THE DEMAND FOR MONEY IN AUSTRALIA: NEW TESTS ON AN OLD TOPIC

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ABSTRACT

The breakdown of conventional short-run demand functions for money in a number of countries, including Australia, is well known. In recent years, there has been a rush of publications, both overseas and in Australia, concerning the long-run relationships between the money stock, activity and interest rates, utilising the technique of cointegration. This paper seeks to contribute to knowledge about these empirical relationships, and their robustness. It reviews some basics of money demand theory, summarises the results of earlier papers on cointegrating relationships in the Australian data and tests for the existence of cointegration between a number of definitions of money aggregates, activity and interest rates. This very wide-ranging investigation is designed to explore the sensitivity of relationships to sensible specification changes. Cointegration between money, income and interest rates is difficult to find, and the outcomes are sensitive to the definition of activity and interest rate and to the testing procedure.

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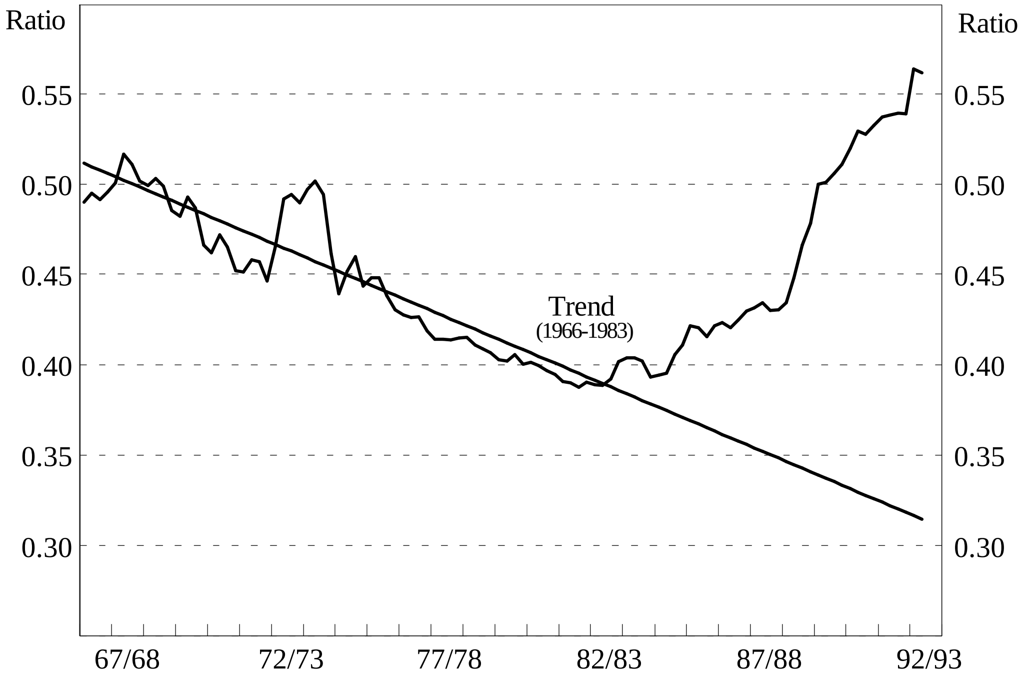
1. INTRODUCTION

One of the most enduring analytical devices in macroeconomics has been the aggregate money demand function. As the theoretical and empirical appeal of monetarism grew through the 1970s, most countries devoted more attention to movements in the monetary aggregates. In an attempt to wind back relatively high inflation, several countries, Australia included, adopted the practice of announcing targets for monetary growth in order to tie down inflationary expectations.

Despite the initial theoretical appeal of this idea, experience with the use of monetary aggregates as targets, or even as indicators, proved disappointing. Financial innovation and regulatory changes often severely distorted the monetary outcome. Several countries either abandoned targeting altogether, as in the case of Canada, or downgraded its importance, as in the US and UK. Australia shared in this experience too. Monetary targets for M3 were discontinued in early 1985, the authorities noting that shifts in the relationship between M3 and economic activity which were occurring and likely to occur in future, rendered M3 unsuitable as a measure of money, and unreliable as a principal indicator of monetary policy (see Battellino and McMillan (1989) and Grenville (1990)).

While this decision was a matter of judgment at the time, it was well supported by subsequent studies demonstrating that conventionally estimated short-run demand functions for M3 were unstable, in the sense that the estimating equations failed standard prediction tests, both post-sample and within sample (Stevens, Thorp and Anderson (1987) and Blundell-Wignall and Thorp (1987)). Figure 1, which plots both the ratio of M3 to GDP and its trend based on its behaviour over the 1960s and 1970s, provides one illustration of the sometimes sharp and sustained shifts in velocity that have affected all the monetary aggregates at one time or another. In this case, attempts to target growth in M3 in the face of substantial and unpredictable changes in the demand for money, would have led the authorities to impose an unnecessarily tight policy regime. More recent research suggests that the use of monetary rules over the 1980s and early 1990s would have been sub-optimal in terms of the inflation and employment objectives of monetary policy (see Coelli and Fahrer (1992) and Blundell-Wignall *et al* (1992)).

Figure 1: Ratio of M3 to Annual GDP



There have been recent developments in time series analysis, however, which seek to uncover *long-run* relationships between variables by testing for cointegration between them. Accordingly, while there may be short-run deviations in the presumed relationship between money and income, there may be some underlying economic relationship to which the two series revert over time. If money and income do in fact move together over time, and if reversion to the joint long-run path is stable, then economic analysts are more likely to regard monetary aggregates as containing useful economic information. Figure 1 indicates that this is unlikely to be the case for M3, at least.

Analysis of the long-run relationship between money and income has been undertaken in many countries (for Japan, the UK and the US, for example, see Yoshida and Rasche (1990), Hall, Henry and Wilcox (1989), Hendry and Ericsson (1991) and Mehra (1991)), and also in Australia (see below).

This paper seeks to contribute to this literature within the standard analytical framework in which the long-run demand for real money balances is a function of real income (or other scale variable) and the opportunity cost of holding money. A range of measures of money, economic activity and opportunity cost are tested, with the emphasis not on mining the data for positive results, but on assessing the robustness of empirical relationships by testing sensitivity to sensible changes in specification and estimating technique. This seems especially important in view of the fact that the cointegration literature is relatively young, such that there is not universal agreement as to the “correct” approach or interpretation of results.

Section 2 of the paper briefly revisits basic money demand theory, and summarises recent empirical work using Australian data. Section 3 gives details of the data used and presents preliminary analysis on the statistical properties of the various series under consideration. Section 4 presents the results from applying the Engle-Granger (Engle and Granger (1987)) and the Johansen (Johansen (1988), Johansen and Juselius (1990)) procedures of cointegration, and offers some interpretation and reflection on the results. Section 5 summarises the main points raised in the paper.

2. THE STATE OF PLAY

There is an extensive theoretical and empirical literature on money demand and excellent summaries of recent developments are provided by Goodhart (1989) and Cuthbertson (1991). At its most rudimentary, demand for money is motivated by the need to fund transactions, the need to hold money to fund unanticipated payments, and the decision to hold wealth in the form of money, which may be motivated by Keynes' speculative motive or by general portfolio theory. According to the transactions and precautionary motives for money demand, a scale transactions variable such as income, expenditure or wealth is a key variable in any money demand equation. The Baumol-Tobin inventory-theoretic approach to transactions demand also implies that money demand is inversely related to the opportunity cost of funds, which may be proxied by an interest rate or vector of interest rates. The speculative motive implies that the demand for funds is also inversely related to the interest rate while portfolio models imply that the own-rate of return enters positively and rates on substitute assets enter negatively.

Assuming that agents do not suffer from money illusion, the demand for money is a demand for real balances and this is conventionally expressed as a function of real income and a nominal interest rate or vector of interest rates. While this is the approach followed here, we also test the relationship between money, income and interest rates all defined in nominal terms. The results do not differ significantly from those obtained using real money and real activity. When the interest rate is defined as the own-rate of return on the monetary asset, the inflation rate and the two-year bond yield are also included as cost variables. In the presentation of the results, the inflation rate is not included since we found that it did not contain explanatory power in addition to nominal interest rates.[1]

This representation is purely static. The view that agents adjust their money holdings to some desired level is well accepted and attained more fulsome expression in the Goldfeld (1973) equation. The subsequent failure of this and other specifications in the 1980s is well documented. If money, income and interest rates are cointegrated, however, then the short-run dynamic relationship can be neatly modelled in the corresponding error-correction representation, which is a more general representation of money stock adjustment than in the Goldfeld equation (see Ericsson, Campos and Tran (1991)).

