A Model of Exchange Rate Innovation with Short and Long Term Determinants

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This paper develops a model of exchange rate determination within an error correction framework. Using daily data, the intention is to identify both short and long-term determinants that can be used to forecast the AUD/USD exchange rate. Specifically, the overnight interest rate differential, Australia's foreign trade-weighted exposure to commodity prices and exchange rate volatility all provide explanatory power for the AUD/USD exchange rate over the post float period 1984-2004. When forecast out of sample, the error correction model is found to perform better then a naïve random walk model based on three different metrics.

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1 Introduction

It is curious that there still is no fundamental model of exchange rate determination that is able to explain price innovation within foreign exchange markets. Failure has not been due to a lack of interest: in fact, the international finance literature is rich with empirical investigation of models which attempt to explain exchange rate innovation (see MacDonald, 2000). The bulk of this research has occurred since the collapse (1971) of the Bretton Woods fixed exchange rate system. None of the models developed so far are no better at forecasting exchange rates then the benchmark model where exchange rate innovation is explained as a simple random walk (see Meese & Rogoff, 1983).

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Recent models developed since the mid 1980's have not performed any better. Cheung *et al.* (2003) points out that they provide poor in sample fit, low out of sample forecasting accuracy (especially at short horizons) and general inconsistency across currencies and sample periods. There has however, been some success forecasting exchange rates at longer horizons (12-18 months) using models grounded in purchasing power parity (PPP) and monetary theory (see MacDonald et al., 2002). Moderate success at forecasting exchange rates in the long run yet not being able to do so in the short run has given rise to the idea that contemporary modelling should try to combine both long and short run variables into a single integrated framework. Taylor (1995) cites this as the most important contemporary challenge facing exchange rate economists. This paper takes up Taylor's (1995) challenge. This is done by incorporating into a single framework for the AUD/USD exchange rate both short and long term variables that are then used to forecast the short term rate. This is done using data covering a twenty year period from December, 1984 to June, 2004.

The paper proceeds as follows. First, theoretical and empirical evidence pertaining to long run structural exchange rate models is reviewed. This is done in order to identify long term variables which have been empirically tested and that have been shown within the literature to have some success at forecasting the long term rate. This is done in Section 2. Based on this evidence, stylized determinants of the AUD/USD exchange rate are identified. These long term variables are interest rates, and commodity prices. In Section 3 testing is then undertaken to determine the equilibrium relationship that exists between the exchange rate and these determinants. An error correction term is then generated from these estimations which is then used as a measure of speed of adjustment back to equilibrium. This is then used within the short-term first differenced error-correction model that is used to forecast the exchange rate. The integrated framework and model is described in Section 4. The forecasting ability of the model is then tested and compared to a bench mark random walk model. This is discussed in Section 4.5.

The forecasting model is found to perform marginally better then the benchmark random walk model based on three comparison criteria. This provides some evidence for the AUD/USD exchange rate over the sample period that when short and long run variables are integrated within a single framework that a model of exchange rate determination can be developed that is superior to a simple random walk modelling approach. Section 5 provides a summary and some possible directions for future research.

2 Review of Exchange Rate Modelling Literature

2.1 Monetary Models

Contemporary exchange rate theory underpinned by macro economics has, in the last four decades, produced several mainstream monetary models of exchange rate determination. These include the purchasing power parity (PPP) model, Frenkel's (1976) flexible price model, the sticky price model of

Dornbusch (1976) and the real interest differential (RID) model developed by Frankel (1979). In order, these models are generally expressed as:

$$s_t = \alpha + \beta_1 p_t - \beta_2 p_t^* + u_t \quad (1)$$

$$s_t = \alpha(m_t - m_t^*) - \phi(y_t - y_t^*) + \lambda(\pi_t - \pi_t^*) \quad (2)$$

$$s_t = \alpha(m_t - m_t^*) - \phi(y_t - y_t^*) - \delta(r_t - r_t^*) \quad (3)$$

$$s_t = \alpha(m_t - m_t^*) - \phi(y_t - y_t^*) - \frac{1}{\theta}(r_t - r_t^*) + (\frac{1}{\theta} + \lambda)(\pi_t - \pi_t^*) \quad (4)$$

Within these expressions '*' denotes a foreign quantity, with a lowercase referring to a log transformation. (s) is a direct exchange rate quotation, (p) represents price level, (m) the money supply, (r) the interest rate, (π) the inflation rate and (y) the income level. Other classes of models, such as the Portfolio balance models (PBM) like those developed by Branson *et al.* (1977) and Dornbusch & Fischer (1980) generalize monetary models to a stock-flow setting, but difficulties involved with data acquisition relating to currency denominated holdings and the modelling of a risk premium have seen empirical testing of the PB approach being less commonplace within the literature.

While early estimations of monetary models were most often supportive of their hypotheses (see Frenkel, 1976, Bilson, 1978, Frankel, 1979, Hooper & Morton ,1982), post 1978, testing led to a number of the original hypotheses being rejected (see Stockman 1980, Dornbusch & Fischer, 1980, Smith & Wickens 1986, Meese & Rogoff 1988). Irrespective, evidence has accumulated to confirm the increasing importance of monetary fundamentals the longer the horizon. Abuaf & Jorion (1990), Pedroni (2001), Rogoff (1996), Mark (1995) and Taylor (2002) corroborate the long run relationship between prices, money stocks, real income and exchange rates. While the general consensus is that exchange rates revert to some form of economic equilibrium in the long run, structural equation models fail to *consistently* explain exchange rates in both the long and short run, across currencies, time periods and forecast horizons (Meese & Rogoff (1983), Cheung *et al.* (2003)).

2.2 Australian Empirical Evidence

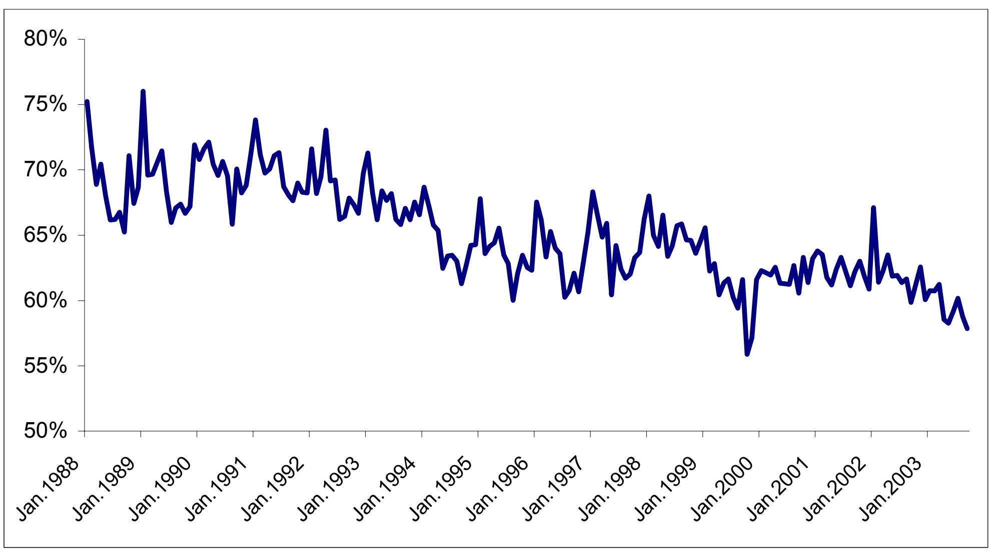
Structural model inconsistency has led researchers on an extensive search for variables relevant to exchange rate determination, with sporadic success usually at periods greater than one to three years. In this section, we review the evidence and theoretical foundations linking commodity prices and short term interest rates to AUD/USD exchange rate dynamics.

2.3 Commodity Prices: A Terms of Trade Proxy

World commodity markets are characterized by price takers, homogeneity and international price discovery. These three attributes allow commodity price movements to act as exogenous shocks to Terms of Trade (TOT) where no one country's actions dominate the world price of a given commodity.[1] In Australia, commodity prices have been shown to play a crucial role in determining the exchange rate, where they form a large, yet declining portion of exports (see for example Blundell-Wignall *et al.* (1993), Chen (2003), Chen & Rogoff (2003), Gruen & Wilkinson (1994), Karfakis & Phipps (1999), and Webber (1997), Tarditi (1996)).

The terms-of-trade (TOT) is central to the monetary approach to the balance of payments approach and implicitly in the monetary models discussed above. Defined as the ratio of a country's export to import prices, the TOT theoretically shares a positive relationship with the exchange rate. A higher TOT results in greater trade income, thereby inducing an exchange rate appreciation. Moreover, a rise in export income channels through into a balance of payments surplus and increases foreign reserves, exerting upward pressure on the exchange rate. Figure 1 shows the importance of commodities in Australia's foreign trade, where they have historically accounted for well over half of total exports.

Figure 1: Australian Major Commodity Exports as a Percentage of Total Exports (Jan. 1988 – Sept. 2003)



Source: Australian Bureau of Statistics Cat. No. 5432.0.65.001

Empirically, the relationship between the Australian dollar and terms-of-trade is well documented. Blundell-Wignall *et al.* (1993) estimate an error-correction model of the Australian-US dollar real exchange rate (and real trade weighted index) from 1973 to 1992.[2] Using real long-term interest differentials and TOT in the equilibrium equation over two sub-sample periods, the TOT has significant coefficient values of 0.619 (1973-1992) and 0.8 (1984-1992). The post-float effect seems stronger and is consistent with greater economic integration during this period. Gruen & Wilkinson (1994) model the real exchange rate and TOT in Engle-Granger and Phillips-Hanson

[1] Both Webber (1997) and Chen & Rogoff (2003) discuss and present evidence on this matter.
[2] Blundell-Wignall *et al.* (1993) give an especially good historical overview of the relationship between the terms-of-trade and Australian dollar.

estimations using quarterly data from 1969 to 1990. They find a one percent increase in the TOT is associated with an appreciation of the real exchange rate between 0.91 and 1.08 percent. Their results also show a stronger relationship over the post-float period. Tarditi (1996) uses an unrestricted error-correction model and finds that contemporaneous and lagged TOT terms are associated with positive real exchange rate returns. The estimated coefficient is 1.41 for a contemporaneous shock and 0.46 for a lagged shock. Karfakis & Phipps (1999) reach similar conclusions for nominal exchange rates in an error-correction model. Using monthly data from 1984-1995, they find the TOT exhibits a strong cointegrating relationship with a positive coefficient value of 0.93. Chen (2003) explores whether commodity prices can explain nominal exchange rates in the small open economies of Australia, Canada and New Zealand where primary commodities in all three countries form a substantial portion of exports. Chen augments four models, including the asset-approach, flexible price and sticky price monetary models as well as the relative PPP model with country specific commodity price indices. For Australia, Chen reports cointegration between commodity prices and the exchange rate in three of the four models, with commodity price coefficients ranging from 0.56 to 0.92. Furthermore, the inclusion of a commodity price index not only substantially improves in-sample fit and out of sample forecasting accuracy, but also leads to more sensible coefficient signs. Chen & Rogoff (2003) extend these results to real exchange rates with the same conclusions for Australia and New Zealand.[3] The empirical evidence supporting the relationship between Australia's terms-of-trade and the exchange rate has become more or less a stylised fact. With an expectation that commodity prices, as a terms-of-trade proxy, exact a significant and positive influence on Australia's exchange rate over the post-float period. We therefore include this within our modelling framework..

