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Testing for Stationarity Using Covariates: An Application to Purchasing Power Parity

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Abstract

We examine the evidence for Purchasing Power Parity using post Bretton Woods exchange rate data for twenty industrialized countries. The two tests we use are covariate tests for stationarity where the null hypothesis of stationarity is tested against the unit root alternative. These tests are generalizations of existing univariate stationarity tests and improve the power of univariate tests by utilizing information contained in related stationary covariates. We conclude that PPP holds for 17 out of the 20 countries tested.

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1. Introduction

Purchasing Power Parity (PPP) has been studied extensively because of its importance as a basic tenant of established macroeconomic theory. Even though it is recognized that PPP does not hold as a short run condition, there is growing evidence in the literature to support it as a long run condition

The time series implication of PPP is the reversion of the exchange rate to a constant mean.[1] Testing for mean reversion in exchange rates usually involves using either a unit root test or a stationarity test. Unit root tests test the null of a unit root against an alternative of stationarity, or mean reversion. If the unit root null hypothesis is rejected, then the series is said to be stationary. Stationarity tests test the null hypothesis of stationarity against a unit root alternative. If the test fails to reject the null, the time series is said to be stationary. These two families of tests have been applied to testing for PPP using flexible exchange rate data for the post Bretton Woods period.

Unit root tests consist of univariate and covariate tests. Univariate tests, such as the Augmented Dickey Fuller (ADF) test of Dickey and Fuller (1979), the generalized least squares ADF (DF-GLS), and the Point Optimal tests (PT) of Elliott, Rothenburg, and Stock (1996), have had mixed results in their application to PPP with the U.S. dollar as numeraire. Very few rejections are reported using the ADF test. Cheung and Lai (2000), Wu and Wu (2001), and Papell (2002) report 0 or 1 rejection out of 20 industrialized countries at the 5% significance level. Amara and Papell (2003) report 4

[1] The most restrictive form of PPP, absolute PPP, defined by Cassel (1918) states that international arbitrage will cause the relative prices of a common basket of goods to be equalized when expressed in the same currency. The relative form of PPP, which is what we measure, emphasizes that the exchange rate will adjust to reflect the movement in the price levels between countries.

rejections using the PT test and 3 rejections using the DF-GLS test at the 5% significance level. The explanation for the low rejection rates has been the low power of these tests over the relatively short time span of data, less than 30 years.[2]

In an effort to increase power of unit root tests, longer data sets that mix both fixed and flexible exchange rates are also used. Frankel (1986), Lothian and Taylor (1996), Taylor (2002), and Lopez, Murray, and Papell (2002) apply univariate unit root tests to data spanning one to two centuries. These studies find stronger evidence of PPP than studies using only post Bretton Woods data. The issue with these studies is that they use data from fixed and flexible exchange rate regimes. This does little to explain if PPP holds for flexible exchange rates.

Rossi (2005) using local to unity asymptotic theory to construct confidence intervals for half life deviations from PPP concludes that the lower bound of the confidence intervals is not inconsistent with PPP but the upper bounds are infinity for all currencies resulting in inconclusive evidence of PPP.

Murray and Papell (2006) use panel methods to sharpen the evidence of purchasing power parity. They show that the panel methods are subject to the same bias problems as univariate methods and conclude that panels do not help solve the PPP puzzle.

Mark et. al. (2006) points to three potential sources of bias in the estimation of PPP convergence. Controlling for the bias, they obtain results consistent with Murray and Papell (2006).

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[2] Multivariate tests, such as the panel unit root tests increase the power of unit root tests without having to mix exchange rate regimes by exploiting cross section and time series variation of the data. However, the issue with panel unit root tests is that the rejection of the unit root null does not indicate which individual exchange rates are mean reverting. Depending on the panel unit root test used , the null is that all real exchange rates have unit roots and the alternative is either that all exchange rates are mean reverting or at least one exchange rate is mean reverting.

Testing for unit roots in a univariate time series ignores relevant information contained in other time series. Hansen (1995) and Elliott and Jansson (2002) derive covariate unit root tests with substantial power gains over their conventional unit root counterparts by exploiting the information in related time series. These tests increase power by modeling correlated stationary economic variables with the dependent variable. The use of stationary covariates results in a new error variance that is smaller than the error variance of a univariate regression. This results in smaller confidence intervals and more powerful test statistics than those of the conventional unit root tests. Hansen (1995) develops the covariate ADF test (CADF). The CADF test essentially modifies the ADF test by using covariates. Caporale and Pitts (1999) apply CADF to Nelson and Plosser (1982) U.S. macroeconomic data and reverse the finding of a unit root in most cases. Amara and Papell (2003) apply the CADF to post Bretton Woods real exchange rate data and reject the unit root null at the 5% level for 2 countries and for 2 additional countries at the 10% level. The covariate feasible point optimal test (CPT) of Elliott and Jansson (2002), which modifies the PT test, also uses stationary variables to increase power.

The CPT results in stronger evidence of PPP than is found without covariates and also stronger evidence than with the CADF test. Elliott and Pesavento (2001) reject the unit root at the 5% significance level for 3 countries and at the 10% level for 1 country out of a total of 7 countries tested. Amara and Papell (2003) reject the unit root for 16 developed countries at the 5% significance level and 2 at the 10% level out of 20 countries tested.