A summary of the Australian literature is provided in Table 1. The studies tend to define money in real terms, with the exceptions being Orden and Fisher (1993) and Juselius (1991). The studies also tend to focus on M3, which probably reflects its historical prominence, but tests have been conducted on the other well-known aggregates. The researchers draw on a variety of estimation techniques, though the Engle-Granger and Johansen procedures are the most popular. Overall, there is evidence supporting a long-run money-income relationship in the cases of currency and broad money. The evidence in the case of M1 and M3 is more ambiguous, with the result depending to some extent on the definition of independent variables, econometric technique and time period. Both Orden and Fisher and de Haan and Zelhorst find that M3 and GDP were cointegrated before deregulation but not after.

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[1] If the Fisher effect holds, expected inflation is included in the nominal interest rate. There is, however, the Friedman-type argument that the inflation rate should enter the equation separately as the opportunity cost of the monetary asset relative to real assets or other excluded financial assets, though the empirical importance of this has been questioned in the US (Emery (1991)). Baba, Hendry and Starr (1992) argue that if the Fisher effect is somehow prevented from working, for example by nominal interest rate ceilings, or if inflation and interest rates are only imperfectly correlated, then the inflation rate should enter the estimating equation separately. To check this, we included inflation in the estimation using the Johansen procedure but with little change to the results. Consequently, we report only the most conventional money demand equation test results.

Lim and Martin (1991), on the other hand, conclude that M3 and GDP are cointegrated even after deregulation.

This paper reviews the evidence for all these aggregates. With financial liberalisation and innovation, the range of bank deposits and their substitutes has expanded rapidly, and distinctions between money and non-monetary financial assets have become even less clear than before. A study of a range of aggregates is therefore appropriate.

The paper also conducts tests for various measures of the money base. There is no shortage of proposals for using the monetary base as an indicator or target (Harper (1988), Sieper and Wells (1989), Porter (1989) and McTaggart and Rogers (1990)). A feature of the existing literature in Australia is the lack of much empirical evidence on the indicator properties of the money base, and this paper seeks to redress this.

3. THE DATA AND THEIR ORDER OF INTEGRATION

3.1 The Data

The various definitions of money, income and interest rates employed in this paper are set out below. Appendix 1 contains full definitions and data sources.

Currency is defined as notes and coins held by the non-bank private sector in Australia and, at December 1992, totalled \$16.3 billion. Figure 2 shows the natural logarithm of real currency.[2]

The standard definition of the money base is the sum of notes and coins held by the private sector, plus deposits of banks with the Reserve Bank (as well as some other minor Reserve Bank liabilities to the private sector). Currency constitutes about 80 per cent of the money base, with bank deposits with the RBA making up the remaining 20 per cent. The latter comprises exchange settlement accounts and, by far the major proportion, non-callable deposits ("required reserves").

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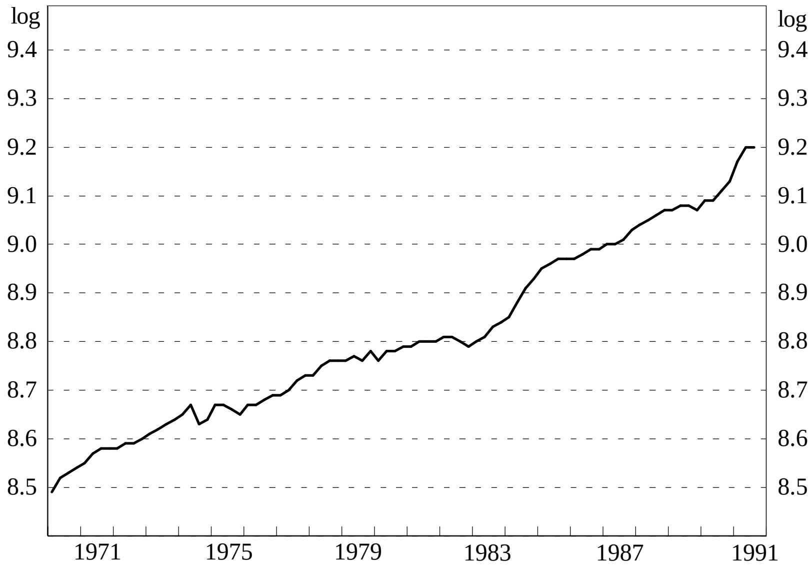
[2] In the graphs which follow, the various monetary aggregates are deflated by the implicit GDP price deflator. By convention, one billion is defined as a thousand million.

Table 1: Studies on Cointegration of Money and Income in Australia

AUTHOR	DEPENDENT VARIABLE	INDEPENDENT VARIABLES	DATA AND METHODS	RESULTS
Orden and Fisher (1993)	Nominal M3	Real GDP, nominal 13-week Treasury note rate and GDP deflator.	Quarterly, 1965:2 to 1989:3. Variables are defined alternatively in seasonally-adjusted terms and seasonally-unadjusted terms, with seasonal dummies included in the latter case. Variables apart from the interest rate are in natural logarithms. Estimated using the Johansen (1988) procedure.	One cointegrating vector between M3, real GDP and prices only in the pre-deregulation sub-period 1965:2 to 1982:4. The result holds for either seasonal adjustment approach.
Lim and Martin (1991)	Real M3 (GDP deflator)	Real GDP, nominal 90-day bill rate, 2-year bond yield and 10-year bond yield and annual percentage change in the GDP deflator.	Quarterly, 1970:4 to 1990:2. Variables apart from interest rates are seasonally-adjusted. Variables apart from interest and inflation rates are in natural logarithms. Estimation method is Park's (1988) H-test.	Long run relationship between real M3, real GDP and 10-year bond yield. ECM estimated including short-term interest rate.
Lim (1991)	Real currency, real bank deposits and real non-bank deposits (GDP deflator)	Real GDP, real broad money, 90-day bank bill rate, 2-year bond yield, 10-year bond yield and annual percentage change in the GDP deflator.	Quarterly, 1976:3 to 1990:2 and monthly 1976:08 to 1990:06. Variables apart from interest rates are seasonally-adjusted. Variables apart from interest and inflation rates are in natural logarithms. Phillips-Hansen (1990) technique used. A structural change dummy was also included for the 1982/83 recession and for the effects of deregulation and rapid depreciation in 1985.	Long run relationships on both data sets including all variables except the bill rate. ECM estimated including bill rate

Lim and Dixon (1991)	Real currency (GNE deflator)	Real GNE and 3 month average of 90-day bill rate.	Quarterly, from 1977:1 to 1989:2. Variables are seasonally-unadjusted and so seasonal dummies are included. Estimation by OLS following the Engle-Granger procedure.	Long-run relationship between real currency and real GNE.
AUTHOR	DEPENDENT VARIABLE	INDEPENDENT VARIABLES	DATA AND METHODS	RESULTS
de Haan and Zelhorst (1991)	Real M3 and real M1 (deflated by the CPI)	Real GDP (deflated by the CPI) and 3-year Treasury bond yield.	Quarterly, from 1960:1 to 1989:2 and variables apart from the bond yield are seasonally-adjusted and in natural logarithms. Engle-Granger (1987) estimation procedure.	Long-run relationship between GDP velocity of M3 and 3-year bond yield from 1960:1 to 1983:4 only.
Hargreaves (1991)	Real money base and real M1 (alternatively deflated by GDP and GNE deflators)	Alternatively GDP and GNE, tax-adjusted 90-day bill rate, 2-year bond yield and savings account interest rate (with the tax rate calculated as the ratio of net household disposable income to total household income), a risk variable (the standard error on 15-year Treasury bond yields) and alternatively the quarterly change in GDP and GNE deflators.	Quarterly, from 1973:3 to 1989:4 and all variables are in natural logarithms. Variables are seasonally-unadjusted. Engle-Granger (1987) estimation procedure.	Long-run relationship between real money base and real M1 and, alternatively, GDP and GNE and, alternatively, tax-adjusted 90-day bill rate and 2-year bond yield.
Juselius (1991)	Nominal M1 and M3	Alternatively real GDP and real GNE, alternatively GDP and GNE implicit price deflator, nominal 90-day bill rate and nominal ten-year bond yield.	Quarterly from 1975:3 to 1991:1. Variables are seasonally-unadjusted and, apart from interest rates, are in natural logarithms. Seasonal dummies are included. Estimated using the Johansen (1988) procedure.	Two cointegrating vectors between money and real activity, prices, short and long-run interest rates and a time trend for each definition of money and each definition of activity.