2.4 Interest rates

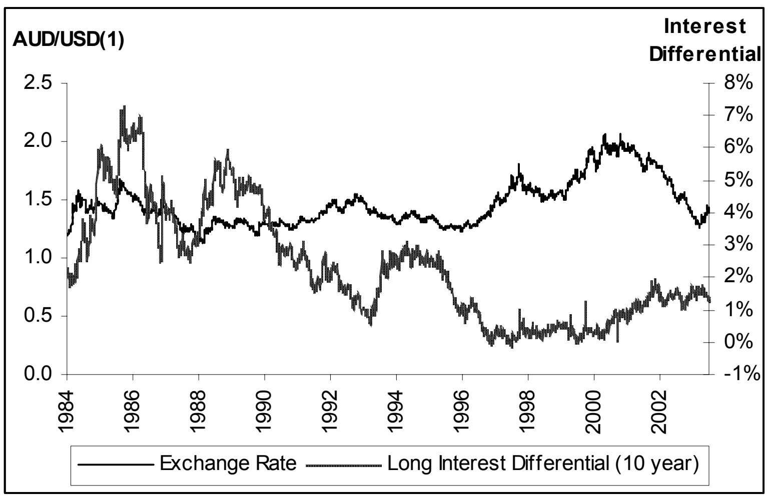
Interest rates play a pivotal role in the economics and determination of exchange rates. Equations (3) and (4) illustrate their expected appreciative effects within a monetary model framework. There is however, ambiguity over the mechanism by which interest rates interact with exchange rates under a floating regime. A relative rise in rates can presumably reflect expected inflation and thus result in a depreciative response on the exchange rate. Alternatively, an asset market perspective strongly predicates an appreciation via increased capital inflows. Similarly, the issue over which interest rate is the best to use within a forecasting model has also not been settled. Arguments involve themes including but not limited to oversimplicity, the inability to capture complementary and substitution effects between long and short rates, information distortion from central bank intervention, time varying risk premia and frequency etc.

Figure 2 highlights the historical relationship between the daily nominal AUD/USD exchange rate and the 10-year interest rate differential from 1984

[3] Chen and Rogoff (2003) give an excellent review of problems associated with using commodity prices in exchange rate models.

to 2004. The relationship is mild with some degree of correlation (-0.43).[4] A brief empirical review of the relation between interest rates and exchange rates in a traditional model setting has been summarized in section 2.1 above. Australian evidence is limited and usually coincides with the terms-of-trade models presented. Gruen & Wilkinson (1994) estimate a long run model in levels of the real exchange rate. Unlike pre-float results, post-float data show the long-term real interest differential (vis-à-vis the world rate) exhibits a positive and strong cointegrating relationship with the exchange rate. An appreciation of 2 to 3.5 percent is associated with a one-percentage increase in the long-term real interest differential. They note that this relationship is stronger than the short-term real interest rate differential, but weaker than expected by theory. Blundell-Wignall *et al.* (1993) estimate a similar model and find a cointegrating relationship, but the long-term interest rate differential coefficient signs are mixed. Post-float tests also indicate it has a positive coefficient sign and is significant indicating it shares an equilibrium relationship with the real exchange rate. Tarditi (1996) is one of a few who uses the yield gap, or the relative difference between the slopes of domestic and foreign yield curves in an unrestricted error-correction model.

Figure 2: AUD/USD and Long (10 year) Interest Rate Differential



Source: Reuters Datastream

The yield gap is used to capture forward-looking expectations as well as the stance on monetary policy. Using quarterly data, Tarditi (1996) finds the yield gap to be statistically significant at one percent in the post-float period when regressed on the real exchange rate. Djoudad *et al.* (2000) build an error-correction model with the real exchange rate, real energy and real non-energy commodity price indices as well as the real Australian-US short-term interest differential. Unlike Gruen & Wilkinson (1994), the short-term real interest differential is positive and significant.

With theoretical ambiguity and mixed evidence surrounding the role that interest rates play in determining the AUD/USD exchange rate, we proceed by testing both short and long and term nominal interest rates. Our expectations

[4] A direct quotation means a fall in this value represents an appreciation.

align with the asset market perspective where it is thought that capital flows directly influence the exchange rate and positive interest rate differentials induce appreciation.

2.5 Volatility

Finance theory clarifies that increased risk requires greater returns. Viewing foreign currency as a tradable asset, ceteris paribus, the same premise would require greater returns as compensation for exposure to exchange rate volatility. Based on evidence presented that volatility influences exchange rate innovation (see Eichengreen, 1988, Dornsusch, 1987, and Goldstein, 1995), we expand our core list of stylized determinants by including a volatility proxy in the modeling framework.

2.6 Summary

Empirical evidence concerning Australia typically reveals that both the long-term interest rate differential and the terms of trade (or commodity prices) share a positive relationship with the exchange rate. Volatility has had a lower level of inquiry than either of these macro variables, but is investigated here as a supplemented measure.

Section 3 provides a description of the data and methodology.

3 Data and Empirical Analysis

The remainder of this paper proceeds to describe the variables in the model as well as tests determining their degree of integration and subsequent cointegration with the exchange rate: a prerequisite for being included within the model. A short-term error correction model is then estimated to examine the relationship between the nominal exchange rate, cointegrated (long-term) and short-term determinants. Finally, the model is evaluated and its forecasting ability compared against a simple random walk.

3.1 Data

Like Chen (2003), this investigation explains nominal exchange rate innovation with interest rates and commodity prices. At this point, we depart from the standard approach of using monthly or quarterly data and seek to extend on previous work by trying to explain higher frequency movements. In addition we look at what effects, if any, the role of volatility plays in determining the AUD/USD exchange rate.[5] The sample encompasses twenty years of the floating period, consisting of daily observations from December, 1984 to June, 2004.

Since neither theory nor empiricism is firm on which interest rate to use, we take the lead from evidence connecting short term interest rates and exchange rate movements and then also include long term interests rates and

[5] Data sources for the following variable definitions are available in Appendix 1.

the yield gap differentials. Four common interest rate variables are applied, each representing a different term. They are the overnight, 90 day and 10 year interest rate differentials as well as the yield gap. The last variable, the yield gap, is the difference between the slopes of the Australian and US yield curves. Essentially, it is a restricted form of the cash and 10 year interest rate differentials. To see this, consider the following:

$$[(i_c - i_{10Y}) - (i_c - i_{10Y})^*] = i_c - i_{10Y} - i_c^* + i_{10Y}^*$$

$$= (i_c - i_c^*) - (i_{10Y} - i_{10Y}^*)$$

Therefore, the coefficient on the foreign yield curve slope is restricted to negative one, whilst the magnitude on both domestic and foreign yield curves is restricted to equality (symmetry).[6]

To proxy Australia's exposure to commodity prices and more generally terms of trade shocks, a daily trade-weighted commodity price futures index is applied.[7] Whilst providing daily observations, we use a futures index in an attempt to capture forward looking expectations that correlates closely with and explains higher frequency movements in the AUD/USD exchange rate. [8,9]

A volatility variable has also been constructed by deriving an index of currencies based on how actively they are traded vis-à-vis the Australian dollar. Specifically, the variances in returns of six currencies are multiplied by the weight of each currency, where the weights represent each currency's level of turnover in relation to the Australian dollar. The volatility variable is described as follows:

$$VOL = \sum_{i=1}^{N} w_i \Delta s_{t,mid}^2 \tag{5}$$

Weights are taken from the BIS 2001 triennial central bank survey and defined as the percentage of foreign exchange turnover with the Australian dollar. Theory suggests increased volatility should lead to increased required rates of return and hence lower prices. Thus, a positive coefficient is expected.

Appendix 2 provides both line-graph plots of all variables as well as their descriptive statistics. Apart from VOL and YGAP, all series appear to exhibit characteristics consistent with a random walk with possible deterministic components. All interest rate differentials have a positive mean, indicating that on average Australian interest rates were above their US counterparts over the sample period. The mean yield gap difference is approximately zero, implying the slopes of each country's yield curve were on average equal.

[6] This estimation is consistent with Tarditi (1996).

[7] Chen and Rogoff (2003) show that commodity prices are an exogenous and important determinant for terms of trade shocks to the Australian dollar.

[8] Westpac Research indicates this index, among others available, has the highest correlation with the AUD/USD exchange rate.

[9] Commodity prices appear to capture more of the higher frequency swings in the exchange rate. Chen (2003)

Table 1 demonstrates that all interest rate differentials are highly correlated with each other, and are negatively correlated with the exchange rate. As expected, the long-term interest rate differential has the strongest correlation with the exchange rate.

Table 1: Variable Correlations

	S	s	RIC	RIL	RIS	COMPI	compi	YGAP
S	1	0.997	-0.304	-0.435	-0.309	-0.686	-0.718	-0.123
s		1	-0.305	-0.435	-0.311	-0.710	-0.740	-0.124
RIC			1	0.887	0.974	0.322	0.316	0.904
RIL				1	0.908	0.441	0.443	0.605
RIS					1	0.353	0.343	0.841
COMPI						1	0.994	0.149
compi							1	0.135
YGAP								1

Also as hypothesized, the commodity price index shares a strong relationship with the exchange rate. Its negative sign implies that on average a rise in the commodity price index is associated with an AUD/USD appreciation. (Remember that the exchange rate is quoted direct.)