The second family of tests, stationarity tests, reverses the null and alternative hypotheses of the unit root tests. The stationarity test examines the null hypothesis of level or trend stationarity, I(0), against the alternative of difference stationarity, I(1).[3] The tests most widely used are those of Kwiatkowski, Phillips, Schmidt, and Shin (1992) (KPSS), Saikkonen and Luukkonen (1993), and Leybourne and McCabe (1994). Culver and Papell (1999) apply KPSS tests to real exchange rates for the time period 1973 to 1996. They report that 15 out of 20 countries fail to reject the null of stationarity. Caner and Kilian (2001) for the time period 1973 to 1997 report 15 countries fail to reject the null of stationarity using KPSS. They also report 3 countries fail to reject the stationarity null using the Leybourne-Mcabe test. However, the statonarity tests are demonstrated to have large size distortions in highly persistent stationary processes as documented by Caner and Kilian (2001).

Jansson (2002) proposes two new stationarity tests that are extensions of the KPSS and Saikkonen and Luukkonen tests and dominate these tests in terms of local asymptotic power. The improvements are achieved by adding related stationary covariates and exploiting the information contained in the covariates. When the zero frequency correlation between the covariates and the dependent variable is non zero, the new tests are more powerful than their univariate counterparts.

We apply Jansson's stationarity tests to real exchange rates and to nominal exchange rates, for test validation and as an indication of the test behavior. We find compelling evidence of PPP using Jansson's stationarity tests. Using the real exchange rates, we fail to reject the null of stationarity for all 20 countries. The nominal exchange rate rejects stationarity for 17 of the 20 countries. We conclude that for 17 of the countries we have strong evidence of PPP and for the remaining 3, we have suspect evidence of long run

[3]Even thought the tests allow for a null hypothesis of trend or level stationarity, we apply the null of level stationarity to exchange rate data. This is consistent with the implication that relative PPP is the reversion of the exchange rate to a constant mean.

PPP. The results complement those of Amara and Papell (2003) where they reject the unit root null for 18 out of 20 countries for real exchange rates.

In Section 2, we provide an overview of the covariate stationarity tests. Section 3 presents the results of testing for PPP using real exchange rates, the results of a robustness test, and compares the findings to those of the CPT test. Section 4 concludes.

2. Overview of the Covariate Augmented Jansson Tests for Stationarity

The stationarity tests proposed by Jansson (2002) are generalizations of existing univariate stationarity tests, the KPSS test and Saikkonen and Luukkonen test. It is based on the observation that we rarely have a time series, y_t, in isolation. More typically, we observe at least one related time series, x_t. The Jansson tests exploit the information in related time series to improve power of stationarity tests and dominate their univariate counterpart whenever the correlation between the covariates and the dependent variable is non zero. When the zero frequency correlation is zero, the Jansson tests coincide with the univariate tests.[4]

Consider a univariate time series, y_t, with a deterministic stationary component, μ_t^y, and an unobserved error component, υ_t^y

$$y_t = \mu_t^y + \upsilon_t^y,$$

[4] The concept of using covariates to enhance the power of stationarity tests is similar to that used in Hansen (1995) and Elliott and Jansson (2002) that use covariates to enhance the power of unit root tests.

The initial condition for the error process is $\upsilon_1^y = u_1^y$ and the generating mechanism for the error

$$\Delta \upsilon_t^y = (1-\theta L)u_t^y$$

where u_t^y is a stationary I(0) process.

Next, consider a time series x_t of stationary covariates,

$$x_t = \mu_t^x + u_t^x$$

where μ_t^x is the deterministic component and u_t^x is an unobserved stationary I(0) process. The covariate stationarity tests propose to exploit the information contained in the covariate x_t when testing the null hypothesis that y_t is stationary. The covariate tests dominate their univariate counterparts in terms of asymptotic local power when the zero frequency correlation between u_t^y and u_t^x is non zero.

The null is $H_0 : \theta = 1$. The alternative is $H_1 : \theta < 1$. We test whether the permanent component, $(1-\theta)\sum_{s=1}^{t-1} u_s^y$, is absent from the permanent transitory decomposition of y_t

$$y_t = \mu_t^y + (1-\theta)\sum_{s=1}^{t-1} u_s^y + u_t^y$$

For the covariate stationarity tests, we consider the transformed series $y_t - \sigma_{xy}' \Sigma_{xx}^{-1} x_t$ with the permanent transitory decomposition

$$y_t - \sigma_{xy}' \Sigma_{xx}^{-1} x_t = \mu_t^{y.x} + (1-\theta)\sum_{s=1}^{t-1} u_s^y + u_t^{y.x}$$

where $\mu_t^{y.x} = \mu_t^y - \sigma_{xy}' \Sigma_{xx}^{-1} \mu_t^x$ and $u_t^{y.x} = u_t^y - \sigma_{xy}' \Sigma_{xx}^{-1} u_t^x$.

Since x_t is stationary, the transformation does not affect the permanent component. The transformation reduces the variance of the transitory component, $Var(u_t^{y.x}) = (1 - \rho^2)Var(u_t^y)$ by a fraction $\rho^2 = \sigma_{yy}^{-1}\sigma'_{xy}\Sigma_{xx}^{-1}\sigma_{xy}$, where ρ^2 is the squared coefficient of multiple correlation computed from the covariance matrix of u_t. Thus, the covariates are used to attenuate the transitory component of y_t without affecting the permanent component, making it easier to detect the permanent component in y_t and leading to improvements in power. The value of ρ^2 represents the contribution of the stationary variables. It will be equal to zero when there is no long run correlation and one if there is perfect correlation. The value of $\rho^2 < 1$ is imposed to rule out the case under the null when the partial sums of x_t cointegrated with y_t.[5]

The two tests proposed by Jansson are the Locally Optimal Test, L test, which contains the KPSS test as a special case, and the Point Optimal Test, Q test, with contains Saikkonen and Luukkonen's univariate model as a special case. Both tests rely on a nonparametric estimator of the variance of the residual under local to null asymptotics. The KPSS test statistic takes the form:

$$\hat{\eta}_\mu = T^{-2}\sum S_t^2 / s^2(l)$$

where the subscript μ indicates that we have extracted a mean and not a trend from *y*. T is the number of data points. S_t^2 is the partial sum process of the residuals squared:

$$S_t = \sum_{i=1}^{t} e_i$$

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[5] If the coefficients of the cointegration are known, the system can be modeled in this framework as proposed by Elliott, Jansson, Pesavento (2002).