Figure 2: Real Currency



This definition, published by the Reserve Bank, is referred to in this paper as MB. There are several alternative or augmented definitions. MB-SRD refers to the standard money base adjusted to eliminate the effect of changes in the Statutory Reserve Deposit (SRD) ratio.[3] The adjustment procedure is explained in Appendix 1.

MB-AMMD adds bank loans to authorised dealers in the short-term money market to the standard definition of the money base. This recognises the fact that banks' excess reserves in the Australian system are not held at the Reserve Bank, but with the dealers. These funds are available on a "same day" basis to banks, and are therefore as good as cash at the Reserve Bank. They also bear interest, in contrast to exchange settlement accounts at the RBA. MB-SRDAMMD further adjusts this definition for the SRD changes. These four definitions of money base are shown in Figure 3.

While the money base is dominated by currency, some economists regard reserves as the analytically important component of the money base and so we examine the non-currency component of the money base separately. NC-MB, NC-MB-SRD, NC-MB-AMMD and NC-MB-SRDAMMD refer respectively to the non-currency

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[3] Before 1981, the SRD ratio was varied as a monetary policy instrument. A tightening of policy by increasing the SRD ratio would mechanically increase the money base, giving a signal contrary to that expected of demand for an asset.

components of the above definitions of money base. These measures are shown in Figure 4.

Figure 3: Measures of the Real Money Base

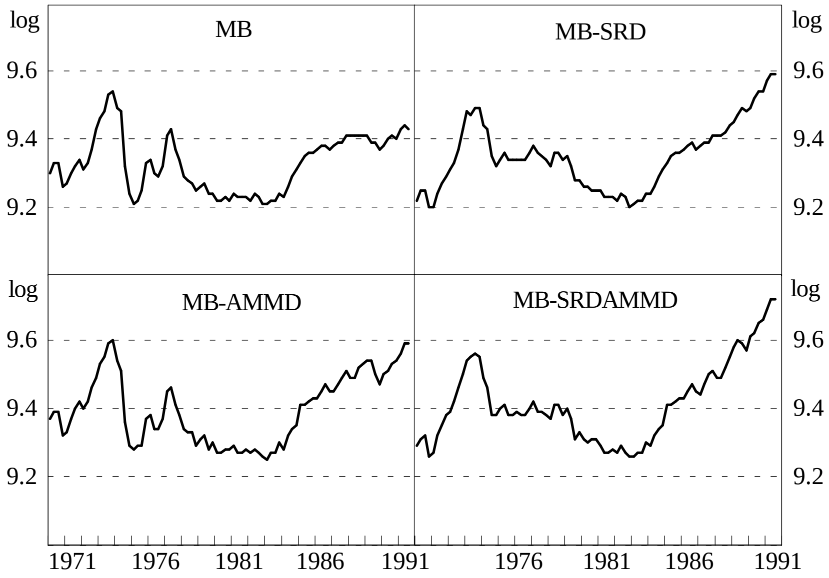
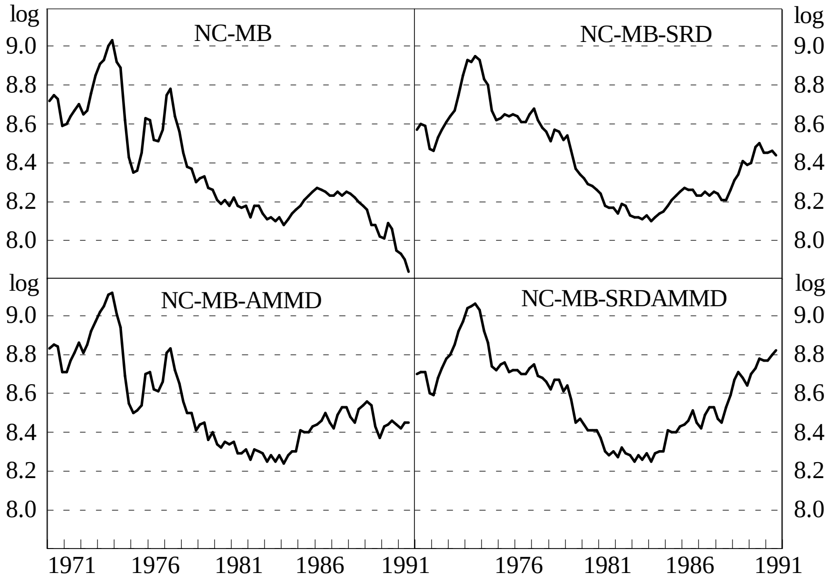


Figure 4: The Non-Currency Component of the Real Money Base

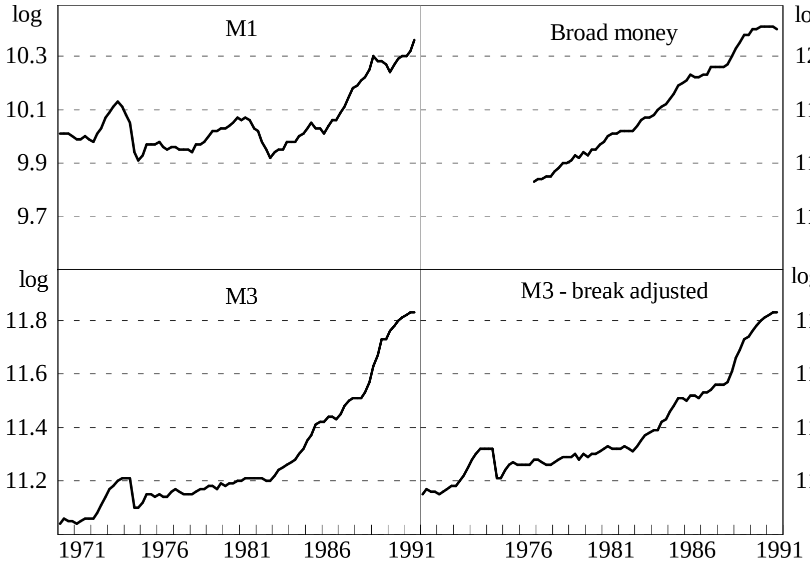


The other definitions of money used in the paper are the conventional ones. M1 in Australia has traditionally been defined as currency plus current deposits held with trading banks. Since the distinction between trading and savings banks was removed in January 1990, this aggregate is technically defunct. Accordingly, we define M1 as currency and current deposits with all banks. [4]

M3 is defined as currency plus bank deposits of the non-bank private sector. Changes in the legal status and operations of financial institutions have had a significant effect on the growth of M3 over time. The series adjusted for changes in the classification of financial institutions is called M3-BA.

Broad Money includes M3 plus borrowings from the private sector by non-bank financial intermediaries (NBFIs), less their holdings of currency and bank deposits. As a broader measure of money, it is substantially less affected by changes in financial intermediation. These last four monetary aggregates are shown in Figure 5.

Figure 5: Real Monetary Aggregates



Selection of the income and interest rate variables is largely an empirical matter. We test relationships across a range of definitions - gross domestic product (GDP), gross national expenditure (GNE) and private final demand (PFD), (all shown in Figure 6), and 3-month, 2-year and 10-year interest rates (Figure 7), as well as measures of own rates of return on the monetary aggregates (Figure 8). This is not

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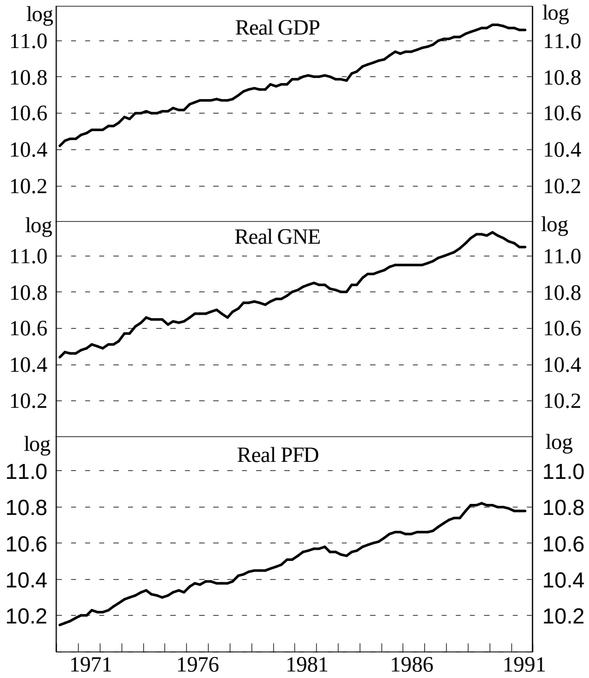
[4] Current deposits placed with savings banks can be identified only from February 1975 and so there is a small break in M1 at this time.