3.2 Integration and Cointegration

Integration is determined using Augmented Dickey Fuller (ADF) and Phillips Perron (PP) tests for unit roots and the KPSS (Kwiatkowski et al. (1992)) test for stationarity. The KPSS test is included to confirm the ADF and PP tests which have low power if the process is stationary but with a root close to the non-stationary boundary. The null of a unit root process is given against three alternative hypotheses that include no constant, a constant, and a trend and constant in the test equation. The levels tests are estimated as:

$$\Delta y_t = \varphi y_{t-1} + \sum_{i=1}^{p} \Delta y_{t-i} + \varepsilon_t \qquad (6)$$

$$\Delta y_t = \alpha + \varphi y_{t-1} + \sum_{i=1}^{p} \Delta y_{t-i} + \varepsilon_t \qquad (7)$$

$$\Delta y_t = \alpha + \lambda t + \varphi y_{t-1} + \sum_{i=1}^{p} \Delta y_{t-i} + \varepsilon_t \qquad (8)$$

Including all three alternatives removes the subjectivity involved in determining the nature of a given time series. Akaike and Schwarz information criterion (AIC and SIC respectively) are used to determine which specification is most appropriate for each variable. This avoids lost power from misspecification and helps identify which values give the most important interpretation. First differenced ADF test statistics are included to confirm each variables order of integration.

Cointegration tests are carried out on all non-stationary variables using both Engle & Granger (1987) (EG) and Johansen & Juselius (1990) vector cointegration methods. The EG cointegrating regression, which regresses the exchange rate on non-stationary variables, is (generically) specified as:

$$y_t = X\beta + Y_1\eta_1 + e_t \qquad (9)$$

ADF critical values follow non-normal distributions that are derived in MacKinnon (1996).[10] The Johansen (1988) and Johansen & Juselius (1990) methods are based on vector auto regressions (VAR's) and take a multivariate approach to overcome some of the deficiencies related to the EG two-step procedure. Two test statistics are used to determine the number of cointegrating relationships:

$$\lambda_{trace}(r) = -T\sum_{i=r+1}^{g}\ln(1-\hat{\lambda}_i) \qquad (10)$$

$$\lambda_{\max}(r, r+1) = -T\ln(1-\hat{\lambda}_{r+1}) \qquad (11)$$

The value r represents the number of cointegrating vectors under the null hypothesis and λ the number of eigenvalues from the ∏ matrix. Significant λ's represent cointegrating vectors. The λ-trace test statistic is a joint test where the null hypothesis is that there exist r-cointegrating vectors against the alternative of greater than r vectors. The λ-max test is separate to each eigenvalue and has the null of r cointegrating vectors against the alternative of r + 1.

3.3 Forecast & Evaluation

The final step is to use the model to make a future forecast and to compare its forecasting ability against that of a simple random walk model.[11] The holdout sample used is from observation 4500 to 5077, leaving 577 days or approximately two years of forecasted values. Forecast evaluation is undertaken using four performance and three variance decomposition statistics. The four performance statistics are the root mean square error (RMSE), mean absolute error (MAE), mean absolute percentage error (MAPE) and Theil's Inequality coefficient. The first two of these are relative measures that can be compared across models, whilst a lower value for all four measures indicates better performance than the random walk benchmark. The latter two are scale invariant. The last three statistics are decompositions of the mean squared forecast error; the bias, variance and covariance proportions. All proportions sum to one, with a superior model having most of the bias concentrated in the covariance proportion.

[10] This is a freely available computer program obtainable from http://www.econ.queensu.edu/faculty/mackinnon.
[11] The random walk model is estimated from the AUD/USD series as $y = \beta y_{t-1}$.

4 Results

4.1 Integration of Variables

This section examines to what order each variable is integrated. A summary of test results is shown in Table 2 with testing details given in Appendix 3. The ADF tests (in levels) show the null of non-stationarity cannot be rejected for s, S, RiC, RiS, RiL, compi and COMPI indicating they all contain a unit root. As expected, VOL is stationary and will therefore only be considered in the short run equation. YGAP yields mixed results with the non-stationary null rejected at 5 and 10 percent significance levels for alternative hypothesis assumptions of a constant and no constant respectively. On this basis alone, the yield gap is concluded to be stationary. Appendix 3 also shows rejection of all test statistics for the null hypothesis of I(2), implying that there are no variables that are greater than I(1).[12] Whilst mainly confirming the ADF test results, the PP test statistics as shown in **Error! Reference source not found.** does highlight the fact that differences exists between the findings for the two tests. YGAP is stationary with rejections at one percent for all model assumptions, but RiC is also rejected at the same significance level for all assumptions, implying that this variable is also stationary. Furthermore, RiL is rejected under a trend and constant assumption at five percent. Finally, the KPSS tests also reveal results which support the ADF tests, but with minor differences. Interestingly, the test rejects the stationarity null of all variables, including RiC and YGAP at one percent for all estimations and VOL at five percent with a constant.

Table 2: Summary of Unit Root Tests

NS = Non-stationary. S = stationary. Please refer to Appendix 3 and **Error! Reference source not found.** for detailed test statistics and p-values.

	ADF - Levels			PP - Levels			KPSS - Levels	
	μ	μ & π	-	μ	μ & π	-	μ	μ & π
S	NS	NS	NS	NS	NS	NS	NS	NS
s	NS	NS	NS	NS	NS	NS	NS	NS
RiC	NS	NS	NS	S	S	S	NS	NS
RiS	NS	NS	NS	NS	NS	NS	NS	NS
RiL	NS	NS	NS	NS	S	NS	NS	NS
YGAP	S	NS	S	S	S	S	NS	NS
COMPI	NS	NS	NS	NS	NS	NS	NS	NS
compi	NS	NS	NS	NS	NS	NS	NS	NS
VOL	S	S	S	S	S	S	NS	S

The tests highlight differences for RiC and YGAP. The PP test statistics indicate stationarity where the other two tests indicate non-stationarity. Intuition would lead one to believe that at least the YGAP is stationary due to the nature of its construction.[13] This aside, objectively drawn conclusions based on minimizing type II error are made when contradictions exist in terms of test results. This is achieved by accepting either ADF or PP results when they are supported by one other test procedure. On this basis, YGAP is considered stationary and RiC non-stationary. To conclude, all variables are found to be non-stationary and integrated of order one except VOL, RiC and YGAP.

4.2 Cointegration Results

For the EG tests, 14 cointegrating regressions are estimated for log-nominal exchange rates and commodity price series. As demonstrated in Appendix 4, only the commodity price index and the spot rate produce a cointegtrating vector. These results are not particularly encouraging. However the shortcomings of the EG procedure including low power to reject the null when the process is near unit root can be improved upon by using the more powerful Johansen tests.

Each Johansen test assumes four different model assumptions, including constants and trends, both in and outside of the cointegration equation. In Appendix 5, a summary of the number of cointegrating vectors found for each set of variables is given. The results are based on both test statistics (values not reported) at five percent significance level. The evidence overwhelmingly indicates that there is a cointegrating relationship between the overnight interest rate differential and the exchange rate. There is one cointegrating vector between the exchange rate yield gap and commodity price index. Both λ-trace and λ-max statistics are rejected for commodity prices and the overnight interest rate when intercept and trend assumptions are made. It is interesting to note that the long-term interest differential shares no such relationship with the exchange rate in isolation, even though it is an element of the yield gap, which does. The strongest cointegrating relationships entails combinations involving the yield gap and overnight interest rates.

Another important fact to be taken into consideration is that interest rates are usually cointegrated across countries and term structures. Therefore, any multiple variable tests involving more than one interest rate series is likely to contain a cointegrating vector between interest rates and not with the exchange rate. Furthermore, such combinations would be undesirable in any equilibrium model because they would induce very high multi-collinearity. Excluding the yield gap, one should only consider the overnight interest rate and commodity prices in forming a cointegrating relationship. The short-term interest rate differential seems to play only a minor role in equilibrium if any, since the S, RiS, and YGAP combination yields multiple rejections. It appears the most plausible relationship that could be viably estimated in a long run model of the AUD/US exchange rate would include the overnight interest rate differential and commodity price index. The next section incorporates these findings into an error-correction model of the exchange rate.

[13] YGAP is the differential of two differentials. Tarditi (1996) also confirms a quarterly yield gap to be stationary.

4.3 Error-correction Model

An error-correction representation between two variables X and Y can be stated as:

$$\Delta Y_t = \alpha + \gamma_1 \hat{u}_{t-1} + \sum_{i=1}^{m} \beta_{1t} \Delta Y_{t-i} + \sum_{i=1}^{m} \beta_{1t} \Delta X_{t-i} + u_{1t} \qquad (12)$$

$$\Delta X_t = \alpha + \gamma_2 \hat{u}_{t-1} + \sum_{i=1}^{m} \beta_{3t} \Delta Y_{t-i} + \sum_{i=1}^{m} \beta_{4t} \Delta X_{t-i} + u_{2t} \qquad (13)$$

Assuming directional causality from X to Y, equation (12) is the basic error-correction model and the one employed within this study.