$s^2(l)$ is an estimator of the long run variance taking the form:

$$s^2(l) = T^{-1}\sum_{t=1}^{T} e_t^2 + 2T^{-1}\sum_{s=1}^{l} w(s,l)\sum_{t=s+1}^{T} e_t e_{t-s}$$

Here $w(s,l)$ is an optional weighing function that corresponds to a spectral window. We use the Bartlett window $w(s,l) = 1 - s/(l+1)$ which guarantees the non-negativity of the estimator of the long run variance.

The L test takes the form:

$$L_T = \sum_{t=1}^{T} \tilde{V}_t' \Sigma^* \tilde{V}_t + \left(\sum_{t=1}^{T} d_t \Sigma^{**} \tilde{V}_t\right)' \left(\sum_{t=1}^{T} d_t \Sigma^{-1} d_t'\right)^{-1} \left(\sum_{t=1}^{T} d_t \Sigma^{**} \tilde{V}_t\right)$$

where

$$\Sigma = \begin{pmatrix} \sigma_{yy} & \sigma'_{xy} \\ \sigma_{xy} & \Sigma_{xx} \end{pmatrix} \qquad \Sigma^* = \begin{pmatrix} \sigma_{yy.x}^{-1} & \sigma^{xy'} \\ \sigma^{xy} & 0 \end{pmatrix} \qquad \Sigma^{**} = \begin{pmatrix} 0 & \sigma^{xy'} \\ -\sigma^{xy} & 0 \end{pmatrix}$$

and

$$\tilde{V}_t = T^{-1}\sum_{s=1}^{t-1} \tilde{v}_s$$

$$\sigma_{yy.x} = \sigma_{yy} - \sigma'_{xy}\Sigma_{xx}^{-1}\sigma_{xy}$$

$$\sigma^{xy} = -\sigma_{yy.x}^{-1}\Sigma_{xx}^{-1}\sigma_{xy}$$

The Saikkonen and Luukkonen test takes the form:

$$R_2 = T^{-2}\sum_{t=1}^{T} w_t^2 / \hat{\sigma}_y^2$$

where

$$w_t = t\bar{y} - \sum_{j=1}^{t} y_j$$

and

$$\hat{\sigma}_y^2 = T^{-1} y'y - \bar{y}^2$$

The Q test takes the form:

$$Q_T = P_T - 2T(1-\bar{\theta})\omega_{yy.x}^{-1}\gamma_{yy.x}$$

$$P_T = \sum_{t=1}^{T} \tilde{\upsilon}_t'(1;\Sigma)\Sigma^{-1}\tilde{\upsilon}_t'(1;\Sigma) - \sum_{t=1}^{T} \tilde{\upsilon}_t'(\bar{\theta};\Sigma)\Sigma^{-1}\tilde{\upsilon}_t'(\bar{\theta};\Sigma)$$

where the long run covariance matrix is

$$\Omega = \begin{pmatrix} \omega_{yy} & \omega_{xy}' \\ \omega_{xy} & \Omega_{xx} \end{pmatrix}$$

the one sided long run covariance matrix

$$\Gamma = \begin{pmatrix} \gamma_{yy} & \gamma_{xy} \\ \gamma_{xy} & \Gamma_{xx} \end{pmatrix}$$

and

$$\gamma_{yy.x} = \gamma_{yy} - \omega_{xy}'\Omega_{xx}^{-1}\gamma_{xy}$$

and

$$\omega_{yy.x} = \omega_{yy} - \omega_{xy}'\Omega_{xx}^{-1}\omega_{xy}$$

3. Results

3.1 . Stationarity of covariates

We run both the covariate point optimal test and the locally optimal test to test for stationarity using quarterly, nominal, average of period exchange rate data for twenty industrialized countries. The data for Iceland and Luxemburg is not used because of the gaps in Iceland CPI and the monetary union between Luxemburg and Belgium. The data are from the International Monetary Fund's *International Financial Statistics* September 2002. The data starts in the first quarter of 1973 and ends in the fourth quarter of 1998 for a total of 104 quarterly observations. The U.S. dollar is used as the numeraire currency. We do not extend the data past 1998 because the national currencies of about half of the countries were eliminated with the establishment of the Euro.

The real dollar exchange rate is calculated as

$$q_t = s_t - p_t + p_t^*$$

where q_t is the logarithm of the exchange rate, s_t is the logarithm of the nominal (dollar) exchange rate, p_t^* is the logarithm of the U.S. CPI, and p_t is the logarithm of the domestic CPI for each country. For Greece and Ireland, some of the data used to construct covariates are not available and, in that case, the associated covariate test is not calculated.

