EXCHANGE RATE CONVERGENCE AND 
MARKET EFFICIENCY 

by 
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ABSTRACT 

The objective of this paper is to examine the market efficiency hypothesis for five major exchange rates of the Australian dollar using multivariate cointegration techniques. The conclusion is that cointegrated relationships exist in foreign exchange markets when interdependence among exchange rates is accounted for.
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1. Introduction

This study investigates firstly the market efficiency hypothesis for five major exchange rates of the Australian dollar (henceforth, AS) before and after the float by means of the cointegration methodology developed by Johansen and Juselius (1990a), and then, if exchange rate convergence exists, it examines which spot rate has borne the burden of adjustment to equilibrium.

In a recent article, MacDonald and Taylor (1989) provided evidence in favour of the hypothesis that foreign exchange markets are efficient, since non-cointegration between a number of US bilateral exchange rates could not be rejected.

The present study argues that foreign exchange markets involve the simultaneous determination of several exchange rates through international arbitrage, and therefore testing the efficiency hypothesis in a bivariate framework is incorrect. The other problem with testing the concept of efficiency in a bivariate framework is the interpretation of nonrejection of the null hypothesis of noncointegration being regarded as equivalent to the market efficiency hypothesis. This paper tries to remedy these problems by using a multivariate procedure for testing the market efficiency.

The rest of the paper is organized as follows. In Section 2, methodological and theoretical issues are presented. Section 3 reports and discusses the results. Concluding remarks are given in Section 4.

2. Methodological and Theoretical Issues

It is an empirical fact that many macroeconomic time series are characterised by nonstationarities. Under nonstationarity, the classical t and F-statistics are inappropriate to test theoretical restrictions because the limiting distribution of the asymptotic variance of the parameter estimates is not finitely defined [see Fuller (1985)]. In order to test whether a time series contains a unit root, i.e., it is integrated of order one (I(1)), the parametric
tests developed by Fuller (1976), and Dickey and Fuller (1981) are used. Recently Phillips (1987) and Perron (1988) have proposed nonparametric tests which allow for serial correlation and heteroscedasticity. These tests were also conducted in this study.

The long run linkage between a number of series can be looked at from the viewpoint of cointegration [see Engle and Granger (1987)]. Let \( x(t) \) be a vector of \( n \)-component time series each integrated of the same order \( k \). Then \( x(t) \) is said to be cointegrated of order \( k \), if there exists a vector \( \lambda \) such that:

\[
\Delta x(t) = \lambda' \Delta x(t-1) = \lambda' x(t-1)
\]

\( \lambda(k-p), p>0 \). Stationarity of \( x(t) \) implies that the \( n \) elements of \( x(t) \) do not drift away from one another over the long run, obeying thus an equilibrium relationship. If \( \lambda \) exists, it may not be unique as there can be several equilibrium relationships. If the number of variables to be tested for cointegration is greater than two, the testing procedure developed by Engle and Granger is not applicable, since it does not address the possibility that more than one cointegrating vector may be present. Recent advances in cointegration theory [Johansen and Juselius (1990a)] have developed a maximum likelihood (ML) testing procedure on the number of cointegrating vectors which also allows for inference on parameter restrictions. The ML method uses the interim multiplier form

\[
\Delta x(t) = \sum_{j=1}^{k} \Pi_j \Delta x(t-j) + \Pi_k x(t-k) + \mu + v(t)
\]

of the vector autoregressive (VAR) representation of the system, where \( x(0) \) is a \( nx1 \) vector of variables of interest and \( \Pi_k \) is a square \( nxn \) matrix of rank \( r \leq n \), \( \mu \) is a \( nx1 \) vector of constant terms, and \( v(t) \) is a \( nx1 \) vector of residuals. The testing procedure involves the null hypothesis \( H_0: \Pi_k = 0 \), i.e., there are at most \( r \) cointegrating vectors \( \beta_1, \beta_2, \ldots, \beta_r \) which provide \( r \) stationary linear combinations \( \beta' x(t-q) \).