Based on the results presented, the most plausible specification for a long run equation is to include the overnight interest rate and the commodity price index. Multicollinearity would imply that attempting to estimate multiple interest rates in a cointegrating equation would lead to unstable coefficient magnitudes and signs. Taking combinations of these variables such as the yield gap is not a viable solution since they induce stationarity (as exhibited by the yield gap). This immediately precludes including them within the cointegrating equation, but does not mean they should be excluded from the short run equation. With this in mind, the following estimation is undertaken:

$$s_t = 2.80 - 0.313RiC - 0.514compi \qquad (14)$$

(0.033) (0.039) (0.007)

$R^2 = 0.511$

All coefficients are significant at one percent and the regressions explain approximately half of the variation in the exchange rate. The complete regression output generated in Eviews is presented in Appendix 6. Respecifying this equation as error-correction terms results in:

$$\hat{u}_{2t} = \left(s_t - 2.80 - 0.313RiC - 0.514compi\right) \qquad (15)$$

Equations (14) and (15) are the final error correction terms that are used within the short run equation. The commodity price coefficient of -0.514 is consistent with the empirical evidence presented above. Moreover, commodity price coefficients between 0.5 and 1 have been shown by Chen & Rogoff (2003) to be theoretically reconcilable with Balassa-Samuelson flexible and sticky price type models.[14] The interest rate coefficients appear to have a weaker relationship with the exchange rate than previous findings suggest. A one percent rise in interest rates causes a simultaneous appreciation of the

[14] The Balassa-Samuelson model is an extension of PPP that incorporates the productivity differential between traded and non-traded goods sectors.

exchange rate of approximately 0.3 percent. A result anticipated by the low correlation as shown in Table 1. The error-correction model is estimated in the form of equation (12) with specification based on minimising Schwarz's information criteria. Table 3 shows the estimates with the full output available in **Error! Reference source not found.**.

Table 3: Error-correction Model

	Log	
Variable	**Coefficient**	**P-Value**
$ECT_{log,\,t-1}$	-0.0039	0.000
VOL	11.405	0.000
VOL_{t-1}	1.321	0.038
VOL_{t-2}	-5.548	0.000
RIS_{t-1}	-0.163	0.030
RIS_{t-2}	0.1568	0.037
$\Delta compi_{t-1}$	-0.040	0.001

All variables are significant to at least five percent. The cointegrating equation implies disturbances take approximately 240 days to adjust back to equilibrium. This equates to roughly one working year. Economically, this adjustment is reasonable and coincides with the real interest differential and terms-of-trade equilibrium defined in Blundell-Wignall *et al.* (1993) where approximately two thirds of the equilibrium equation error is corrected within five to six quarters. The variable estimates obtained from the model reveal the short run dynamic adjustment that takes place. The negative commodity price coefficient is consistent with the idea that higher commodity prices appreciate the exchange rate, even in the short run on a daily basis. For a one percent rise in commodity prices, the exchange rate appreciates approximately 0.4 percent.

The volatility variable indicates increased risk contemporaneously depreciates the exchange rate. The short-term interest rate also reveals a different relationship. After an appreciating effect in the first period, the exchange rate depreciates by an almost equal magnitude in the next. It therefore seems that the AUD/USD's short-term dynamics are influenced by both the 'transactional' risk associated with highly traded counterparty currencies as well as the 90-day interest rate differential. Moreover, interest rates affect the exchange rate in both the long and short run. This finding might be interpreted as cash rates reflecting the stance of monetary policy, whilst the 90 day rates indicate the markets short-term expectations.

4.4 Diagnostic Tests

For statistically valid inferences to be made, the models presented need to exhibit characteristics that do not violate OLS assumptions. The test results for these assumptions are briefly discussed. Firstly, values of the Durbin

Watson test statistics are close to two, indicating no serial correlation in the errors. Secondly, normality tests were carried out on the error distribution revealing returns to be leptokurtic and slightly negatively skewed. Non-normal residuals however are not necessarily a problem.[15] Homoskedastic error terms are also necessary for valid OLS estimation. Using the test proposed by White (1980), the errors are in fact shown to be heteroskedastic. To combat this, all equations are estimated with White's heteroskedasticity consistent standard error estimates. Next, the correct functional form of the equation was tested using Ramsey (1969) auxiliary equations with higher order fitted terms. The null of correct form was rejected at one percent, indicating non-linear dynamics may be present. Finally, a likelihood ratio based test for omitted variables indicates no bias to be present.[16] Therefore, whilst some OLS assumptions have been violated, they either impose trivial consequences or are easily corrected.[17]

4.5 Comparison of Model to Random Walk

Table 4 compares the forecasting ability of our ECM against a random walk.

Table 4: Out of Sample Forecast Comparison with a Random Walk

Random Walk is estimated as $\Delta s_t = \phi \Delta s_{t-1} + u_t$

	$\Delta s_{\text{random walk}}$	log ECM
RMSE	0.2223	0.1117
MAE	0.1843	0.0820
MAPE	52.1475	24.5895
Theil Inequality Coefficient	0.1972	0.1108
Bias Proportion	0.6874	0.3150
Variance Proportion	0.3126	0.4104
Covariance Proportion	0.0000	0.2746

The RMSE and MAE indicate that the model is superior to an estimated random walk model. The Theil statistic also confirms the dominance over a random walk with values close to zero. The variance decomposition statistics show that not all the bias is derived from the covariance, but the proportion it does account for is not trivial. Overall, there is strong evidence to show that the model can forecast the AUD/USD exchange rate significantly better than an estimated or naïve random walk model.

[15] Given a sample size of 5077, the central limit theorem means that such a violation is virtually inconsequential, with test statistics being asymptotically distributed even in the face of non-normality.
[16] Omitted variables included only those specified. All tests were conducted in Eviews.
[17] Appendix 9 discusses the issue of symmetry in modelling interest rates.

5 Summary and Conclusion

Establishing whether exchange rates and economic variables share equilibrium relationships, has been the focus of many empirical investigations in recent years. Finding what causes exchange rate variation is important to improving both business planning and economic policy. Whilst exchange rates are extremely difficult to predict in the short run, they share equilibrium or cointegrating relationships with economic variables that can be combined with short run dynamics to predict the exchange rate more accurately than a simple random walk.

The AUD/USD exchange rate moves in equilibrium with the overnight interest rate differential and a trade-weighted commodity price index. Theories of exchange rate determination such as the monetary model or portfolio balance model explain these relationships through financial arbitrage or monetary equilibrium. Whilst 90-day and 10-year interest rate differentials were not cointegrated with the exchange rate, Engle-Granger and Johansen tests show a weak cointegrating relationship between the exchange rate, commodity prices and the overnight interest rate differential. Subsequently, an error-correction model was constructed including an equilibrium correction term, short-term interest rate differential, commodity prices and a foreign exchange transaction weighted volatility proxy. Commodity prices and interest rate differentials tend to appreciate the exchange rate whilst volatility depreciates it. The fact that commodity prices influence the exchange rate may have significant policy implications for Australia as well as other developing countries with commodity based economies. Finally, the full model specification was forecasted out of sample and shown to dominate an estimated and naïve random walk based on three different metrics. This result goes someway to bridging the Meese & Rogoff (1983) forecasting puzzle and is useful because predicting the exchange rates movements better allows policy makers and practitioners to manage their risk exposures.

To conclude, this study has contributed to the literature in three distinct ways. It has shown that the AUD/USD exchange moves in equilibrium with the Australian-US overnight interest rate differential and Australia’s foreign trade-weighted exposure to commodity prices. Increases in both of these induce an appreciating affect on the Australian dollar. Volatility, commodity prices and the Australian-US short-term interest rate differential further influence its short run dynamics. Unlike interest rates or commodity prices, volatility has an immediate depreciating effect on the Australian dollar.

Exchange rate modeling is a notoriously difficult exercise. Identifying variables that affect one exchange rate does not necessarily imply they will generalize to other exchange rates. The analysis of commodity prices in particular will be less significant for manufacturing or service oriented economies, than developing or commodity-based economies. To this end, the evidence presented can only be considered relevant to the AUD/USD exchange rate, although worthwhile insights may result from extending this approach to other small, open economies with free floating exchange rate mechanisms.

Appendix 1

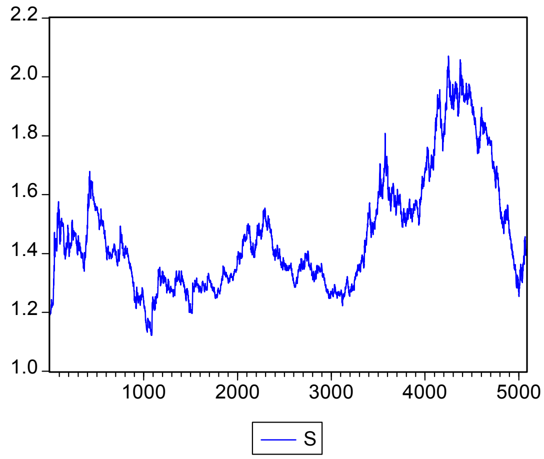
Data Sources

Variable	Data Description	Type	Datastream Code
	Exchange Rates		
S	AUD / USD(1)	Bid	BBAUDSP(EB)
	AUD / USD(1)	Offer	BBAUDSP(EO)
	USD / EUR(1)	Index	USEURWD
	CAD / USD(1)	Bid	BBCADSP(EB)
	CAD / USD(1)	Offer	BBCADSP(EO)
	USD / GBP(1)	Bid	BBGBPSP(EB)
	USD / GBP(1)	Offer	BBGBPSP(EO)
	JPY / USD(1)	Bid	BBJPYSP(EB)
	JPY / USD(1)	Offer	BBJPYSP(EO)
	CHF / USD(1)	Bid	BBCHFSP(EB)
	CHF / USD(1)	Offer	BBCHFSP(EO)
	Interest Rates		
i_c	Australia 11 AM Cash Rate Call - Middle rate	Cash	AUUOFFL
i_{90}	Australia Dealer Bill 90 Day - Middle Rate	90 day	ADBR090
i_{10Y}	Australia Bond Yield 10 Year - Middle Rate	10 year	ABND10Y
i_c^*	US Federal Funds - Middle Rate	Cash	USFEDFD
i_{90}^*	US Bankers Accept. Discount 90 Day - Middle Rate	90 day	USBA90D
i_{10Y}^*	US Treas. Benchmark Bond 10 Yr (DS) - Red. Yield	10 year	USBD10Y
	Commodity Prices		
COMPI	Westpac Commodity Futures Index - Price Index		WCFINDX