The kernel used to estimate the long run variance is the Bartlett Kernel. The autocorrelation lag truncation is set at 12 the number of data points, T.[6] The size of the KPSS test is highly sensitive to the choice of truncation lag. KPSS (1992) recommend a comparatively large value of lag, where $l = \text{int}[12(T/100)^{1/4}]$. This choice produced the most accurate results in their studies. The data are not prewhitened. Asymptotic critical

[6] Lag truncation values of 4 and 8 are also used but not reported because the size distortions in generating the finite sample critical values are large.

values used are those provided in Jansson (2002) with intermediate values derived by interpolation.[7]

The choice of covariates used is motivated by macroeconomic theory. The covariates are a combination of income, money, inflation, and current account variables. The covariates used are:

- The growth rate of U.S. income Δy_{us}.
- The growth rate of home country income Δy_h.
- The growth rate of U.S. money supply Δm_{us}.
- The growth rate of home country money supply Δm_h.
- The growth rate of U.S. inflation $\Delta \Pi_{us}$.
- The growth rate of home country inflation $\Delta \Pi_h$.
- The growth rate of the current account of the home country relative to income of the home country $\Delta(ca_h / y_h)$.

Since only stationary covariates can be used, each covariate for every country is tested for stationarity using ADF and DF-GLS tests. The non-stationary covariates are discarded.

All the covariates are stationary for Australia, Austria, Belgium, Canada, Denmark, France, Germany, Greece, Ireland, Japan, Netherlands, New Zealand, Spain, Switzerland, and the U.K.

Finland's nonstationary covariate is the growth rate of home country income. For Italy, the nonstationary covariates are the growth rate of home country income, and the

[7] The Bartlett kernel and lag truncation of 12 are used to allow comparison with Caner and Kilian (2001). Lag truncation of T is used to maintain consistency with Jansson (2002). We propose to regenerate the data using the Quadratic spectral kernel and prewhitening as recommended by Jansson (2002).

growth of home country money supply. Norway is nonstationary for the growth rate of home country income. Portugal data is nonstationary for the growth rate of home country income, and the current account covariate. Sweden data is nonstationary for the growth of home country money supply.

3.2. Testing Using Real Exchange Rates

Using real exchange rates, we find overwhelming evidence of PPP. All countries fail to reject stationarity for various combinations of covariates. We begin to see evidence of stationarity in the exchange rates for Canada and Japan where in previous studies these two countries in particular always exhibited unit root behavior. Tables 1 and 2 present the results of testing using the real exchange rates.

Austria, Belgium, Finland, France, Germany, Greece, Italy, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, and the U.K. real exchange rates are stationary for all covariates.

Using the Locally Optimal test, Australia is not stationary for both truncation lags for the change in U.S. inflation and for truncation lag T for the change in home inflation..

Canada is not stationary for the change of home country inflation, the change of U.S. inflation, and the growth of the home country money supply using the Locally Optimal test for truncation lag T.

Denmark is not stationary using the growth rate of the home country income, and the current account covariate for both truncation lags of the Point Optimal test. It also rejects stationarity for both truncation lags for the Point Optimal using the growth rate of the home country income.

Ireland rejects stationarity for both truncation lags of the Locally Optimal test for the growth of home county inflation.

Japan rejects stationarity for both truncation lags of the Locally Optimal test for the growth of U.S. inflation and the current account covariate. It also rejects stationarity for truncation lag 12 of the Locally Optimal test for the growth of home country inflation.

With the real exchange rates, we fail to reject the null of stationarity for all 20 countries for varying combinations of stationary covariates for each country. Amara and Papell (2002) find evidence of PPP for 19 countries using the CPT test. Canada is the only country which fails to reject the unit root. Culver and Papell (1999) fail to reject the null of stationarity for 17 countries using KPSS and a truncation lag of 12. The countries that reject the null of stationarity are Australia, Ireland, and Japan.

3.3. Testing Nominal Exchange Rates

We also run Jansson's stationarity tests for nominal exchange rates for test validation and as an indication of the test behavior. It is generally accepted that the nominal exchange rate is not stationary. So if over the same time period, the stationary null can not be rejected for the real exchange rates and the nominal exchange rates, the failure to reject for the nominal rate can be construed as an indication of low power of the tests. Table 3 and 4 present the results of the stationarity tests using nominal exchange rate data.

A point of interest is the much higher frequency of rejection of stationarity using the locally optimal test as opposed to using the point optimal test. Jansson (2002) notes that even as the sample size increases, power increases but remains low in the case of the point optimal test. He points out that the locally optimal test is likely to outperform the point optimal test in cases where the time series data is highly persistent.

Of the 20 countries tested, 17 countries using stationary covariates reject stationarity using the nominal exchange rates and fail to reject stationarity using the real exchange rates. We can safely say that these countries exhibit evidence of PPP. Belgium, Ireland, and Norway are the 3 countries that fail. Table 5 summarizes the stationarity results classified by covariates.

Using the univariate counterparts to the L Test and Q Test, we reject the null of stationarity for Germany, Italy, Netherlands, New Zealand, Spain, Sweden, and the UK at the ten percent level and for Greece, Portugal, and Switzerland at the five percent level applying the L Test. We reject the null of stationarity using the Q Test for Australia, Canada, and Japan at the ten percent level. Table 6 details the results of the univariate stationarity tests.

Culver and Papell (1999) reject the null of stationarity for 16 countries using KPSS and a truncation lag of 12. The countries that fail to reject the null of stationarity are Belgium, Denmark, Finland, and France. They conclude that 13 countries exhibit evidence of PPP.

Comparing the results of Jansson's stationarity tests with the CPT tests, the following emerges. Australia, Austria, Denmark, Finland, France, Germany, Greece, Italy, Netherlands, New Zealand, Portugal, Spain, Sweden, Switzerland, and the U.K fail to reject stationarity and reject the unit root. Both the CPT test and Jansson's stationarity tests confirm the evidence of PPP in these 15 countries.

