.57	
5% critical value:	−5.08	
10% critical value:	−4.82	

* Probability values are calculated from a standard t-distribution and do not take into account the breakpoint selection process.

Engel Granger Cointegration Test:

Table 4.1.

Dependent Variable: USD_EUR
Method: Least Squares
Date: 05/01/13 Time: 03:14
Sample (adjusted): 2000M04 2013M03
Included observations: 156 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.016163	0.006128	2.637689	0.0092
USD_EUR_3MO(-3)	0.941235	0.024469	38.46685	0.0000
R-squared	0.905735	Mean dependent var		0.192267
Adjusted R-squared	0.905123	S.D. dependent var		0.165170
S.E. of regression	0.050876	Akaike info criterion		−3.106122
Sum squared resid	0.398605	Schwarz criterion		−3.067022
Log likelihood	244.2775	Hannan-Quinn criter.		−3.090241
F-statistic	1479.699	Durbin-Watson stat		0.482103
Prob (F-statistic)	0.000000			

Table 4.1(b)

Null Hypothesis: EC has a unit root
Exogenous: None
Lag Length: 4 (Automatic-based on SIC, maxlag = 13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−5.650002	0.0000
Test critical values:	1% level	−2.580366	
	5% level	−1.942952	
	10% level	−1.615307	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(EC)
Method: Least Squares
Date: 05/01/13 Time: 03:18
Sample (adjusted): 2000M09 2013M03
Included observations: 151 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
EC(-1)	−0.344118	0.060906	−5.650002	0.0000
D(EC(-1))	0.599784	0.082439	7.275472	0.0000
D(EC(-2))	0.062442	0.079378	0.786637	0.4328
D(EC(-3))	−0.317191	0.074719	−4.245099	0.0000
D(EC(-4))	0.351241	0.076499	4.591427	0.0000
R-squared	0.479342	Mean dependent var		0.000108
Adjusted R-squared	0.465077	S.D. dependent var		0.035368
S.E. of regression	0.025868	Akaike info criterion		−4.439101
Sum squared resid	0.097693	Schwarz criterion		−4.339191
Log likelihood	340.1521	Hannan-Quinn criter.		−4.398513
Durbin-Watson stat	1.879001			

Table 4.2.

Dependent Variable: USD_EUR

Method: Least Squares

Date: 05/01/13 Time: 03:12

Sample (adjusted): 2000M04 2013M03

Included observations: 159

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.000525	0.000377	−1.391272	0.1661
USD_EUR_3MO	1.000492	0.001502	666.1035	0.0000
R-squared	0.999646	Mean dependent var		0.188391
Adjusted R-squared	0.999644	S.D. dependent var		0.166004
S.E. of regression	0.003132	Akaike info criterion		−8.681760
Sum squared resid	0.001540	Schwarz criterion		−8.643158
Log likelihood	692.1999	Hannan-Quinn criter.		−8.666084
F-statistic	443693.9	Durbin-Watson stat		0.157920
Prob (F-statistic)	0.000000			

Table 4.2(b)

Null Hypothesis: EC2 has a unit root

Exogenous: None

Lag Length: 1 (Automatic-based on SIC, maxlag = 13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−2.402287	0.0162
Test critical values:	1% level	−2.579774	
	5% level	−1.942869	
	10% level	−1.615359	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable: D(EC2)

Method: Least Squares

Date: 05/01/13 Time: 03:21

Sample (adjusted): 2000M03 2013M03

Included observations: 157 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
EC2(−1)	−0.073882	0.030755	−2.402287	0.0175
D(EC2(−1))	−0.254660	0.076717	−3.319472	0.0011
R-squared	0.114773	Mean dependent var		3.80E − 05
Adjusted R-squared	0.109062	S.D. dependent var		0.001247
S.E. of regression	0.001177	Akaike info criterion		−10.63914
Sum squared resid	0.000215	Schwarz criterion		−10.60020
Log likelihood	837.1723	Hannan-Quinn criter.		−10.62332
Durbin-Watson stat	2.064020			