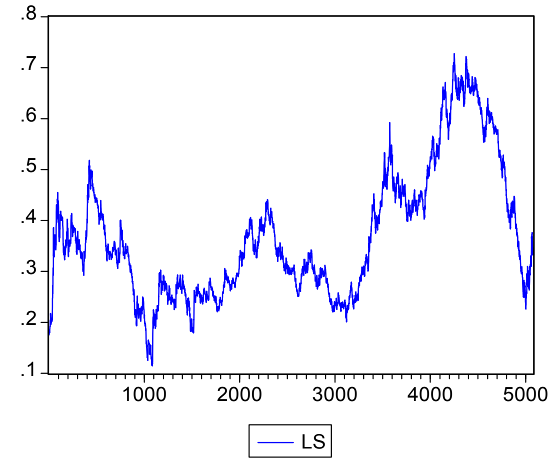
Appendix 2

Variables: Graph Plots

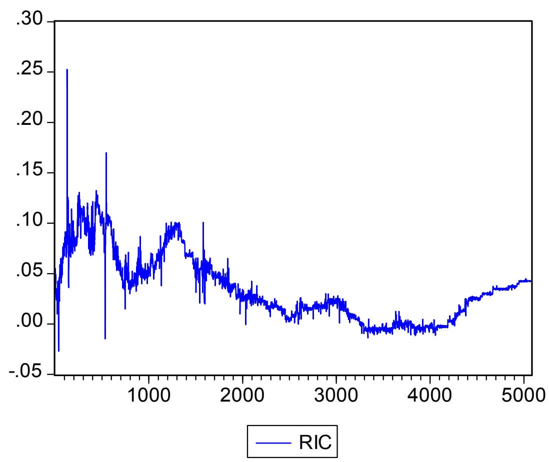
(S) Nominal Exchange Rate



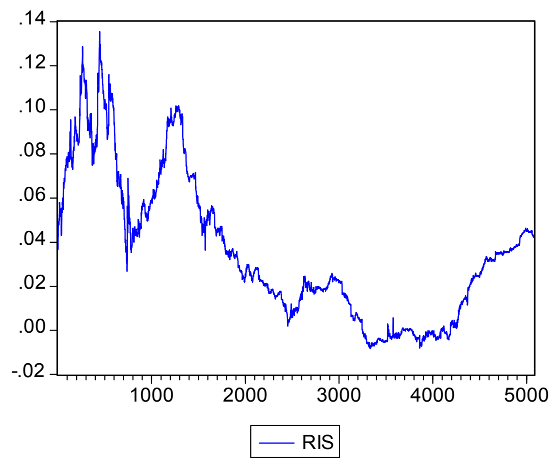
(s) Log Nominal Exchange Rate



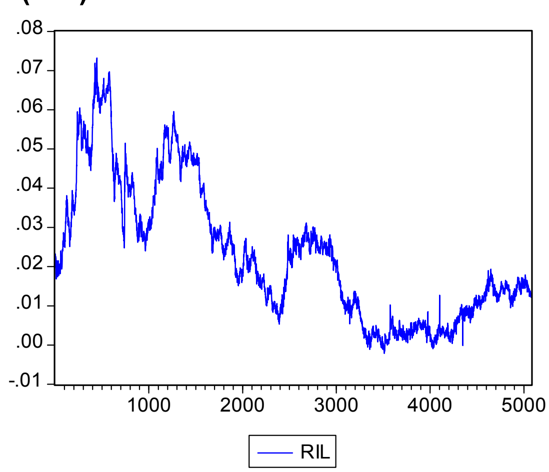
(RiC) Overnight Interest Rate Differential



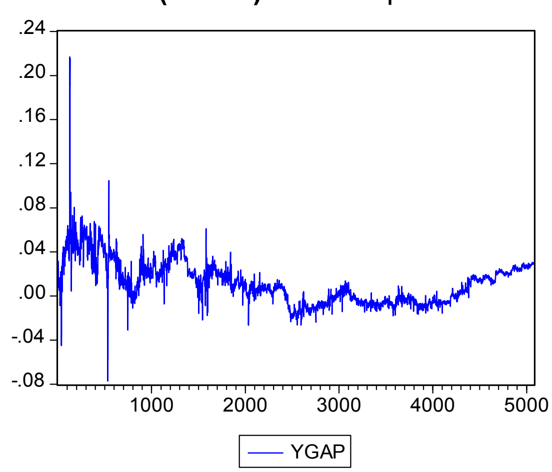
(RiS) 90 Day Interest Rate Differential



(RiL) 10 Year Interest Rate Differential

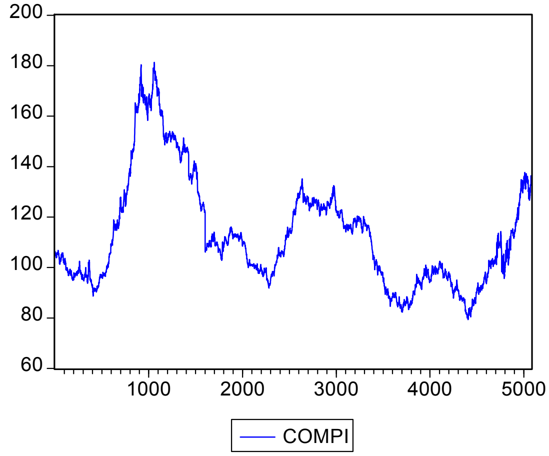


(YGAP) Yield Gap

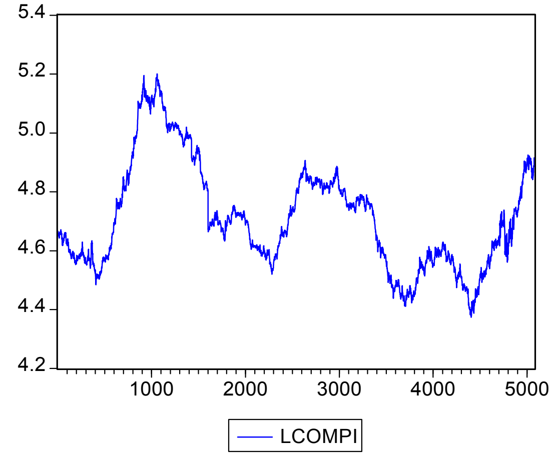


Appendix 2 contd.

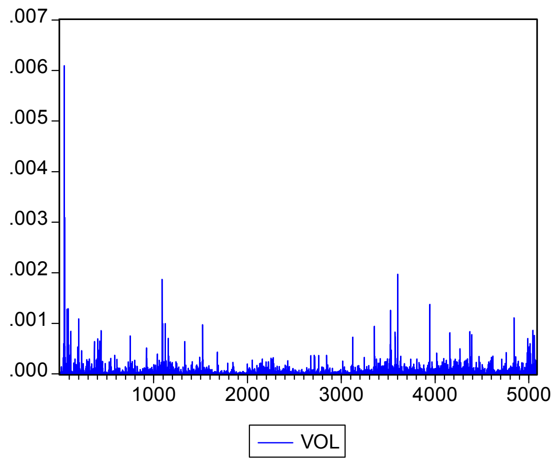
(COMPI) Commodity Price Index



(compi) Log Commodity Price Index



(VOL) Volatility Proxy



Variable Descriptive Statistics

	S	s	RiC	RiS	RiL	YGAP	COMPI	compi
Mean	1.461	0.370	0.035	0.036	0.023	0.012	113.124	4.712
Median	1.403	0.339	0.028	0.028	0.020	0.009	108.670	4.688
Maximum	2.071	0.728	0.253	0.136	0.073	0.217	181.350	5.200
Minimum	1.121	0.115	-0.027	-0.008	-0.002	-0.077	79.350	4.374
Std. Dev.	0.200	0.130	0.033	0.033	0.018	0.019	21.642	0.180
Skewness	1.039	0.800	0.872	0.743	0.706	1.220	0.999	0.625
Kurtosis	3.316	2.874	3.640	2.680	2.574	9.707	3.450	2.740
Jarque-Bera	934.38	544.59	730.09	488.97	459.58	10773.39	886.81	344.76
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sum	7417.95	1881.01	177.66	181.01	117.52	60.14	574331.10	23920.86
Sum Sq. Dev.	202.17	85.27	5.43	5.45	1.56	1.83	2377373.00	165.27

Appendix 3

Summary of ADF test statistics

***, **, *** denote rejection of the null of stationarity at 10, 5 and 1 percent respectively. All lags are minimised by Schwarz information criteria. P-values are in parentheses. The null hypothesis is of non-stationarity. An intercept is denoted by μ and a trend by π. AIC and SIC values correspond to the estimation (constant, constant and trend, no constant) for which they are minimised.**

	ADF - Levels					
	μ	μ & π	-	μ	μ & π	-
S	-2.01	-1.89	0.04	AIC		SIC
	(0.284)	(0.658)	(0.696)			
s	-2.10	-1.98	-0.35	AIC		SIC
	(0.243)	(0.611)	(0.560)			
RiC	-1.58	-2.17	-0.99	AIC		SIC
	(0.494)	(0.508)	(0.288)			
RiS	-1.28	-1.65	-0.82			AIC
	(0.643)	(0.773)	(0.363)			SIC
RiL	-1.5	-2.91	-1.04			AIC
	(0.535)	(0.159)	(0.268)			SIC
YGAP	-2.61*	-2.84	-2.08**	AIC		SIC
	(0.091)	(0.183)	(0.036)			
COMPI	-1.16	-1.06	0.29			AIC
	(0.693)	(0.934)	(0.769)			SIC
compi	-1.26	-1.15	0.42			AIC
	(0.651)	(0.920)	(0.805)			SIC
VOL	-20.19***	-20.22***	-13.67***	AIC		
	(0.000)	(0.000)	(0.000)	SIC		

	ADF - First Difference					
	μ	μ & π	-	μ	μ & π	-
S	-68.87***	-68.87***	-68.88***			AIC
	(0.000)	(0.000)	(0.000)			SIC
s	-68.56***	-68.56***	-68.56***			AIC
	(0.000)	(0.000)	(0.000)			SIC
RiC	-25.32***	-25.32***	-25.32***			AIC
	(0.000)	(0.000)	(0.000)			SIC
RiS	-71.64***	-71.63***	-71.65***			AIC
	(0.000)	(0.000)	(0.000)			SIC
RiL	-60.37***	-60.36***	-60.37***			AIC
	(0.000)	(0.000)	(0.000)			SIC
YGAP	-26.08***	-26.08***	-26.08***			AIC
	(0.000)	(0.000)	(0.000)			SIC
COMPI	-68.74***	-68.74***	-68.75***			AIC
	(0.000)	(0.000)	(0.000)			SIC
compi	-68.17***	-68.17***	-68.17***			AIC
	(0.000)	(0.000)	(0.000)			SIC
VOL	-24.18***	-24.17***	-24.18***			AIC
	(0.000)	(0.000)	(0.000)			SIC