Ireland and Norway reject stationarity and reject the unit root null using CPT. However, they both reject the unit root null for a combination of ADF, PT, DF-GLS, and KPSS. It would appear plausible to assume that these 2 countries exhibit evidence of PPP.

Canada fails to reject stationarity for covariate and univariate stationarity tests and fails to reject the unit root null for covariate and univariate unit root tests. It would still appear reasonable to assume that it exhibits evidence of PPP. Japan exhibits evidence of PPP using the covariate stationarity test and the CPT test. Belgium exhibits evidence of stationarity using the univariate PT and DF-GLS test. Using a combination of univariate and covariate unit root and stationarity tests, we can find evidence of mean reversion in all 20 countries.

It is important to note that the evidence of mean reversion, when both real and nominal exchange rates are considered, is stronger using CPT with more covariates contributing to evidence of PPP. This calls into question the power and size of Jansson's stationarity tests.

Univariate stationarity tests are demonstrated to have large size distortions in highly persistent stationary processes as documented by Caner and Kilian (2001). Since most processes in empirical macroeconomics tend to be highly persistent, very little is learned from the test except in the case of a rejection of stationarity. Due to the size distortions, the results obtained from stationarity tests may contradict those obtained by applying unit root tests. Caner and Kilian use size adjusted critical values to circumvent the problem of size distortions. They apply the KPSS to quarterly real exchange rate data and find only one rejection of the stationary null for Japan using a half life of 5 years. However, they caution against interpreting this as convincing evidence of long run PPP since the power of KPSS after size corrections may fall as low at 20% at the 5% level.

4. Conclusion

We have taken Jansson's tests for stationarity and applied them to post Bretton Woods exchange rate data for 20 industrialized countries. The results of the locally optimal and the point optimal test for the real exchange rate data are very encouraging. We fail to reject stationarity for all countries using real exchange rates and we reject stationarity for 17 countries using nominal rates. Reconciling the results from both real and nominal exchange rates, we can support PPP for 17 countries. The results for the 17 countries can be collaborated by univariate and covariate unit root tests

While there are obviously gains from using the covariate stationarity tests, we conclude that further simulation work needs to be done to understand the power and size distortion of these tests. Size adjusted critical values based on plausible assumptions about half life deviations from PPP need to be calculated and their effect on the results assessed.

References

Amara, J. and David H. Papell (2003), "Testing for Purchasing Power Parity Using Stationary Covariates," working paper, University of Houston.

Caner, M. and L. Kilian (2001), "Size Distortions of Tests of the Null Hypothesis of Stationarity: Evidence and Implications for the PPP Debate," *Journal of International Money and Finance*, 20, 639-657.

Caporale, G. M., and N. Pittis (1999), "Unit Root Testing Using Covariates: Some Theory And Evidence," *Oxford Bulletin of Economics and Statistics*, 61, 583-595.

Cassel, G. (1918), "Abnormal Deviations in International Exchanges," *The Economic Journal*, 28, 413-415.

Cheung, Y-W, and K. Lai (200), "On Cross Country Differences in the Persistence of Real Exchange Rates," *Journal of International Economics*, 50, 375-397.

Culver, S. E., and D. H. Papell (1999), "Long –Run Purchasing Power Parity with Short Run Data: Evidence with a Null Hypothesis of Stationarity," *Journal of Internaltional Money and Finance*,18, 751-768.

Dickey, D. A., and W. A. Fuller, "Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root," *Econometrica*, 49, 1057-1072.

Elliott, G., and M. Jansson (2003), "Testing for Unit Roots with Stationary Covariates," *Journal of Econometrics*, 115, 75-89.

Elliott, G., E. Pesavento (2001), "Higher Power Tests for Bilateral Failure of PPP after 1973," manuscript, Emory University.

Elliott, G., T. J. Rothenburg and J. H. Stock (1996), "Efficient Tests for an Autoregressive Unit Root," *Econometrica*, 64, 813-836.

Frankel, J. (1986), "International Capital Mobility and Crowding Out in the U.S. Economy: Imperfect Integration of Financial Markets or of Goods Markets?" in R. Hafer, ed., *How Open is the U.S Economy?,* Lexington Books.

Hansen, B. E. (1995), "Rethinking The Univariate Approach To Unit Root Testing," *Economic Theory,* 11, 1148-1171.

Jansson, M. (2002), " Stationarity Testing with Covariates," *Econometric Theory,* forthcoming.

Kwiatkowski, D., P.C.B. Phillips, P. Schmidt, and Y. Shin (1992), "Testing the Null of Stationarity Against the Alternative of a Unit Root: How Sure Are We That Economic Time Series Have a Unit Root?" *Journal of Econometrics,* 54, 159-178.

Leybourne, S. J. and B. P. M. McCabe (1994), "A consistent test for a unit root," *Journal of Business and Economic Statistics,* 12, 157-166.

Lopez, C., C. J. Murray and D. H. Papell (2002), "State of the Art Unit Root Tests and the PPP Puzzle," working paper, University of Houston.

Lothian, J. R. and M. P. Taylor (1996), "Real Exchange Rate Behavior: The Recent Float from the Perspective of the Past Two Centuries," *Journal of Political Economy,*104, 488-509.

Murray, Chris and David Papell (2005) "Do Panels Help Solve the Purchasing Power Parity Puzzle?" Jo*urnal of Business and Economic Statistics* 23: 410-415.