The testing procedure is based on regressing the \( n \)-element vectors \( \Delta x(t) \) and \( x(t-q) \) on \( \Delta x(t-1), \ldots, \Delta x(t-q+1) \), and possibly on a constant and seasonal dummies, and obtaining the associated \( n \)-element residual vectors \( R(t) \) and \( R(0) \). The test statistic for the number of cointegrating vectors is obtained by solving the eigenvalue problem

\[
\lambda S_n = S_n S_0 S_n S_0' S_n
\]

where \( S_n = \sum_{t=1}^{T} \Delta x(t) \), \( i=0, q \), and \( T \) denotes the number of observations. The likelihood ratio (LR) statistic for the hypothesis \( H_0: \Pi_k = 0 \)

\[
-2 \ln (Q^0|H_0) = -2 \ln (1-\lambda^2)
\]

is a test that there are at most \( r \) cointegrating vectors versus the general alternative (trace), where \( \lambda \) corresponds to the \( n-r \) smaller eigenvalues. The \( nxn \) matrix of cointegrating vectors \( \Phi \) can be obtained as the \( n \)-element eigenvectors corresponding to \( \lambda \).

The LR statistic for testing \( H_0(r) \) in \( H_0(r+1) \) is given by:

\[
-2 \ln (Q^r|H_0) = -2 \ln (1-\lambda_{r+1}^2)
\]

The LR statistic for testing the hypothesis for zero loading factors \( H_{10} : \alpha = \lambda \Psi \) is

\[1\] The calculation of the eigenvectors of \( S_n S_0' S_n \) with respect to \( S_n \) can be transformed into a standard eigenvalue problem by using Choleski decomposition \( S_n = C \), since the eigenvalues that solve \( |A S_n S_0' S_n| \) also solve \( |A I^2 C S_n S_0' S_n| \). Premultiplying the eigenvectors of the standardized problem by \( C' \), one can obtain the original eigenvectors normalized such that \( E S_n = I \). The calculations of the eigenvectors have been performed using the computer package RATS 3.0, VAR Econometrics, Inc./Down Associates.
which is asymptotically distributed as \( \chi^2 \) with \((n-k-1)\) degrees of freedom; \( k \) denotes the restrictions on matrix \( \alpha \).

Let \( x(t) = (x_1(t) \ldots x_k(t))^T \) be a 5-dimensional vector of spot rates. The weak form of market efficiency for the spot rate \( x^i(t) \) requires that there is no difference between its expected value \( E(x^i(t)) \) conditional on two different information sets [see Fama (1970)]. That is,

\[
E(x^i(t)|\Omega(t-1)) = E(x^i(t)|f(t-1))
\]

where \( \Omega(t-1) = (x^1(t-1) \ldots , x^k(t-1)) \), and \( f(t-1) = (x^1(t-1) \ldots , x^k(t-1)) \), with \( j = 2, \ldots , 5 \). In other words, the past history of \( s^i(t) \) incorporates all useful information in predicting its current value. If the hypothesis of noncointegration is rejected, it will be regarded as an evidence against the market efficiency hypothesis because of the prevalence of the error correction mechanism.

3. Empirical Results

Monthly data on the exchange rate of the A$ against the US dollar (US), the Japanese yen (J), the pound Sterling (UK), the German mark (G) and the French franc (F) are used for the period January 1975 to February 1990.²

With respect to the univariate time series properties of the data, the results reported in Table 1 indicate that the null hypothesis of unit root is not rejected for the levels of all the series at a 5% significance level. In contrast, when first differences are used, nonstationarity is rejected in all cases.