Phillips Perron and KPSS Test Statistics

***, **, *** denote rejection of the null hypothesis at 10, 5 and 1 percent respectively. PP tests have the null of non-stationarity whilst KPSS tests have the null of stationarity. An intercept is denoted by μ and a trend by π. AIC and SIC values correspond to the estimation (constant, constant and trend, no constant) for which they are minimised. For both tests, spectral estimation is done with a Bartlett kernel and bandwidth is selected using a Newey-West procedure. See Phillips & Perron (1987) and Kwiatkowski *et al.* (1992).**

	Phillips Perron - Levels					
	μ	**μ & π**	**-**	**μ**	**μ & π**	**-**
S	-2.00	-1.90	0.05	AIC		SIC
	(0.288)	(0.657)	(0.698)			
s	-2.13	-1.98	-0.35	AIC		SIC
	(0.232)	(0.611)	(0.559)			
RiC	-5.10***	-7.01***	-3.03***		AIC	
	(0.000)	(0.000)	(0.002)		SIC	
RiS	-1.32	-1.73	-0.84			AIC
	(0.623)	(0.738)	(0.350)			SIC
RiL	-1.59	-3.43**	-1.06		AIC	SIC
	(0.488)	(0.048)	(0.262)			
YGAP	-10.13***	-10.80***	-7.32***		AIC	
	(0.000)	(0.000)	(0.000)		SIC	
COMPI	-1.16	-1.06	0.28		AIC	
	(0.692)	(0.934)	(0.767)		SIC	
compi	-1.18	-1.06	0.45			AIC
	(0.684)	(0.934)	(0.812)			SIC
VOL	-79.28***	-79.17***	-94.43***	SIC	AIC	
	(0.000)	(0.000)	(0.000)			

	KPSS - Levels			
	μ	**μ & π**	**μ**	**μ & π**
S	3.80***	0.81***		AIC
				SIC
s	3.77***	0.81***		AIC
				SIC
RiC	5.65***	1.22***		AIC
				SIC
RiS	5.68***	1.29***		AIC
				SIC
RiL	6.41***	0.58***		AIC
				SIC
YGAP	3.69***	1.36***		AIC
				SIC
COMPI	2.01***	0.47***	AIC	
			SIC	
compi	2.03***	0.49***		AIC
				SIC
VOL	0.61**	0.58	AIC	SIC

Appendix 4

Engle Granger 2 step ADF Tests for Stationarity of Residuals (Null hypothesis is no cointegration)

*,**,*** denotes rejection at 1,5 and 10 percent respectively. All critical values are derived from MacKinnon (1996) computer program based on a sample size of 5077. Source: http://www.queensu.econ.edu/faculty/mackinnon

	Log Nominal Exchange Rate/Commodity Prices			Minimised Criterion		
	Constant	Constant & Trend	No Constant	Constant	Constant & Trend	No Constant
s, RiC	-2.39 (0.146)	-2.32 (0.424)	-2.39** (0.017)			AIC SIC
s, RiS	-2.32 (0.165)	-2.22 (0.477)	-2.32** (0.020)			AIC SIC
s, RiL	-2.63* (0.087)	-2.50 (0.327)	-2.63*** (0.008)			AIC SIC
s, YGAP	-2.13 (0.234)	-2.07 (0.561)	-2.13** (0.032)	AIC		SIC
s, compi	-3.11** (0.026)	-3.17* (0.091)	-3.11*** (0.002)			AIC SIC
s, RiC, RiL	-2.73	-2.59	-2.73			AIC SIC
s, RiS, RiL	-2.95	-2.82	-2.95			AIC SIC
s, RiS, YGAP	-2.90	-2.85	-2.90		AIC	SIC
s, RiC, compi	-3.33*	-3.38	-3.33			AIC SIC
s, RiS, compi	-3.11*	-3.12	-3.11			AIC SIC
s, RiL, compi	-3.36**	-3.34	-3.36			AIC SIC
s, YGAP, compi	-3.11*	-3.16	-3.11			AIC SIC
s, RiC, RiL, compi	-3.39	-3.35	-3.39			AIC SIC
s, RiS, RiL, compi	-3.53	-3.65	-3.53			AIC SIC

Appendix 5

Summary of Johansen Cointegration Tests (λ_{Trace} / λ_{Max} Statistics)

Numbers are representative of cointegrating vectors significant at five percent. An intercept is represented by α and a trend by t. These may enter either the Cointegrating equation (CE) or Vector autoregression (VAR). See Eviews (2002) for a detailed analysis of exact specifications.

Log Nominal Exchange Rates/Commodity Prices				
eterministic Data Tren	None	None	Linear	Linear
	-	α	α	α
CE	-	-	-	t
	-	-	α	α
VAR	-	-	-	-
s, RiC	0	1	2	1
	1	1	2	1
s, RiS	0	0	0	0
	0	0	0	0
s, RiL	0	0	0	0
	0	0	0	0
s, YGAP	1	1	2	1
	1	1	2	1
s, compi	0	0	0	0
	0	0	0	0
s, RiC, RiL	1	1	1	1
	1	1	1	1
s, RiS, RiL	0	0	0	0
	0	0	0	0
s, RiS, YGAP	1	1	1	1
	1	1	1	1
s, RiC, compi	0	0	1	1
	0	0	0	1
s, RiS, compi	0	0	0	0
	0	0	0	0
s, RiL, compi	0	0	0	0
	0	0	0	0
s, YGAP, compi	1	1	1	1
	1	1	1	1
s, RiC, RiL, compi	1	1	1	1
	1	1	1	1
s, RiS, RiL, compi	0	0	0	0
	0	0	0	0

Appendix 6

Eviews Output

Cointegrating Regression

Dependent Variable: LS
Method: Least Squares
Date: 10/11/04 Time: 00:13
Sample: 1 5077
Included observations: 5077

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.802945	0.033064	84.77427	0.0000
RIC	-0.312557	0.039173	-7.978790	0.0000
LCOMPI	-0.513945	0.007099	-72.39510	0.0000

R-squared	0.553796	Mean dependent var	0.370497
Adjusted R-squared	0.553620	S.D. dependent var	0.129610
S.E. of regression	0.086595	Akaike info criterion	-2.054562
Sum squared resid	38.04825	Schwarz criterion	-2.050702
Log likelihood	5218.505	F-statistic	3148.742
Durbin-Watson stat	0.006350	Prob(F-statistic)	0.000000

Error-correction Model – First Difference Specification

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
ect_{t-1}	-0.0039	0.0010	-3.8204	0.0001
VOL	11.4048	0.6577	17.3393	0.0000
VOL_{t-1}	1.3213	0.6380	2.0711	0.0384
VOL_{t-2}	-5.5477	0.6587	-8.4226	0.0000
RIS_{t-1}	-0.1632	0.0752	-2.1707	0.0300
RIS_{t-2}	0.1568	0.0751	2.0878	0.0369
$\Delta compi_{t-1}$	-0.0402	0.0125	-3.2166	0.0013

R-squared	0.06607	Mean dependent var	3.30E-05
Adjusted R-squared	0.064964	S.D. dependent var	0.006522
S.E. of regression	0.006307	Akaike info criterion	-7.292988
Sum squared resid	0.201585	Schwarz criterion	-7.283979
Log likelihood	18512.96	Durbin-Watson stat	1.968647

Appendix 7

Imposing symmetry restrictions on interest rates coefficients by modelling them as relative factors is a contested assumption, with evidence showing that it is an erroneous imposition (MacDonald & Taylor (1994), Goldberg (2000)).[18] The overnight interest differentials plausibility in the cointegrating equation depends on the restrictions that the domestic and foreign interest rates have symmetrical effects on the exchange rate. By definition, the differential form has arbitrarily imposed equal coefficient magnitudes for domestic and foreign rates based on monetary and interest rate parity theories. To test if this restriction is warranted, an unrestricted version of the long run equation is estimated, with domestic and foreign interest rates entering as separate variables. This produced:

$$S = 2.17 - 0.364 RICA_t - 0.6914 RICUS_t - 0.0056 COMPI_t$$

(.011) (.068) (.141) (.0001)

$$s = 2.69 - 0.176 RICA_t - 0.51 RICUS_t - 0.484 compi_t$$

(.034) (.041) (.084) (.008)

RiCA and RiCUS denote the Australian and US overnight interest rates respectively. Standard errors are in parentheses. All variables remain significant at one percent, although the exclusion of a differential restriction leads both interest rates to have the same coefficient signs.[19] This outcome negates both the flexible and sticky price monetary models, but is not fully unexpected given the high multicollinearity between the series. Formal t-tests confirm rejection that the coefficients are of equal magnitude.

Goldberg (2000) shows symmetry restrictions rest on the assumptions of imperfect capital mobility and rational expectations. Another less complex interpretation can be taken if interest rates are viewed as the price of bonds (or financial assets).[20] Then, it can be shown that a change in exchange rates resulting from an interest rate differential shock can be apportioned to domestic and foreign interest rates in a manner that depends on market power in the respective bond.[21] For interest rates, it implies changes in the Australian exchange rate resulting from interest rate differentials would largely derive from US side shocks as they have larger market power. Therefore, the rejection of symmetry is in fact partially consistent within this framework even though it is not so with monetary theory. This issue is important when interpreting the results of the model presented in section 4.3 above.

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[18] This is strictly consistent with log estimations only.

[19] This fact seemed to improve for longer interest rates, with the 10 year unrestricted rates having the correct signs but different magnitudes.

[20] This implies bonds to be homogenous assets similar to gold. Risk varies across countries, yet to the extent that one country's bonds are substitutable to that of another country's of similar risk, the analysis' conclusions can be paralleled.

[21] Manzur (2003) pp 146-158. Manzur analyses a differential shock in terms of apportionment between domestic and foreign commodity prices.

References

Abuaf, N., & Jorion, P. (1990). Purchasing Power Parity in the Long Run. *Journal of Finance, 45*(1).