Mark, Nelson and C.Y. Choi and D. Sul (2006) " Unbiased Estimation of the Half-Life to PPP Convergence in Panel Data,"Jo*urnal of Money, Credit, and Banking 38:* 921-938.

Nelson, C. and C. Plosser (1982), "Trends and Random Walks in Macroeconomic Time Series: Some Evidence and Implications," *Journal of Monetary Economics*, 10, 139-162.

Papell, D. H. (2002), "The Great Appreciation, the Great Depreciation and the Purchasing Power Parity Hypothesis," *Journal of International Economics*, 57, 51-82.

Rossi, Barbara (2005), "Confidence Intervals for Half-Life Deviations from Purchasing Power Parity," Jo*urnal of Business and Economic Statistics,* 23(4), 432-442.

Saikkonen, P., and R. Luukkonen (1993), "Testing for a Moving Average Unit Root in Autoregressive Integrated Moving Average Models," *Journal of the American Statistical Association,* 88, 596-601.

Taylor, A. (2002), "A Century of Purchasing – Power Parity," *Review of Economics and Statistics*, 84, 139-150.

Wu, Jyh-Lin and S. Wu (2001), "Is Purchasing Power Parity Overvalued?" *Journal of Money, Credit, and Banking,* 33, 804-812.

Table 1: Testing for stationarity using Jansson's covariate stationarity tests for real exchange rates

	Δy_{us}			Δy_h			Δm_{us}			Δm_h		
	ρ	L Test	Q Test	ρ	L Test	Q Test	ρ	L Test	Q Test	ρ	L Test	Q Test
lag truncation		T	T		T	T		T	T		T	T
Australia	0.64	0.00	-8.52	0.48	0.03	-6.74	0.29	0.21	-4.52	0.00	0.39*	-2.64
Austria	0.17	0.09	-4.02	0.34	0.16	-3.74	0.47	0.00	-5.49	na	na	na
Belgium	0.06	0.10	-4.41	0.00	0.25	-3.79	0.01	-3.84	-3.82	na	na	na
Canada	0.28	0.16	-3.77	0.40	0.08	-4.61	0.10	0.25	-3.10	0.65	0.37*	-2.26
Denmark	0.04	-4.20	-3.89	0.14	0.26	0.63**	0.27	0.07	-4.34	0.53	-4.63	-5.46
Finland	0.02	0.08	-3.96	-	-	-	0.17	0.10	-4.14	na	na	na
France	0.00	0.10	-3.97	0.03	0.10	-3.87	0.76	-0.05	-7.41	0.08	0.16	-3.05
Germany	0.01	0.11	-3.99	0.01	0.12	-4.13	0.07	0.13	-3.68	0.00	-3.90	-3.85
Greece	0.01	0.12	-3.82	na	na	na	0.03	0.10	-3.39	na	na	na
Ireland	0.63	-0.10	-7.51	na	na	na	0.86	-0.39	-15.88	na	na	na
Italy	0.35	0.03	-4.91	-	-	-	0.63	0.00	-5.47	-	-	-
Japan	0.74	-0.08	-9.72	0.74	-0.08	-9.72	0.90	0.75	-27.37	0.23	-0.11	-8.49
Netherlands	0.10	0.10	-4.33	0.17	0.15	-4.31	0.12	0.12	-3.80	0.27	0.20	-4.27
New Zealand	0.19	0.10	-3.26	0.17	0.19	-4.33	0.47	0.05	-4.19	0.28	0.12	-3.12
Norway	0.00	0.09	-4.06	-	-	-	0.00	0.08	-4.86	0.00	0.08	-4.85
Portugal	0.11	0.11	-3.87	-	-	-	0.77	-0.12	-7.69	0.06	0.21	-3.85
Spain	0.22	0.50	-4.49	0.21	0.06	-4.28	0.56	-0.06	-6.72	0.10	-0.11	-3.75
Sweden	0.13	0.08	-4.63	0.18	0.03	-4.92	0.00	0.14	-3.77	-	-	-
Switzerland	0.28	0.08	-4.28	0.32	0.12	-5.86	0.58	-0.05	-6.66	0.19	0.35	-2.87
UK	0.26	0.10	-3.61	0.01	0.26	-2.27	0.38	0.04	-4.75	0.46	0.27	-2.43

Note : *** reject stationarity at 1%, ** reject stationarity at 5%, * reject stationarity at 10%
- covariate is not stationary
^ correlation is not within limits of 0 and 1
na data is not available

Table 2: Testing for stationarity using Jansson's covariate stationarity tests for real exchange rates