**Table 2**

<table>
<thead>
<tr>
<th>Dep. Variance</th>
<th>SSE</th>
<th>Q(24)</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>pre-float</td>
<td>14.059(0.09)</td>
<td>2.90(0.00)*</td>
<td>12.35(0.00)*</td>
<td>0.0005</td>
</tr>
<tr>
<td>post-float</td>
<td>38.560(0.14)</td>
<td>-0.45(0.02)</td>
<td>16.20(0.00)*</td>
<td>0.0006</td>
</tr>
<tr>
<td>pre-float</td>
<td>17.260(0.97)</td>
<td>-1.34(0.00)</td>
<td>8.59(0.00)*</td>
<td>0.0008</td>
</tr>
<tr>
<td>post-float</td>
<td>26.400(0.65)</td>
<td>-0.15(0.03)</td>
<td>1.49(0.00)</td>
<td>0.0007</td>
</tr>
<tr>
<td>pre-float</td>
<td>23.120(0.61)</td>
<td>0.54(0.03)</td>
<td>3.82(0.00)</td>
<td>0.0005</td>
</tr>
<tr>
<td>post-float</td>
<td>34.19(0.08)</td>
<td>0.21(0.04)</td>
<td>2.04(0.00)</td>
<td>0.0007</td>
</tr>
<tr>
<td>pre-float</td>
<td>30.26(0.18)</td>
<td>-0.57(0.00)</td>
<td>6.03(0.00)</td>
<td>0.0012</td>
</tr>
<tr>
<td>post-float</td>
<td>24.02(0.40)</td>
<td>-0.06(0.13)</td>
<td>1.27(0.00)</td>
<td>0.0014</td>
</tr>
<tr>
<td>pre-float</td>
<td>31.10(0.15)</td>
<td>0.54(0.02)</td>
<td>3.02(0.00)</td>
<td>0.0013</td>
</tr>
<tr>
<td>post-float</td>
<td>34.70(0.07)</td>
<td>-0.30(0.07)</td>
<td>1.86(0.00)</td>
<td>0.0011</td>
</tr>
</tbody>
</table>

²The skewness and kurtosis tests seem to suggest the presence of nonnormality in the pre-float regime.

²The period 1975-1983 was mainly the era during which the Australian currency moved to a managed float from a pegged exchange rate to US dollar. The system of a market determined exchange rate was adopted in December 1983.
In order to check for the presence of a linear trend in the nonstationary part of the data generation process, the hypothesis that a linear trend is absent (c(1)=0) is tested by means of the approach suggested by Johansen (1991). The trace test results given in Table 3 indicate that the absence of a linear trend cannot be rejected.

The results of testing for the number of cointegrating vectors between the five-A$ bilateral rates are also reported in Table 3. The LR test statistics that there are zero cointegrating vectors or five common trends reject the null hypothesis against the 95% critical value in both time periods. The trace test does not reject the hypothesis that at least two but possibly three or four cointegrating vectors are present in the pre-Float regime. The maximum eigenvalue test does not reject the hypothesis r=2 against r=3. The trace test statistic for the post-Float regime indicates the existence of four cointegrating vectors, implying that the change in the exchange rate regime has imposed two additional equilibrium constraints on the data. This suggests that future movements of one exchange rate can be predicted by using the information of other currencies. One implication of these findings is that the market efficiency hypothesis is rejected in a multivariate context.

The other implication is that overall the system has moved to a greater stability in the post-Float regime with four cointegrating vectors and one common trend.

Table 3

<table>
<thead>
<tr>
<th>r</th>
<th>n-r</th>
<th>T,</th>
<th>95%</th>
<th>T,</th>
<th>95%</th>
<th>m.L</th>
<th>95%</th>
<th>m.L</th>
<th>95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>pre-Float</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r=4</td>
<td>1</td>
<td>6.31</td>
<td>9.094</td>
<td>1.03</td>
<td>0.03</td>
<td>0.63</td>
<td>0.23</td>
<td>0.294</td>
<td>0.193</td>
</tr>
<tr>
<td>r=3</td>
<td>2</td>
<td>15.09</td>
<td>22.448</td>
<td>3.54</td>
<td>17.844</td>
<td>9.62</td>
<td>15.752</td>
<td>8.51</td>
<td>14.095</td>
</tr>
<tr>
<td>r=1</td>
<td>4</td>
<td>58.13</td>
<td>53.347</td>
<td>33.77</td>
<td>49.419</td>
<td>28.34</td>
<td>28.167</td>
<td>21.94</td>
<td>27.341</td>
</tr>
<tr>
<td>r=0</td>
<td>5</td>
<td>97.65</td>
<td>75.328</td>
<td>34.36</td>
<td>89.977</td>
<td>31.34</td>
<td>34.387</td>
<td>27.51</td>
<td>33.262</td>
</tr>
<tr>
<td>post-Float</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r=4</td>
<td>1</td>
<td>4.94</td>
<td>9.094</td>
<td>0.94</td>
<td>0.04</td>
<td>0.92</td>
<td>0.23</td>
<td>0.924</td>
<td>0.23</td>
</tr>
<tr>
<td>r=3</td>
<td>2</td>
<td>20.57</td>
<td>22.148</td>
<td>19.27</td>
<td>23.144</td>
<td>16.00</td>
<td>15.752</td>
<td>14.33</td>
<td>14.095</td>
</tr>
<tr>
<td>r=2</td>
<td>3</td>
<td>41.43</td>
<td>35.068</td>
<td>39.75</td>
<td>31.256</td>
<td>28.34</td>
<td>28.167</td>
<td>20.48</td>
<td>21.595</td>
</tr>
<tr>
<td>r=1</td>
<td>4</td>
<td>69.71</td>
<td>53.347</td>
<td>34.61</td>
<td>48.419</td>
<td>28.34</td>
<td>28.167</td>
<td>26.28</td>
<td>27.341</td>
</tr>
<tr>
<td>r=0</td>
<td>5</td>
<td>121.05</td>
<td>75.328</td>
<td>39.55</td>
<td>69.977</td>
<td>31.34</td>
<td>34.207</td>
<td>31.34</td>
<td>33.262</td>
</tr>
</tbody>
</table>