Adler, M., & Lehmann, B. (1983). Deviations from Purchasing Power Parity in the Long Run. *Journal of Finance, 38*(5).

Aggarwal, R., & Schirm, D. (1992). Balance of Trade Announcements and Asset Prices: Influence on Equity Prices, Exchange Rates, and Interest Rates. *Journal of International Money and Finance, 11*(1), 80-95.

Allen, H., & Taylor, M. P. (1990). Charts, Noise and Fundamentals in the London Foreign Exchange Market. *Economic Journal, 100*(400), 49-59.

Allen, H., & Taylor, M. P. (1992). The Use of Technical Analysis in the Foreign Exchange Market. *Journal of International Money and Finance, 11*(3), 304-314.

Balduzzi, P., Bertola, G., & Foresi, S. (1995). Asset Price Dynamics and Infrequent Feedback Trades. *Journal of Finance, 50*(5), 1747-1766.

Berben, R. B., & van Dijk, D. J. (1998). *Does the absence of cointegration explain the typical findings in long horizon regressions?* Rotterdam: Erasmus University. Report.

Bergin, P. R., & Feenstra, R. C. (2001). Pricing-to-Market, Staggered Contracts, and Real Exchange Rate Persistence. *Journal of International Economics, 54*(2), 333-359.

Berkowitz, J., & Giorgianni, L. (2001). Long-Horizon Exchange Rate Predictability? *Review of Economics and Statistics, 83*(1), 81-91.

Bilson, J. F. O. (1978). The Current Experience with Floating Exchange Rates: An Appraisal of the Monetary Approach. *American Economic Review, 68*(2), 392-397.

BIS. (2002). *Trienniel Central Bank Survey: Foreign Exchange and Derivatives Market Activity in 2001*: Bank for International Settlements.

Blundell-Wignall, A., Fahrer, J., & Heath, A. (1993). *Major Influences on the Australian Dollar Exchange Rate*: Reserve Bank of Australia. The Exchange Rate, International Trade and the Balance of Payments.

Boothe, P., & Glassman, D. (1987). Off the Mark: Lessons for Exchange Rate Modelling. *Oxford Economic Papers, 39*(3), 443-457.

Branson, W. H., Halttunen, H., & Masson, P. (1977). Exchange Rates in the Short Run: The Dollar-Deutschemark Rate. *European Economic Review, 10*(3), 303-324.

Brooks, C. (2002). *Introductory Econometrics for Finance*. Cambridge: Cambridge University Press.

Campa, J. M., & Wolf, H. C. (1997). *Is Real Exchange Rate Mean Reversion Caused by Arbitrage?* : National Bureau of Economic Research. Working Paper No. 6162.

Caporale, G. M., Pittis, N., & Sakellis, P. (2003). Testing for PPP: The Erratic Behaviour of Unit Root Tests. *Economics Letters, 80*(2), 277-284.

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

Cassel, G. (1928). *Foreign Investments*: University of Chicago Press.

Chen, J., & Mark, N. C. (1996). Alternative Long-Horizon Exchange-Rate Predictors. *International Journal of Finance and Economics, 1*(4), 229-250.

Chen, Y.-C. (2003). *Exchange Rates and Fundamentals: Evidence from Commodity Economies* (Mimeopgraph): Havard University.

Chen, Y.-C., & Rogoff, K. (2003). Commodity Currencies. *Journal of International Economics, 60*(1), 133-160.

Cheung, Y.-W., Chinn, M., & Fujii, E. (2001). Market Structure and the Persistence of Sectoral Real Exchange Rates. *International Journal of Finance and Economics, 6*(2), 95-114.

Cheung, Y.-W., Chinn, M., & Pascual, A. G. (2003). *Empirical Exchange Rate Models of the Nineties: Are Any Fit to Survive?* : University of California, Santa Cruz. Working Paper No. 03-14.

Cheung, Y.-W., & Chinn, M. D. (2001). Currency Traders and Exchange Rate Dynamics: A Survey of the US Market. *Journal of International Money and Finance, 20*(4), 439-471.

Cheung, Y.-W., Chinn, M. D., & Marsh, I. W. (2000). *How Do UK-Based Foreign Exchange Dealers Think Their Market Operates?* : National Bureau of Economic Research Working Paper: 7524.

Cheung, Y.-W., & Lai, K. S. (2000). On Cross-Country Differences in the Persistence of Real Exchange Rates. *Journal of International Economics, 50*(2), 375-397.

Cheung, Y.-W., & Wong, C. Y.-P. (2000). A Survey of Market Practitioners' Views on Exchange Rate Dynamics. *Journal of International Economics, 51*(2), 401-419.

Chinn, M. D., & Meese, R. A. (1995). Banking on Currency Forecasts: How Predictable Is Change in Money? *Journal of International Economics, 38*(1-2), 161-178.

De Grauwe, P. (1996). *International Money: Postwar Trends and Theories* (Second ed.). Oxford and New York: Oxford University Press.

De Long, J. B. (1990). Positive Feedback Investment Strategies and Destabilizing Rational Speculation. *Journal of Finance, 45*(2), 379-395.

Deravi, K., Gregorowicz, P., & Hegji, C. E. (1988). Balance of Trade Announcements and Movements in Exchange Rates. *Southern Economic Journal, 55*(2), 279-287.

Dickey, D. A., & Fuller, W. (1979). Distribution of the Estimators for Autoregressive Time Series with a Unit Root. *Journal of the American Statistical Association, 74*(366), 427-431.

Djoudad, R., Murray, J., Chan, T., & Daw, J. (2000). *The Role of Chartists and Fundamentalists in Currency Markets: The Experience of Australia, Canada and New Zealand*: Bank of Canada. Working Paper.

Dornbusch, R. (1976). Expectations and Exchange Rate Dynamics. *Journal of Political Economy, 84*(6), 1161.

Dornbusch, R., & Fischer, S. (1980). Exchange Rates and the Current Account. *American Economic Review, 70*(5), 960-971.

Edison, H. J. (1997). The Reaction of Exchange Rates and Interest Rates to News Releases. *International Journal of Finance and Economics, 2*(2), 87-100.

Enders, W. (1989). Unit Roots and the Real Exchange Rate before World War I: The Case of Britain and the USA. *Journal of International Money and Finance, 8*(1), 59-73.

Engel, C., & Hamilton, J. D. (1990). Long Swings in the Dollar: Are They in the Data and Do Markets Know It? *American Economic Review, 80*(4), 689-713.

Engle, R. F., & Granger, C. W. J. (1987). Co-integration and Error Correction: Representation, Estimation and Testing. *Econometrica, 55*(2), 251-277.

Eun, C. S., & Sabherwal, S. (2002). Forecasting Exchange Rates: Do Banks Know Better? *Global Finance Journal, 13*(2), 195-215.

Eviews. (2002). *Eviews Users Guide 4.1*.Unpublished manuscript.

Fang, Y., & Xu, D. (2003). The predictability of asset returns: an approach combining technical analysis and time series forecasts. *International Journal of Forecasting, 19*, 369-385.

Farmer, D. J., & Joshi, S. (2002). The Price Dynamics of Common Trading Strategies. *Journal of Economic Behavior and Organization, 49*, 149-171.

Farrell, M. J. (1966). Profitable Speculation. *Economica, 33*(2), 183-194.

Frankel, J. A. (1979). On the Mark: A Theory of Floating Exchange Rates Based on Real Interest Differentials. *American Economic Review, 69*(4), 610-622.

Frankel, J. A. (1983). Estimation of Portfolio-Balanced Functions That Are Mean-Variance Optimizing: The Mark and the Dollar. *European Economic Review, 23*(3), 315-327.

Frankel, J. A., & Froot, K. A. (1990). Chartists, Fundamentalists, and Trading in the Foreign Exchange Market. *American Economic Review, 80*(2), 181-185.

Frankel, J. A., & Rose, A. K. (1996). A Panel Project on Purchasing Power Parity: Mean Reversion within and between Countries. *Journal of International Economics, 40 1-2*, 209-224.

Frankel, J. A., Rose, A. K., & Grossman, G. M. (1995). Empirical Research on Nominal Exchange Rates. In K. Rogoff (Ed.), *Handbook of international economics. Volume 3* (pp. 1689-1729). Amsterdam; New York and Oxford.

FRB_St._Louis. (2004). *10-Year Constant Treasury Maturity Rate*. Retrieved 02/06/2004, 2004, from http://research.stlouisfed.org/fred2/series/DGS10/47/Max

Frenkel, J. A. (1976). A Monetary Approach to the Exchange Rate: Doctrinal Aspects and Empirical Empirical Evidence. *Scandinavian Journal of Economics, 78*(1-4), 200.

Frenkel, J. A. (1978). Purchasing Power Parity: Doctinal perspective and evidence from the 1920's. *Journal of International Economics, 8*(2), 169.

Frenkel, J. A. (1981). Flexible Exchange Rates, Prices, and the Role of "News": Lessons from the 1970s. *Journal of Political Economy, 89*(4), 665-705.

Friedman, M. (1953). *The Case for Flexible Exchange Rates*. Chicago: University of Chicago Press.

Froot, K. A. (1990). *Short Rates and Expected Asset Returns*: National Bureau of Economic Research. NBER Working Paper No. 3247.

Galati, G., & Ho, C. (2003). Macroeconomic News and the Euro/Dollar Exchange Rate. *Economic Notes, 32*(3), 371-398.

Glen, J. D. (1992). Real Exchange Rates in the Short, Medium, and Long Run. *Journal of International Economics, 33*(1-2), 147-166.

Goldberg, M. D. (2000). On Empirical Exchange Rate Models: What Does a Rejection of the Symmetry Restriction on Short-Run Interest Rates Mean? *Journal of International Money and Finance, 19*(5), 673-688.

Groen, J. J. J. (2000). The Monetary Exchange Rate Model as a Long-Run Phenomenon. *Journal of International Economics, 52*(2), 299-319.

Gruen, D. W. R., & Wilkinson, J. (1994). Australia's Real Exchange Rate--Is It Explained by the Terms of Trade or by Real Interest Differentials? *Economic Record, 70*(209), 204-219.

Hakkio, C. S. (1984). A Re-examination of Purchasing Power Parity: A Multi-country and Multi-period Study. *Journal of International Economics, 17*(3-4), 265-277.