	$\Delta\Pi_{us}$			Π_h			Δ` $_h/y_h$)		
	ρ	L Test	Q Test	ρ	L Test	Q Test	ρ	L Test	Q Test
lag truncation		T	T		T	T		T	T
Australia	0.07	0.39*	-2.65	0.01	0.43*	-2.60	0.22	0.26	-4.13
Austria	0.08	0.22	-4.27	0.01	0.20	-3.70	0.04	0.24	-3.72
Belgium	0.15	0.12	-4.60	0.06	0.09	-4.12	0.00	0.26	-3.72
Canada	0.10	0.38*	-2.38	0.00	0.37*	-2.36	0.13	0.41	-3.04
Denmark	0.11	0.13	-4.77	0.11	0.12	-4.40	0.01	0.15	-1.50*
Finland	0.18	0.07	-5.09	0.00	-4.58	-3.92	0.01	0.08	-3.82
France	0.09	0.09	-4.68	0.51	-6.87	-7.02	0.00	0.11	-3.83
Germany	0.09	0.10	-4.65	0.06	0.13	-3.95	0.43	0.10	-4.99
Greece	0.03	0.14	-4.11	0.09	0.17	-5.14	na	na	na
Ireland	0.05	0.38	-3.36	0.03	0.36*	-3.04	na	na	na
Italy	0.12	0.22	-4.51	0.06	0.21	-3.97	0.04	0.19	-3.76
Japan	0.04	0.47**	-2.95	0.23	0.35	-4.04	0.26	0.40*	-4.56
Netherlands	0.28	0.09	-4.75	0.03	0.11	-3.95	^	^	^
New Zealand	0.09	0.22	-3.97	0.02	0.17	-3.32	0.13	0.28	-4.72
Norway	0.15	0.07	-5.17	0.02	0.08	-4.16	0.05	0.04	-6.31
Portugal	0.04	0.18	-4.07	0.02	0.19	-3.91	-	-	-
Spain	0.08	0.21	-4.23	0.08	0.20	-4.01	0.01	0.15	-4.07
Sweden	0.10	0.14	-4.34	0.07	0.13	-4.34	0.05	0.32	-3.73
Switzerland	0.06	0.31	-3.73	0.01	0.27	-3.31	na	na	na
UK	0.01	0.30	-2.73	0.05	0.30	-2.79	0.31	0.51	-2.24

Note: *** reject stationarity at 1%, ** reject stationarity at 5%, * reject stationarity at 10%

- covariate is not stationary

^ correlation is not within limits of 0 and 1

na data is not available

Table 3: Testing for stationarity using Jansson's covariate stationarity tests for nominal exchange rates

	Δy_{us}			Δy_h			Δm_{us}			Δm_h		
	ρ	L Test	Q Test	ρ	L Test	Q Test	ρ	L Test	Q Test	ρ	L Test	Q Test
lag truncation		T	T		T	T		T	T		T	T
Australia	0.88	-0.20	-12.89	0.78	-0.20	-12.89	0.64	0.35	-7.88	0.03	0.44*	-2.86
Austria	0.65	0.00	-7.29	0.85	0.17	-3.43	0.85	0.23	-16.35	na	na	na
Belgium	0.02	0.11	-3.81	0.14	0.28	-3.74	0.20	0.08	-4.16	na	na	na
Canada	0.58	0.17	-6.48	0.62	-0.06	-9.30	0.30	0.29	-4.08	0.90	-0.27	-21.01
Denmark	0.02	0.11	-4.11	0.00	-0.02	-3.04	0.04	0.21	-3.95	0.20	0.13	-3.67
Finland	0.37	0.07	-5.41	-	-	-	0.10	0.19	-3.75	na	na	na
France	0.19	0.09	-5.02	0.06	0.10	-4.75	0.21	0.33	-4.85	0.08	0.20	-1.62*
Germany	0.62	0.01	-6.72	0.83	0.40*	-2.91	0.83	0.06	-15.07	0.00	0.41*	-2.91
Greece	0.62	0.94	-36.63	na	na	na	0.57	0.10	-3.98	na	na	na
Ireland	0.33	0.09	-5.49	na	na	na	0.08	0.22	-3.48	na	na	na
Italy	0.69	0.08	-9.66	-	-	-	0.41	0.19	-5.87	-	-	-
Japan	0.87	-0.06	-18.48	0.87	-0.16	-7.96	0.89	1.53	-23.11	0.81	-0.18	-11.93
Netherlands	0.51	0.03	-5.52	0.73	0.36*	-3.18	0.80	-0.31	-12.52	0.71	-11.36	-11.36
New Zealand	0.44	-0.11	-14.88	0.80	0.16	-5.09	0.51	0.22	-6.48	0.03	0.49**	-2.29
Norway	0.61	-0.57	-8.91	-	-	-	0.00	0.08	-5.24	0.00	0.07	-4.87
Portugal	0.84	-0.04	-17.97	-	-	-	0.49	0.32	-4.52	0.78	0.33	-11.71
Spain	0.63	0.02	-8.74	0.72	-0.12	-11.85	0.53	0.14	-7.73	0.25	0.22	-4.72
Sweden	0.73	-0.07	-11.39	0.80	0.26	-1.30*	0.39	0.32	-3.25	-	-	-
Switzerland	0.75	0.21	-9.63	0.87	0.47*	-3.07	0.79	0.87	-11.91	0.02	0.53**	-1.86*
UK	0.60	0.04	-8.16	0.02	0.37	-4.46	0.29	0.63**	-1.72*	0.05	0.49**	-1.77*

Note: *** reject stationarity at 1%, ** reject stationarity at 5%, * reject stationarity at 10%.

- covariate is not stationary

^ correlation is not within limits of 0 and 1

na data is not available

Table 4: Testing for stationarity using Jansson's covariate stationarity tests for nominal exchange rates