"specification searching" [5], in pursuit of the “best” result. Rather, it is motivated by our prior that a relationship which is sensitive to arbitrary changes in specification is not particularly robust.

Figure 6: Measures of Real Activity



The money demand equations are estimated on a quarterly basis from the March quarter of 1970 to the September quarter of 1991, except for broad money and the broad money own-rate which are only available from the December quarter of 1976. The data, except for the interest rates and inflation rates, are expressed in natural logarithms. In accord with a substantial body of the empirical literature, the variables, apart from interest rates, are seasonally-adjusted. Using seasonally-adjusted data avoids the need to test for seasonal integration and reduces nuisance parameters. Furthermore, most of the seasonal adjustment is conducted by the Australian Bureau of Statistics using all available information, and so the seasonal adjustment is more comprehensive and accurate than that obtained by using more elementary seasonal adjustment procedures[6] or by including seasonal dummies. The results of Orden and Fisher suggest that the method of seasonal adjustment is

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[5] See Cooley and LeRoy (1981).

[6] As explained in Appendix 1, the seasonally-adjusted M1, M3 and break-adjusted M3 series are spliced at February 1975. Our judgment is that splicing two ABS seasonally-adjusted series to obtain one seasonally-adjusted series is preferable to using a seasonal adjustment procedure such as X-11Q to deseasonalise the longer unadjusted data series.

inconsequential. If the seasonal patterns are themselves stationary, as should be the case since they have a mean of unity, then the issue of seasonal adjustment should be irrelevant to the long-run relationship between the variables.

Figure 7: Interest Rates

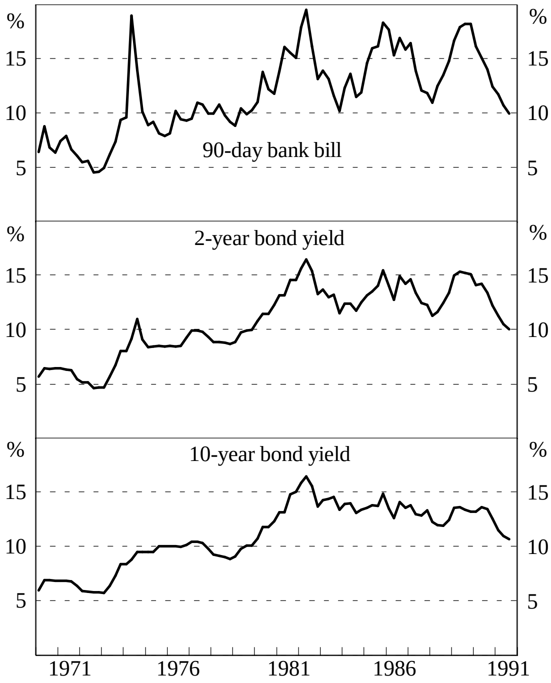
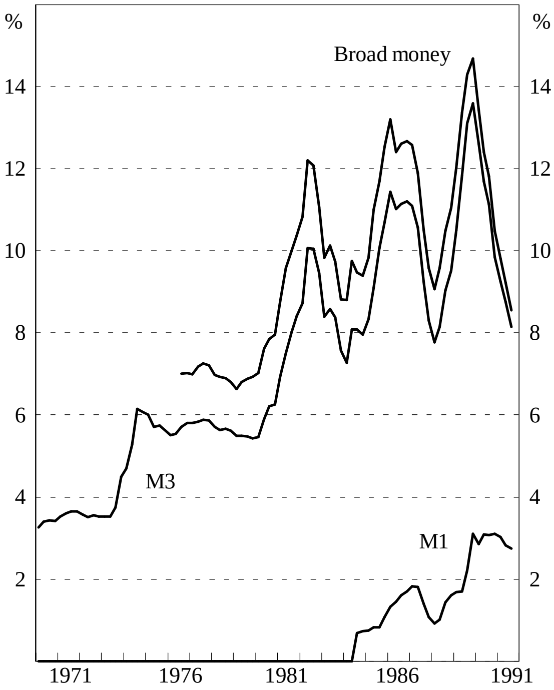


Figure 8: Return on Money



3.2 The Order of Integration of the Data

The augmented Dickey-Fuller (ADF) test (Said and Dickey (1984)) and Z_t test (Phillips (1987)) are used for determining the order of integration of the variables under consideration. The tests are initially conducted allowing for a deterministic trend in order to commence with the most general data-generating process. The results, assessed at the 5 per cent critical level, are summarised in Table 2.[7] The unit root testing procedures are outlined in Appendix 2.

The unit root tests indicate that the monetary aggregates defined in real terms are integrated of order one. Real activity appears to be integrated of order one in the case of real GDP for both the ADF and Z_t tests, though not necessarily for real

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[7] Full details of all results reported in this paper are available from the authors on request. The lag ordering is set so that the residuals in the ADF test equation are not serially correlated (based on the Lagrange multiplier test). A constant and time trend are included only if statistically significant at the 5 per cent level. The lag ordering for the Z_t test is set arbitrarily at 5 and 10.

GNE and real PFD, where the ADF tests indicate that the levels of real GNE and real PFD are stationary around a deterministic trend.

The ten-year and two-year bond yields and the estimated M1 own-rate are clearly I(1), while the bill rate, the estimated broad money own-rate and the estimated M3 own-rate are I(1) under the Z_t procedure but I(0) around a deterministic trend under the ADF procedure. Given the low power of these tests in differentiating the underlying data generating process, we are inclined to treat the series as I(1).

Table 2: Summary of Order of Integration (5% Significance Level)*

Variable	ADF	Z_t	ADF after considering break in deterministic trend
Currency	I(1)	I(1)	I(1)
MB	I(1)	I(1)	I(0)
MB-SRD	I(1)	I(1)	I(0)
MB-AMMD	I(1)	I(1)	I(0)
MB-SRDAMMD	I(1)	I(1)	I(1)
NC-MB	I(1)	I(1)	I(1)
NC-MB-SRD	I(1)	I(1)	I(0)
NC-MB-AMMD	I(1)	I(1)	I(0)
NC-MB-SRDAMMD	I(1)	I(1)	I(1)
M1	I(1)	I(1)	I(0)
M3	I(1)	I(1)	I(1)
M3-BA	I(1)	I(1)	I(1)
Broad Money	I(1)	I(1)	-
GDP	I(1)	I(1)	I(1)
GNE	I(0)#	I(1)	I(0)
PFD	I(0)#	I(1)	I(0)
90-Day Bank Bill Rate	I(0)#	I(1)	-
2-Year Bond Yield	I(1)	I(1)	I(0)
10-Year Bond Yield	I(1)	I(1)	I(1)
M1 Own-Rate	I(1)	I(1)	-
M3 Own-Rate	I(0)#	I(1)	-
Broad Money Own-Rate	I(0)#	I(1)	-

* real values for monetary aggregates presented here are deflated by GDP deflator.

\# I(0) in the presence of a deterministic trend.

The tests applied above are standard. Perron (1989, 1990), however, demonstrates that standard tests of the unit root hypothesis are biased toward acceptance of the null hypothesis of a unit root if the true data generating process is stationary around a trend line with one break. Perron (1989) models a break in the trend level, a break in the trend slope and a combination of the two and estimates critical values for unit root tests for each of these models. This is relevant to the present study: even a summary glance at Figures 2 to 5 of the real monetary aggregates shows that many of the series appear to contain at least one break in the level or in the slope of its trend. The limitation of Perron's method is that it is properly applied only when the date of the break is known and when there is only one break. We determine break dates by inspection of the series and then suggest reasons for the break. The results are summarised in the final column of Table 2.

Evidence of stationarity around a broken trend is found only for the money base variables and M1. The break in the money base occurs in 1982/83 in the reserve deposit component. The accelerated growth in SRDs is due to the rise in fixed deposits and certificates of deposit as banks were freed from regulation and were able to compete for funds in an economy undergoing a strong recovery. M1 may also be modelled as a stationary process around a deterministic time trend but with a single break in the slope occurring some time in 1985 or 1986. This coincides with the removal of the restriction of the payment of interest on current deposits in August 1984.

For both the money base and M1, there are a number of possible break dates, almost all of which yield the same result that the aggregate is I(0) around a broken trend, suggesting that the results are not mere chance outcomes. The other aggregates remain I(1), though most of the selected trend breaks appear to be significant.