Hakkio, C. S., & Rush, M. (1991). Cointegration: How Short Is the Long Run? *Journal of International Money and Finance, 10*(4), 571-581.

Hallwood, C. P., & MacDonald, R. (2000). *International money and finance* (Second ed.). Oxford and Cambridge, Mass.: Blackwell.

Hogan, K., Melvin, M., & Roberts, D. J. (1991). Trade Balance News and Exchange Rates: Is There a Policy Signal? *Journal of International Money and Finance, 10*, S90-99.

Hooper, P., & Morton, J. (1982). Fluctuations in the dollar: A model of nominal and real exchange rate determination. *Journal of International Money and Finance, 1*, 39-56.

Irwin, D. A. (1989). Trade Deficit Announcements, Intervention, and the Dollar. *Economics Letters, 31*(3), 257-262.

Ito, T., Lyons, R., & Melvin, M. T. (1998). Is There Private Information in the FX Market? The Tokyo Experiment. *Journal of Finance, 53*(5), 1111-1130.

Johansen, S. (1988). Statistical Analysis of Cointegration Vectors. *Journal of Economic Dynamics and Control, 12*(2/3), 231-254.

Johansen, S., & Juselius, K. (1990). Maximum Likelihood Estimation and Inference on Cointegration--With Applications to the Demand for Money. *Oxford Bulletin of Economics and Statistics, 52*(2), 169-210.

Karfakis, C., & Kim, S.-J. (1995). Exchange Rates, Interest Rates and Current Account News: Some Evidence from Australia. *Journal of International Money and Finance, 14*(4), 575-595.

Karfakis, C., & Phipps, A. (1999). Modeling the Australian Dollar-US Dollar Exchange Rate Using Cointegration Techniques. *Review of International Economics, 7*(2), 265-279.

Kilian, L. (1999). Exchange Rates and Monetary Fundamentals: What Do We Learn from Long-Horizon Regressions? *Journal of Applied Econometrics, 14*(5), 491-510.

Kritzman, M. (1989). Serial Dependence in Currency Returns: Investment Implications. *Journal of Portfolio Management, 16*(1), 96-102.

Kwiatkowski, D., Phillips, P. C. B., Schmidt, P., & Shin, Y. (1992). Testing the Null Hypothesis 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*(1-3), 159-178.

Lee, C. I., Gleason, K. C., & Mathur, I. (2001). Trading Rule Profits in Latin American Currency Spot Rates. *International Review of Financial Analysis, 10*(2), 135-156.

Levin, A., & Lin, C.-F. (1992). *Unit Root Tests in Panel Data: Asymptotic and Finite-Sample Properties*: University of California, San Diego Department of Economics. Working Paper: 92-23.

Lothian, J. R., & Taylor, M. P. (1996). Real Exchange Rate Behavior: The Recent Float from the Perspective of the Past Two Centuries. *Journal of Political Economy, 104*(3), 488-509.

Lui, Y.-H., & Mole, D. (1998). The Use of Fundamental and Technical Analyses by Foreign Exchange Dealers: Honk Kong Evidence. *Journal of International Money and Finance, 17*(3), 535-545.

Lyons, R. K. (2001). New Perspective on FX Markets: Order-Flow Analysis. *International Finance, 4*(2), 303-320.

MacDonald, G., Allen, D., & Cruickshank, S. (2002). Purchasing Power Parity: Evidence from a New Panel Test. *Applied Economics, 34*(11), 1319-1324.

MacDonald, R. (2000), *Economics of Exchange Rates: Theories and Evidence*, Routledge, London.

MacDonald, R., & Marsh, I. W. (1997). On Fundamentals and Exchange Rates: A Casselian Perspective. *Review of Economics and Statistics, 79*(4), 655-664.

MacDonald, R., & Taylor, M. (1994). The Monetary Model of the Exchange Rate: Long Run Relationships, Short Run Dynamics and How to Beat a Random Walk. *Journal of International Money and Finance, 13*(3), 276-290.

MacDonald, R., & Taylor, M. P. (1992). *Exchange Rate Economics: A Survey*: International Monetary Fund. IMF Staff Papers.

MacKinnon, J. G. (1996). Numerical Distribution Functions for Unit Root and Cointegration Tests. *Journal of Applied Econometrics, 11*(6), 601-618.

Manzur, M. (Ed.). (2003). *Exchange Rates, Interest Rates and Commodity Prices*. UK: Edward Elgar.

Mark, N. C. (1990). Real and Nominal Exchange Rates in the Long Run: An Empirical Investigation. *Journal of International Economics, 28*(1-2), 115-136.

Mark, N. C. (1995). Exchange Rates and Fundamentals: Evidence on Long-Horizon Predictability. *American Economic Review, 85*(1), 201-218.

McNown, R., & Wallace, M. (1989). Co-integration Tests for Long Run Equilibrium in the Monetary Exchange Rate Model. *Economics Letters, 31*(3), 263-267.

McNown, R., & Wallace, M. (1994). Cointegration Tests of the Monetary Exchange Rate Model for Three High-Inflation Economies. *Journal of Money, Credit & Banking, 26*(3), 396.

Meese, R., & Rogoff, K. (1983). Empirical Exchange Rate Models of the Seventies. *Journal of International Economics, 14*, 3-24.

Meese, R. A., & Rogoff, K. (1988). Was It Real? The Exchange Rate-Interest Differential Relation over the Modern Floating-Rate Period. *Journal of Finance, 43*(4), 933-948.

Menkhoff, L. (1997). Examining the Use of Technical Currency Analysis. *International Journal of Finance and Economics, 2*(4), 307-318.

Mills, T. C., & Taylor, M. P. (1989). Random Walk Components in Output and Exchange Rates: Some Robust Tests on UK Data. *Bulletin of Economic Research, 41*(2), 123-135.

Neely, C. J. (1998). Technical Analysis and the Profitability of U.S. Foreign Exchange Intervention. *Federal Reserve Bank of St. Louis Review, 80*(4), 3-17.

Oberlechner, T. (2001). Importance of Technical and Fundamental Analysis in the European Foreign Exchange Market. *International Journal of Finance and Economics, 6*(1), 81-93.

Obstfeld, M. (1982). Can We Sterilize? Theory and Evidence. *American Economic Review, 72*(2), 45-50.

Oh, K.-Y. (1996). Purchasing Power Parity and Unit Root Tests Using Panel Data. *Journal of International Money and Finance, 15*(3), 405-418.

Pedroni, P. (2001). Purchasing Power Parity Tests in Cointegrated Panels. *Review of Economics and Statistics, 83*(4), 727-731.

Phillips, P. C. B., & Perron, P. (1987). *Testing for a Unit Root in Time Series Regression*: Yale University. Cowles Foundation Discussion Papers: 795R.

Pilbeam, K. (1995). The Profitability of Trading in the Foreign Exchange Market: Chartists, Fundamentalists, and Simpletons. *Oxford Economic Papers, 47*(3), 437-452.

Pippenger, J. (2004). In Search of Overshooting and Bandwagons in Exchange Rates. *Journal of International Financial Markets, Institutions and Money, 14*(1), 87-98.

Ramsey, J., B,. (1969). Tests for Specification Errors in Classical Linear Regression Analysis. *Journal of the Royal Statistical Society, 31*(2), 350-371.

Rogoff, K. (1996). The Purchasing Power Parity Puzzle. *Journal of Economic Literature, 34*(2), 647.

Sentana, E., & Wadhwani, S. B. (1992). Feedback Traders and Stock Return Autocorrelations: Evidence from a Century of Daily Data. *Economic Journal, 102*(411), 415-425.

Sercu, P., Uppal, R., & Van Hulle, C. (1995). The Exchange Rate in the Presence of Transaction Costs: Implications for Tests of Purchasing Power Parity. *Journal of Finance, 50*(4), 1309-1319.

Shiller, R. J., & Perron, P. (1985). *Testing the Random Walk Hypothesis: Power vs. Frequency of Observation*: National Bureau of Economic Research. Technical Paper: 45.

Smith, J., & Gruen, D. W. R. (1989). *A Random Walk around the A$: Expectations, Risk, Interest Rates and Consequence for External Imbalance*: Reserve Bank of Australia. Discussion Paper No. 8906.

Smith, P. N., & Wickens, M. R. (1986). An Empirical Investigation into the Causes of Failure of the Monetary Model of the Exchange Rate. *Journal of Applied Econometrics, 1*(2), 143-162.

Stockman, A. C. (1980). A Theory of Exchange Rate Determination. *Journal of Political Economy, 88*(4), 673-698.

Swift, R. (2001). Exchange Rates and Commodity Prices: The Case of Australian Metal Exports. *Applied Economics, 33*(6), 745-753.

Tarditi, A. (1996). *Modelling the Australian Exchange Rate, Long Bond Yield and Inflationary Expectations*: Reserve Bank of Australia. Research Discussion Paper: 9608.

Tawadros, G. B. (2002). Purchasing Power Parity in the Long-Run: Evidence from Australia's Recent Float. *Applied Financial Economics, 12*(9), 625-631.

Taylor, A. M. (2002). A Century of Purchasing-Power Parity. *Review of Economics and Statistics, 84*(1), 139-150.

Taylor, M. (1995). Exchange Rate Modelling and Macro Fundamentals: Failed Partnership or Open Marriage? *British Review of Economic Issues, 17*(42), 1-41.

Vigfusson, R. (1997). Switching between Chartists and Fundamentalists: A Markov Regime-Switching Approach. *International Journal of Finance and Economics, 2*(4), 291-305.

Webber, A. G. (1997). Australian Commodity Export Pass-through and Feedback Causality from Commodity Prices to the Exchange Rate. *Australian Economic Papers, 36*(68), 55-68.

White, H. (1980). A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. *Econometrica, 48*, 817-838.

Yang, J. H. S., & Satchell, S. E. (2002). *The Impact of Technical Analysis on Asset Price Dynamics*: Department of Applied Economics, University of Cambridge. Working Papers in Economics: 219.

Zumaquero, A. M., & Urrea, R. P. (2002). Purchasing Power Parity: Error Correction Models and Structural Breaks. *Open Economies Review, 13*(1), 5-26.