	$\Delta\Pi_{us}$			$\Delta\Pi_{h}$			$_{h}$ $/y_{h})$		
	ρ	L Test	Q Test	ρ	L Test	Q Test	ρ	L Test	Q Test
lag truncation		T	T		T	T		T	T
Australia	0.00	0.49**	-2.35	0.03	0.50**	-2.37	0.26	0.38	-4.58
Austria	0.02	-2.94	-2.58	0.00	0.42*	-2.82	0.23	0.41*	-3.41
Belgium	0.00	0.14	-3.86	0.05	0.14	-3.85	0.00	0.30	-3.64
Canada	0.03	0.46**	-2.17	0.00	0.46**	-2.04	0.00	0.47**	-2.10
Denmark	0.10	0.11	-4.42	0.12	0.12	-4.21	0.57	0.17	-2.72
Finland	0.08	0.30	-3.33	0.04	0.41*	-1.57*	0.31	0.08	-4.32
France	0.04	0.16	-3.96	0.47	0.09	-4.96	0.18	0.17	-3.54
Germany	0.03	0.43*	-3.03	0.00	0.40*	-2.90	0.14	0.47*	-3.42
Greece	0.00	-1.67*	-2.53	0.09	0.53**	-2.35	na	na	na
Ireland	0.04	0.26	-3.18	0.26	0.31	-4.74	na	na	na
Italy	0.02	0.45*	-2.44	0.34	0.58**	-4.62	0.37	0.40	-4.78
Japan	0.00	0.75	-27.37	0.31	0.44*	-4.28	0.06	0.40*	-4.56
Netherlands	0.03	0.39*	-3.30	0.05	0.34	-3.30	^	^	^
New Zealand	0.00	0.43*	-2.49	0.50	0.38	-3.83	0.44	0.47*	-0.27
Norway	0.32	0.32	-3.34	0.02	0.32	-3.89	0.73	0.56	-12.40
Portugal	0.00	0.46*	-2.48	0.64	0.36*	-3.45	-	-	-
Spain	0.02	0.40*	-2.72	0.04	0.42*	-2.66	0.52	0.38*	-2.60
Sweden	0.02	0.41*	-2.89	0.16	0.42*	-3.81	0.00	0.29	-1.02*
Switzerland	0.01	0.56**	-2.20	0.00	0.51*	-2.18	na	na	na
UK	0.01	0.37*	-2.55	0.01	-0.08	-11.43	0.17	0.47*	-2.01

Note: **** reject stationarity at 1%, reject stationarity at 5%, reject stationarity at 10%.

- \- covariate is not stationary
- ^ correlation is not within the limits of 0 and 1
- na data is not available

Table 5: Summary of covariates that reject stationarity

Country	Real Exchange Rates	Nominal Exchange Rates
Australia	Δm_h, $\Delta\pi_{us}$, $\Delta\pi_h$	Δm_h, $\Delta\pi_{us}$, $\Delta\pi_h$
Austria		$\Delta\pi_h$, $\Delta\pi_{us}$, $\Delta(ca_h/y_h)$
Belgium		
Canada	Δm_h, $\Delta\pi_{us}$, $\Delta\pi_h$	$\Delta\pi_h$, $\Delta\pi_{us}$, $\Delta(ca_h/y_h)$
Denmark	Δy_h, Δm_h,$\Delta(ca_h/y_h)$	Δm_{us}
Finland		$\Delta\pi_h$
France		Δm_h
Germany		Δy_h, Δm_h, $\Delta\pi_{us}$, $\Delta\pi_h$, $\Delta(ca_h/y_h)$
Greece		$\Delta\pi_h$, $\Delta\pi_{us}$
Ireland	$\Delta\pi_h$	
Italy		$\Delta\pi_h$, $\Delta\pi_{us}$, $\Delta(ca_h/y_h)$
Japan	$\Delta\pi_h$, $\Delta\pi_{us}$, $\Delta(ca_h/y_h)$	$\Delta\pi_h$, $\Delta(ca_h/y_h)$
Netherlands		Δy_h , $\Delta\pi_{us}$
New Zealand		Δm_h, $\Delta\pi_h$, $\Delta\pi_{us}$, $\Delta(ca_h/y_h)$
Norway		
Portugal		$\Delta\pi_h$, $\Delta\pi_{us}$
Spain		$\Delta\pi_h$, $\Delta\pi_{us}$, $\Delta(ca_h/y_h)$
Sweden		Δy_h, Δm_h,Δm_{us}, $\Delta\pi_{us}$, $\Delta(ca_h/y_h)$
Switzerland		Δy_h, Δm_h, $\Delta\pi_{us}$, $\Delta\pi_h$
UK		Δy_h, Δm_h,Δm_{us}, $\Delta\pi_{us}$, $\Delta(ca_h/y_h)$

Table 6: Testing for stationarity using Univariate stationarity tests for nominal and real exchange rates

	Nominal Exchange		Exchange	
	L Test	Q Test	L Test	Q Test
Australia	0.50*	-2.37	0.39*	-2.58
Austria	0.42	-2.82	0.20	-3.70
Belgium	0.13	-3.86	0.11	-3.94
Canada	0.46	-2.11	0.37*	-2.30
Denmark	0.11	-3.87	0.13	-3.93
Finland	0.30	-2.82	0.08	-3.93
France	0.17	-3.56	0.10	-3.92
Germany	0.40*	-2.90	0.11	-3.87
Greece	0.50**	-2.52	0.14	-3.88
Ireland	0.28	-2.80	0.34	-3.18
Italy	0.45*	-2.29	0.18	-3.89
Japan	0.48**	-2.70	0.43*	-2.81
Netherlands	0.36*	-3.10	0.11	-3.90
New Zealand	0.43*	-2.49	0.20	-3.33
Norway	0.32	-3.12	0.09	-4.06
Portugal	0.47**	-2.45	0.17	-3.88
Spain	0.40*	-2.57	0.19	-3.77
Sweden	0.41*	-2.69	0.16	-3.67
Switzerland	0.51**	-2.18	0.28	-3.31
UK	0.39*	-2.29	0.29	-2.71

Note: **** reject stationarity at 1%, reject stationarity at 5%, reject stationarity at 10%.

- covariate is not stationary

^ correlation is not within the limits of 0 and 1

na data is not available