In terms of cointegration analysis, if the money base and M1 are I(0) processes around a broken trend, then, strictly speaking, the analysis stops there: money and income are not integrated of the same order and so cannot be cointegrated. There are, however, two alternatives:

- it still makes sense to talk of a relationship between the time series examined if income and interest rates are also I(0) around a broken trend. Perron tests were applied to these series but they do not appear to be I(0) processes around a broken trend, with the exception of GNE, PFD and the two-year bond yield, the break in the latter coinciding with the shift in the early 1980s from a tap to tender system for government bonds; or

- given that unit root tests on the whole have weak power in identifying the true statistical properties of the data series, and that cointegration methodology is still in its infancy, it may be legitimate to treat the money base variables and M1 as I(1) processes.

We proceed on the basis of the second alternative.

4. COINTEGRATION

In this section, we use the Engle-Granger procedure and the Johansen procedures to test for the existence of cointegration (see Appendix 2 for a summary of the procedures). The Engle-Granger procedure is a static, single-equation, residual-based test for cointegration. Critical values are drawn from Phillips and Ouliaris (1990). The Johansen procedure is a general dynamic systems technique, where the variables are parameterised in terms of lagged first differences and the lagged level of the systems variables. Johansen and Juselius developed a maximum likelihood procedure to decompose the coefficient matrix on the lagged level variables into a matrix of cointegrating vectors and a matrix of “speed of adjustment” vectors, which is interpreted analogously to the coefficient on the error-correction variable in the Engle-Granger error-correction representation. They also developed two likelihood ratio tests to determine the number of stationary combinations of the variables under consideration. Critical values are drawn from Osterwald-Lenum (1992). Since the data are quarterly, the lag length for the Johansen procedure is set at four.

The findings of cointegration are summarised in Table 3, where “E” and “J” stand for rejection of the null hypothesis of no cointegration at the 5 per cent level using the Engle-Granger and Johansen procedures respectively, and “NO” means no cointegration. Using the Johansen technique, there was at most one cointegrating vector for each money-income relationship, and these are presented in Tables 4 to 7, along with restrictions on the real income elasticities and nominal interest rate semi-elasticities. The restrictions on the long run parameter estimates are tested using the coefficients obtained from a Bewley (1979) transform of the autoregressive distributed lag model (which are virtually identical to the coefficients estimated using the Johansen procedure). The restrictions tested are whether the income elasticity and the interest semi-elasticity are different from zero. While the standard errors from a Bewley transform are not asymptotically normal, Inder (1991) shows that inferences drawn from such dynamic specifications are not misleading (see also Lim and Martin (1992)).[8]

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[8] The critical statistics are drawn from the standard t-statistic tables with a critical value for 60 degrees of freedom of 2.00 at the 5 per cent level and 2.66 at the 1 per cent level.

Table 3: Summary of Cointegration Results

Regressors Money Aggregates	GDP	GDP O/R	GDP BILL	GDP 2yr	GDP 10yr	GNE	GNE O/R	GNE BILL	GNE 2yr	GNE 10yr	PFD	PFD O/R	PFD BILL	PFD 2yr	PFD 10yr	Out-come
CURRENCY	NO	-	NO	E/J	E/J	NO	-	NO	E/J	NO	NO	-	J	J	NO	8/24
MB	NO	-	NO	E	NO	NO	-	NO	NO	NO	NO	-	NO	NO	NO	1/24
MB-SRD	NO	-	NO	J	NO	NO	-	NO	J	NO	NO	-	NO	NO	NO	2/24
MB-AMMD	NO	-	NO	NO	NO	NO	-	NO	NO	NO	NO	-	NO	NO	NO	0/24
MB-SRDAMMD	NO	-	NO	J	NO	NO	-	NO	J	NO	NO	-	NO	J	NO	3/24
NC-MB	NO	-	NO	NO	NO	NO	-	NO	NO	NO	NO	-	NO	NO	NO	0/24
NC-MB-SRD	NO	-	NO	J	NO	NO	-	NO	J	NO	NO	-	NO	NO	NO	2/24
NC-MB-AMMD	NO	-	NO	NO	NO	NO	-	NO	NO	NO	NO	-	NO	NO	NO	0/24
NC-MB-SRDAMMD	NO	-	NO	J	NO	NO	-	NO	J	NO	NO	-	NO	J	NO	3/24
M1	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0/30
M3	NO	J	NO	J	NO	NO	NO	NO	NO	NO	NO	NO	NO	J	NO	3/30
M3-BA	NO	J	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	1/30
BROAD MONEY	NO	NO	NO	NO	NO	J	NO	J	J	J	NO	NO	E	NO	NO	5/30

E = cointegration at the 5 per cent critical level using the Engle-Granger Procedure.

J = cointegration at the 5 per cent critical level using the Johansen Procedure.

We now discuss the results for each of the aggregates, and then proceed to draw these together in a general discussion.

4.1 Currency

Of a possible 24 combinations between currency, activity and interest rates, we found 8 cases of cointegration. Both procedures produce results which are very similar, indicating the importance of GDP/GNE and the two/ten-year bond yields in identifying a long-run relationship. The Johansen procedure also suggests that PFD is a relevant scale variable in explaining currency. The cointegrating vectors estimated using the Johansen procedure are set out in Table 4.

Table 4: Long-Run Income Elasticity and Interest Rate Semi-Elasticity of Currency

Equation	GDP	GNE	PFD	BILL	2YR	10YR
Currency	1.1019 (25.11)*				-0.0104 (-4.07)	
Currency		1.1632 (16.20)*			-0.0180 (-4.75)*	
Currency			1.2118 (15.92)*		-0.0203 (-4.45)*	
Currency	1.0559 (29.31)*					-0.0086 (-3.48)*
Currency			1.3129 (8.68)*	-0.0255 (-2.83)*		

* indicates significance at the 1 per cent level, t-statistic in parentheses.

While the incidence of cointegration is small, the equations themselves produce plausible results. The elements of the cointegrating vectors are statistically significant and “correctly” signed, and indicate a greater than unitary real income elasticity of demand for real currency balances and a low negative interest sensitivity. The result of Lim and Dixon (1991) that currency and GNE alone are cointegrated in real terms is not replicated for either procedure on our longer data set and for different measures of activity.[9]

4.2 Money Base

Given eight definitions of the real money base, three definitions of real activity, three definitions of nominal interest rates and two estimating procedures, there are 192 feasible combinations. Evidence supporting cointegration was found in only 11 of these. Only 1 cointegrating vector was found using the Engle-Granger procedure: a relationship between the real money base, as conventionally defined, and real GDP and the two-year bond yield.

Using the Johansen procedure, there are 10 cointegrating vectors out of a possible 96. In this case, the SRD-adjusted money base measures are the only ones which exhibit a long-run relationship with activity and interest rates. The cointegrating vectors are set out in Table 5.

Table 5: Long-Run Income Elasticity and Interest Rate Semi-Elasticity of Money Base

EQUATION	GDP	GNE	PFD	2YR
MB-SRD	0.9623 (4.10)*			-0.0570 (-3.67)*
MB-SRD		0.9920 (5.19)*		-0.0627 (-4.97)*
MB-SRDAMMD	1.1983 (5.22)*			-0.0676 (-4.65)*
MB-SRDAMMD		1.2633 (5.93)*		-0.0756 (-5.47)*
MB-SRDAMMD			1.2952 (5.59)*	-0.0770 (-5.18)*
NC-MB-SRD	0.6331 (1.02)			-0.1129 (-3.21)*
NC-MB-SRD		0.7054 (1.51)		-0.1201 (-4.12)*
NC-MB-SRDAMMD	1.3234 (3.02)*			-0.1343 (-4.69)*
NC-MB-SRDAMMD		1.4545 (3.46)*		-0.1458 (-5.15)*
NC-MB-SRDAMMD			1.4721 (3.05)*	-0.1459 (-4.66)*

* indicates significance at the 1 per cent level, t-statistic in parentheses.

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[9] Lim and Dixon (1991) test for the long-run relationship using twelve years of data but have stated in correspondence that this result holds for the sample period used in our paper in both log and natural number form. They use seasonally-unadjusted data without seasonal dummies and argue that the periodic or seasonal patterns of transactions dominate the relationship between currency and expenditure. The difficulty with this is that seasonal patterns net out over a year and should be stationary over time.

It is unclear to what extent the money base result is driven by currency or by the non-currency components. There is a high degree of correspondence between the results for the SRD-adjusted money base and the results for currency, which suggests that the money base is driven by currency. For example, the real income elasticity of real money base is similar to that of real currency (that is, unity). This is hardly surprising since currency constitutes 80 per cent of the money base.