r and n-r denote the number of eigenvectors and common trends respectively. T, (T,) and m.L (m.L) denote, respectively, the trace and maximum eigenvalue statistics for the restricted (unrestricted) model. Critical values are taken from Johansen and Juselius (1990a, Tables A2, A3).

Having established the existence of a long run exchange rate convergence, the analysis proceeds to investigate whether this convergence has been achieved in a symmetric way through adjustments by all exchange rates. In the VAR system (1), with \(x(t), \alpha, \beta, \delta, \eta, \delta, \xi \) and \( \alpha \), the equations for \( \beta(x(t+1) - x(t)) \) and \( \beta(x(t+1) - x(t)) \) are included. It is desirable to test whether the cointegrating relationship \( \beta(x(t+1) - x(t)) \) does not enter all the equations of the VAR system. In fact, the loading factors \( \alpha \) entering the \( j \)th equation serves as a test of weak exogeneity of \( \Delta x \) with respect to the cointegrating parameters \( \beta \) [see Johansen and Juselius (1990a)].

The results of the likelihood ratio tests on loading factors reported in Table 4 indicate that the null hypothesis of zero loading is rejected for all currencies other than US dollar during the pre-Float period. This means that all other currencies adjust to clear disequilibrium in foreign exchange markets. On the other hand, during the post-Float regime, the hypothesis of zero loading is rejected for US dollar, mark, and franc. In this period, adjustment in these currencies clear the disequilibrium. The analytical interpretation of these findings implies that exchange rate convergence has been achieved in an asymmetric manner.

Table 4

<table>
<thead>
<tr>
<th>Testing for Zero Loading Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H_0: \beta_{ij}=0 )</td>
</tr>
<tr>
<td>pre-Float</td>
</tr>
<tr>
<td>( H_0: \beta_{ij}=0 )</td>
</tr>
<tr>
<td>( H_0: \beta_{ij}=0 )</td>
</tr>
<tr>
<td>( H_0: \beta_{ij}=0 )</td>
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<tr>
<td>( H_0: \beta_{ij}=0 )</td>
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<tr>
<td>( H_0: \beta_{ij}=0 )</td>
</tr>
<tr>
<td>( H_0: \beta_{ij}=0 )</td>
</tr>
<tr>
<td>post-Float</td>
</tr>
<tr>
<td>( H_0: \beta_{ij}=0 )</td>
</tr>
<tr>
<td>( H_0: \beta_{ij}=0 )</td>
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<tr>
<td>( H_0: \beta_{ij}=0 )</td>
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<tr>
<td>( H_0: \beta_{ij}=0 )</td>
</tr>
<tr>
<td>( H_0: \beta_{ij}=0 )</td>
</tr>
<tr>
<td>( H_0: \beta_{ij}=0 )</td>
</tr>
</tbody>
</table>

* indicates significance at 5%.
4. Concluding remarks

The analysis of similarly integrated I(1) variables in a multivariate VAR framework rejected noncointegration between the A$ and other five leading currencies, and thus did not support the market efficiency hypothesis. One implication is that the efficiency hypothesis should be addressed in a multivariate context, when foreign currency movements are interdependent through international arbitrage. Furthermore, the nonexistence of a cointegrated relationship should not be interpreted as an evidence in favour of market efficiency.

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