On the other hand, in the cases where cointegration holds, it also does so for the non-currency component of the money base, though the income elasticity of demand for money is statistically insignificant in two of the five instances. There is only a separate meaningful long-run relationship between the non-currency component of the money base, income and the two-year bond yield when the non-currency component of the money base is defined as SRD-adjusted reserves plus loans to dealers.

4.3 M1

There is no evidence of cointegration between real M1, real activity and interest rates using either technique. This is consistent with de Haan and Zelhorst’s (1991) result of no cointegration. While the results are not reported, there are cointegrating relationships between real M1, the own-rate of return on M1, the two-year bond yield and activity on all three measures. The coefficients on the activity variable and the two-year bond yield, however, are signed inconsistently with theory, which renders the result of little practical use. Including the inflation rate does not change this outcome.

4.4 M3

Using the Engle-Granger procedure, there is no evidence of cointegration between either M3, real activity and interest rates. Using the Johansen procedure, 4 out of a possible 60 estimations yielded cointegration, and these are presented below in Table 6.

Table 6: Long-Run Income Elasticity and Interest Rate Semi-Elasticity of M3

Equation	GDP	PFD	Own Rate	2YR
M3	3.2730 (0.27)		-0.1924 (-0.15)	
M3	1.7101 (2.24)#			-0.0542 (-1.71)
M3		2.0141 (5.48)*		-0.0705 (-3.58)*
M3-BA	2.8185 (0.21)		-0.1592 (-0.18)	

* indicates significance at the 1 per cent level, t-statistic in parentheses.

# indicates significance at the 5 per cent level, t-statistic in parentheses.

In general, the M3 results are ambiguous and difficult to interpret. First, in two of the cointegrating equations, none of the coefficients are significantly different from zero. Second, the reported M3 series would be expected to be conceptually inferior to the break-adjusted, since it is a less accurate measure of the aggregate, but it is only the reported series which contains significant coefficients in the cointegrating equation. Third, if the principal use of money is to fund transactions, then the long-run income elasticity would be expected to be around one. For those cointegrating vectors which are significant, however, the income elasticity is about 2, which is apparently distorted by rapid M3 growth in the latter half of the 1980s, reflecting increased demand for monetary assets. Furthermore, the coefficient on the own-rate (where included) in these equations is negative and hence “wrongly” signed, and including the inflation rate as a measure of opportunity cost reverses the finding of cointegration. Overall, evidence of cointegration between M3, activity and interest rates is very weak.

4.5 Broad Money

There are 5 cointegrating relationships out of a possible 30 in this case. Using the Engle-Granger procedure, there is only one cointegrating vector -- relating broad money, PFD and the bill rate. Using the Johansen procedure, there are 4 cointegrating relationships with GNE the only cointegrating scale variable. The vectors are set out in Table 7.

Table 7: Long-Run Income Elasticity and Interest Rate Semi-Elasticity of Broad Money

Equation	GNE	Bill Rate	2 Year Bond	10 Year Bond
Broad Money	1.3523 (32.16)*			
Broad Money	1.3521 (38.04)*	-0.0040 (-1.18)		
Broad Money	1.3495 (34.41)*		-0.0045 (-1.34)	
Broad Money	1.3211 (39.09)			-0.0023 (-0.73)

* indicates significance at the 1 per cent level, t-statistic in parentheses.

The elements of the cointegrating vectors are signed as expected, but the semi-elasticities on the interest rate variables are all statistically insignificant. The broad money own-rate does not contribute anything to the analysis. It is worth noting that the sample size of broad money is considerably smaller than for the other monetary aggregates, and this may have an effect on estimation bias and the confidence with which a result of cointegration can be accepted as depicting a long-run relationship (Juselius (1991)).

4.6 Some General Observations

The results are not particularly supportive of the proposition that there is a long-run linear relationship between money, income and interest rates in Australia. Of a total of over 300 feasible combinations of real money, real income and nominal interest rates, we found cointegration only in 28 cases, or 8 per cent of the total. As expected, there were more cases of cointegration when money and income were defined in nominal values, due to a common price trend, but this was insubstantial, with cointegration occurring only in 40 cases, or 12 per cent of the total. [10]

The results vary to some extent with the monetary aggregate under consideration. One would expect that broad money would have a more reliable relationship with activity than M3 or M1, for example, since it is less distorted by regulation, deregulation and technological change (though its composition would be heavily affected by such factors). This appears to be the case, although there is not much in

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[10] There were 16 cases of cointegration for all the money base measures, 8 for currency, 3 for M3, 3 for break-adjusted M3, and 10 for broad money.

it. The results for broad money, moreover, are sensitive to the choice of the activity variable. The evidence of cointegration for M1 and M3 is particularly weak. The evidence of cointegration is much weaker for the Engle-Granger procedure than for the Johansen procedure (see below).

Currency is the aggregate which exhibits the most consistent relationship with activity and interest rates, in the sense that the results are least sensitive to the choice of activity variable or interest rate. This relationship is not as strong now, however, as it was over the sample period used in the formal tests since, as shown in Figure 9, the ratio of currency to income shifted markedly from 1990/91, in response to a number of factors. [11]

Figure 9: Ratio of Currency to Annual GDP

Since the money base is mostly currency, we anticipated that the results for the money base estimations would be similar to those for currency. Given that the evidence of cointegration between M3 and activity is weak, we expected that the relationship between bank reserves and activity would also be weak. As it turned out, there are proportionally fewer cases of cointegration with the money base

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[11] The velocity of currency had been relatively stable over the past few decades until 1990/91 when currency holdings rose sharply in response to changes to taxation arrangements and crises in the Victorian non-bank financial sector. See "Recent Trends in Money and Credit", Reserve Bank Bulletin, December 1991.

(including currency) than for currency itself and those cases that do occur do so only with the Johansen procedure.

There are two alternative (but not mutually exclusive) explanations of why the Johansen technique may uncover more cases of cointegration than the Engle-Granger procedure:

- the Engle-Granger test for cointegration imposes a common factor restriction on the variables which is only appropriate when there are no short-run dynamics or when short-run and long-run adjustment is the same. If this restriction is invalid, the power of the test in identifying cointegration is low (Kremers, Ericsson and Dolado (1992)). The Johansen procedure, on the other hand, is a dynamic modelling procedure which does not impose the restriction. Both procedures produce similar results with regard to currency, giving rise to the inference that the public adjusts its currency balances to the desired level fairly rapidly. On the other hand, the Engle-Granger procedure uncovers few, if any, relationships between the other aggregates -- money base, M1, M3 and Broad Money -- and activity, giving rise to the inference that the restriction is not valid for them. Changes in income do not have the same effect on deposits with financial institutions in the short-run as in the long-run: it takes time for the public to adjust the portfolio composition of its assets. Since deposits are not adjusted instantaneously to changes in income, neither are required reserves; and

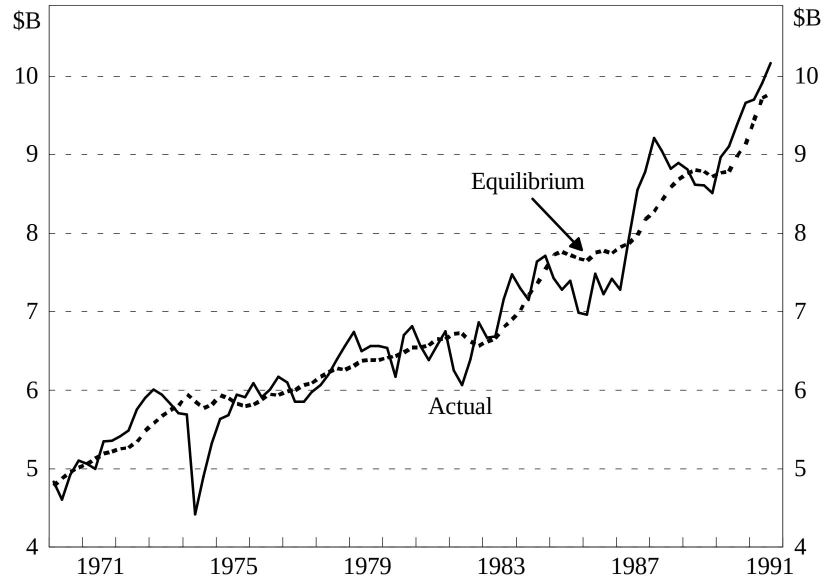
- Monte Carlo experiments by Gregory and Nason (1991) indicate that adjusted Dickey-Fuller residual-based tests for cointegration, such as the Engle-Granger procedure, fail to reject the null hypothesis of no cointegration in the presence of structural breaks in the cointegrating relations between the series. The unit root tests indicated that the reserves components of the money base and M1 contained at least one major trend break, and this may also be expected to hold for the putative cointegrating relation with income.

Overall, the results are sensitive to the definition of both the activity variable and the interest rate. Gross domestic product is the activity variable which occurs most frequently in the cointegrating vectors, twice as often as private demand (twelve times to six). The two-year bond yield is the key rate, appearing in 19 of the 28 cointegrating vectors. Such sensitivity of the results to fairly arbitrary changes in the definition of the variables curtails the policy relevance of monetary aggregates.

The prevalence of the two-year bond yield suggests that people look to medium-term interest rates in determining their long-run real demand for money. It has the further implication that a policy of controlling the medium-term growth of a nominal variable such as the money stock through short-term interest rates would only be effective if the short-term rate changes were expected to endure, such that they affected rates further out on the yield curve.

Finally, it is one thing to be able to say that there is a long-run relationship between money and income, but it is quite another to be able to exploit that relationship for policy purposes. This raises a raft of issues, including causation between money and income, stability and speed of adjustment to equilibrium, and whether substitutes for money can be readily created to avoid control of the money supply. Consider actual real demand for currency and the equilibrium implied by one of the cointegrating relationships in Table 4 (chosen at random), as shown in Figure 10. The actual value can deviate from the estimated equilibrium value for up to two years at a time, and the deviation from equilibrium has been neither systematic nor of regular duration. There also appears to be a tendency for growth in actual real demand for currency to overshoot rises and falls in growth of equilibrium real demand.

Figure 10: Actual and Predicted Equilibrium Real Currency*



* The equilibrium value is based on the estimated long run equation: log real currency = - 4.68 + 1.3129 log real PFD - 0.0255 bill rate. The long-run constant is calculated as the average value of the log of real currency less 1.3129 times the average of the log of real PFD plus 0.0255 times the average bill rate from the first quarter of 1970 to the third quarter of 1991.

5. CONCLUSION

Theories concerning the relationship between money, income and prices have a well-established pedigree in the history of economic analysis. The jump in inflation in the 1970s brought with it the idea that targeting money growth could tie down inflationary expectations and inflation. In the face of financial innovation and regulatory changes, however, the short-run demand for real money balances proved unstable, and the policy unworkable.

Recent econometric developments in time series analysis offer the prospect of testing for the existence of a short *and long run* demand for real money balances, through tests for cointegration. This has been the subject of a number of applied econometric studies in Australia. This literature is a mixed bag in terms of the definitions of money, income and interest rates used and the econometric techniques applied and the conclusions are also mixed.

The aim of this paper was to put the Australian literature into perspective by assessing the sensitivity of the long-run relationship between money, income and interest rates to sensible alternative definitions of these variables, and to different testing procedures. Overall, evidence of cointegration between money, income and interest rates was not particularly strong, and the results were sensitive to changes in the definition of activity and interest rate and to the testing procedure used. There was no evidence of cointegration between M1 and income, and only scarce evidence for the money base, M3 and Broad Money. Evidence was strongest in the case of currency, though events after the sample period used for the formal tests cast doubt on this. These conclusions hold whether money and income are defined in real or nominal values.

A finding of cointegration between money and income would not, in itself, necessarily establish a paramount role for monetary aggregates in policy-making. It would mean that the variables in question "move together" over time, with change in one associated with particular change in the other. That may mean that monetary aggregates have some useful indicator properties, but it implies nothing about causation between the variables, or about whether money is suitable as a control variable for income. Those issues ultimately turn on views about the transmission mechanism, exogeneity issues, the stability and speed of adjustment paths, acceptable bands for predictive errors and the ease with which substitutes for the control variable can be created.

APPENDIX 1: DATA

Currency

Definition: Holdings of notes and coins by the non-bank private sector. Seasonal adjustment by the Australian Bureau of Statistics.

Source: Reserve Bank of Australia *Bulletin*

MB

Definition: Money base, that is holdings of notes and coins by the private sector, plus deposits of banks with the Reserve Bank of Australia and other Reserve Bank liabilities to the private sector. Seasonally-adjusted using the SAS X-11Q seasonal adjustment procedure.

Source: Unadjusted data from Reserve Bank of Australia *Bulletin*.

MB-SRD

Definition: Money base estimated with constant statutory reserve deposit (SRD) ratio set at 7 per cent. Up to September 1988, MB-SRD is estimated as $MB_t+[((7/a_t)-1)xSRD_t)]$ where MB_t is the money base set out above at time t, a_t is the actual SRD ratio prevailing at time t, and SRD_t is the value of SRDs at time t. From October 1988, after the abolition of the SRD requirement and the introduction of non-callable deposits (NCDs), MB-SRD is calculated as $MB_t-NCD_t+SRD^{\#}{}_t$ where NCD_t is the value of NCDs for trading banks up to December 1989 and all banks from January 1990 at time t, and $SRD^{\#}{}_t$ is assumed SRDs at time t, estimated as banks' total liabilities at time t multiplied by the ratio of SRDs to banks' total liabilities at September 1988. Seasonally-adjusted using the SAS X-11Q seasonal adjustment procedure.

MB-AMMD

Definition: Money base plus loans by banks to authorised money market dealers. Seasonally-adjusted using the SAS X-11Q seasonal adjustment procedure.

MB-SRDAMMD

Definition: MB-SRD plus loans by banks to authorised money market dealers. Seasonally-adjusted using the SAS X-11Q seasonal adjustment procedure.

NC-MB

Definition: Non-currency component of money base. Seasonally-adjusted using SAS X-11Q seasonal adjustment procedure.

NC-MB-SRD

Definition: Non-currency component of money base estimated with a constant SRD ratio set at 7 per cent. Seasonally-adjusted using the SAS X-11Q seasonal adjustment procedure.

NC-MB-AMMD

Definition: Non-currency component of money base plus loans by banks to authorised money market dealers. Seasonally-adjusted using the SAS X-11Q seasonal adjustment procedure.

NC-MB-SRDAMMD

Definition: Non-currency component of money base estimated with a constant SRD ratio set at 7 per cent, plus loans by banks to authorised money market dealers. Seasonally-adjusted using the SAS X-11Q seasonal adjustment procedure.

M1

Definition: Currency plus total current deposits with banks, excluding Commonwealth and State Government deposits and interbank deposits. Seasonal adjustment by the Australian Bureau of Statistics. The series before February 1975 excludes savings bank current deposits. Spliced at February 1975.

Source: Reserve Bank of Australia *Bulletin*

M3

Definition: Currency plus bank deposits of the private non-bank sector, excluding Commonwealth and State Government deposits and interbank deposits. Seasonal adjustment by the Australian Bureau of Statistics. The series consists of two data sets of seasonally-adjusted M3, spliced at February 1975.

Source: Reserve Bank of Australia *Bulletin* and Reserve Bank of Australia

M3-BA

Definition: Seasonally-adjusted M3 adjusted for breaks due to the transfer of non-bank financial intermediary (NBFI) business to banks or the establishment of new banks. See Bullock, Morris and Stevens (1989).

Broad Money (BM)

Definition: M3 plus borrowings from the private sector by NBFIs less the latter's holdings of currency and bank deposits. Borrowings by NBFIs include borrowings by permanent building societies, credit co-operatives, finance companies, authorised money market dealers, pastoral finance companies, money market corporations, general financiers and cash management trusts, less borrowings by authorised money market dealers from those non-bank intermediaries. Seasonal adjustment by the Australian Bureau of Statistics.

Source: Reserve Bank of Australia *Bulletin*

Gross Domestic Product (GDP)

Definition: Seasonally-adjusted by the Australian Bureau of Statistics. Real values are in constant 1984/85 prices.

Source: Quarterly Estimates of National Income and Expenditure, ABS Cat. No. 5206.0.

Gross National Expenditure (GNE)

Definition: Seasonally-adjusted by the Australian Bureau of Statistics. Real values are in constant 1984/85 prices.

Source: Quarterly Estimates of National Income and Expenditure, ABS Cat. No. 5206.0.

Private Final Demand (PFD)

Definition: Seasonally-adjusted by the Australian Bureau of Statistics. Real values are in constant 1984/85 prices.

Source: Quarterly Estimates of National Income and Expenditure, ABS Cat. No. 5206.0.

Inflation Rates

Definition: Quarter-on-quarter growth rate of the implicit price deflator for the activity variables defined above.

The 90-Day Bank-Accepted Bill Rate (Bill)

Definition: Three-month average of the average nominal 90-day bank-accepted bill rate for the week-ending last Wednesday of the month.

Source: Reserve Bank of Australia *Bulletin*

The Two-Year Bond Yield (B2)

Definition: Three-month average of the two-year Treasury bond yield for the last business day of the month. Assessed secondary market yields.

Source: Reserve Bank of Australia *Bulletin*

The Ten-Year Bond Yield (B10)

Definition: Three-month average of the ten-year Treasury bond yield for the last business day of the month. Assessed secondary market yield.

Source: Reserve Bank of Australia *Bulletin*

M1 Own Rate (M1OR)

Definition: A weighted-average interest rate paid on interest-bearing current deposits (IBCDs) by National Australia Bank, further weighted by multiplying by the proportion of total IBCDs in M1. The interest rate series contains a break in the March quarter 1990, reflecting the shift to the payment of more market-related current deposit rates by banks at that time.

M3 Own Rate (M3OR)

Definition: The sum of the interest rates paid on the interest-bearing deposit components of M3 weighted by the share of those components in the M3 aggregate. See Blundell-Wignall and Thorp (1987).

BM Own Rate (BMOR)

Definition: The sum of the interest rates paid on the interest-bearing deposit components of broad money weighted by the share of those components in the broad money aggregate. See Blundell-Wignall and Thorp (1987).

APPENDIX 2: TEST PROCEDURES

Standard Unit Root Tests

If the series, y, is drawn from the m-order autoregressive process,

$$y_t = a + \sum_{i=1}^{m} r_i y_{t-i} + u_t, \tag{1}$$

then it is stationary and integrated of order zero if the absolute value of $\sum_{i=1}^{m} r_i$ is less than unity. If it is equal to unity, then the series possesses a unit root and is non-stationary and integrated of order one.

The augmented Dickey-Fuller (ADF) test is a standard test for the existence of a unit root and is estimated in the form,

$$y_t = \alpha_1 + \alpha_2 time + \beta y_{t-1} + \sum_{i=1}^{m-1} g \Delta y_{t-i} + e_t, \tag{2}$$

where

$$\beta = \sum_{i=1}^{m} r_i - 1 \text{ and } \gamma_i = - \sum_{k=i+1}^{m} r_k \tag{3}$$

The null hypothesis is that a unit root exits, $\beta=0$, and the alternative is that the series is stationary, $\beta<0$. The standard t-ratio tests do not apply, with critical values taken from Fuller (1976). The lagged dependent variables represent higher order autoregressive processes of y, with the lag order selected in order to eliminate serial correlation (based on Lagrange multiplier tests). If lags of the dependent variable are not included, equation (2) reduces to the Dickey-Fuller (DF) test equation. A time trend is also included in equation (2) to test for the presence of a deterministic trend. The critical values for the constant and trend in the ADF equation are drawn from Tables I, II and III of Dickey and Fuller (1981).

Phillips' (1987) Z_t test procedure is a non-parametric adjustment of the t-statistic of the unit root variable in the DF test equation. It includes a weighted average of lagged covariances of the error term, the truncation for which can be based on the number of significant sample autocorrelations of the first-differenced variable, or arbitrarily set to 5 and 10 and testing for other lag truncations only if the outcomes vary (Leong and Ouliaris (1991)). The latter method is applied in this paper. The limiting distribution for Z_t is identical to that of the ADF statistic.

Unit Root Tests in the Presence of a Broken Trend

Following Perron (1989), a two-step procedure for testing for unit roots in the presence of a break in the slope of the trend is used:

$$\text{Step 1: } y_t = \delta + \varepsilon T + \phi(T\text{-}B) + z_t \tag{4}$$

where T indicates a time trend and B is the time value of the break with T-B=0 for T<B, and

$$\text{Step 2: } \Delta z_t = \beta z_{t-1} + \sum_{i=1}^{m-1} g \Delta z_{t-i} + u_t \tag{5}$$

where

$$\beta = \sum_{i=1}^{m} r_i - 1 \text{ and } \gamma_i = - \sum_{k=i+1}^{m} r_k \tag{6}$$

The 'm' lags are selected on the basis of Lagrange Multiplier tests for serial correlation. The critical value for β is taken from Table V.B on page 1377 of Perron (1989) and varies with L, the time of the break relative to the sample size. For example, the 5-lag ADF statistic for the money base with break date at 1982:2 is -4.543. The critical value with an L of 0.6 (rounded-up from 0.58=50/87) is -3.95 at the 5 per cent level and -4.57 at the 1 per cent level, and so the money base is stationary around a broken trend at 1982:2 at the 5 per cent level.

Engle-Granger Test for Cointegration

Engle and Granger (1987) set out a well-known and simple residual-based test for cointegration, where the residuals of the estimated hypothesised long-run relationship are tested for a unit root using the ADF procedure. The critical values are drawn from Phillips and Ouliaris (1990).

Johansen Test for Cointegration

Johansen (1988) and Johansen and Juselius (1990) set out a maximum likelihood procedure for the estimation of the cointegrating vectors in the VAR system and which enables tests for the number of cointegrating vectors. Suppose the vector of p variables, $X_t=(X_{1t}, \ldots ,X_{pt})'$, is generated by the k-order vector autoregressive process,

$$X_t=\mu+\sum_{i=1}^{k}\Pi_i X_{t-i}+e_t \tag{7}$$

where μ is a vector of constants, Π_i are pxp coefficient matrices and e_t is independently and identically normally distributed with a mean and variance, $(0,\Lambda)$. This process may be rewritten without loss of generality as

$$\Delta X_t=\mu+\sum_{i=1}^{k-1}\Gamma_i \Delta X_{t-i}-\Pi X_{t-k}+e_t \tag{8}$$

where $$\Gamma_i=-I+\Pi_1+\ldots+\Pi_i \quad \text{for } i=1, \ldots , k-1 \tag{9}$$

and $$\Pi=I-\Pi_1-\ldots-\Pi_k \tag{10}$$

The matrix Π contains the long-run information in the system and is analogous to the error-correction representation of Engle and Granger (1987). There are three scenarios of interest concerning the rank of Π:

Case 1 If rank(Π)=r where r=0, then Π is a null matrix and there is no long-run relationship between the I(1) variables under consideration. As such, there is no cointegrating relationship between the variables and the system is properly estimated as a VAR system in first differences;

Case 2 If rank(Π)=r where $0<r<p$, then there are r cointegrating vectors. The linear combinations of the rows (or columns) of Π span r dimensions in p space; and

Case 3 If rank(Π)=r where r=p, then Π has full rank and there are p independent linear combinations between the variables under consideration and they span all dimensions in p space. This indicates that all the variables are individually I(0) and so the system is properly estimated as a VAR in levels.

If there is cointegration then the coefficient matrix Π can be decomposed as $\alpha\beta'$ where α and β are matrices of dimension pxr. Equation (8) may be rewritten as

$$\Delta X_t=\mu+\sum_{i=1}^{k-1}\Gamma_i\,\Delta X_{t-i}+\alpha\beta' X_{t-k}+e_t \tag{11}$$

where β contains the cointegrating vectors such that the rows of β' create linear combinations of the elements in X_{t-k} which are stationary. The matrix α contains the loading vectors. The loading vectors may be interpreted analogously to the coefficient on the error-correction variable in the ECM of Engle and Granger (1987).

Johansen (1988) and Johansen and Juselius (1990) develop a maximum likelihood estimation procedure for μ, Γ_i, α, β and Λ and also provide tests for the number of cointegrating vectors. The lagged ΔX_{t-i} and μ in (11) are stacked in a vector Z_{1t} with the parameter coefficients arranged in the matrix Γ. The model may be rewritten as

$$\Delta X_t-\alpha\beta' X_{t-k}=\Gamma Z_{1t}+e_t \tag{12}$$

Regressing ΔX_t and X_{t-k} on Z_{1t} using OLS yields matrices of the residuals $\hat{r}_{0t}$ and $\hat{r}_{kt}$,

$$\Delta X_t=\hat{\mu}+\sum_{i=1}^{k-1}\hat{\Gamma}_i\Delta X_{t-i}+\hat{r}_{0t} \tag{13}$$

$$X_{t-k}=\hat{\mu}+\sum_{i=1}^{k-1}\hat{\Gamma}_i\Delta X_{t-i}+\hat{r}_{kt} \tag{14}$$

These residuals represent the variables ΔX_t and X_{t-k} after the removal of short-run dynamics and constant terms. Using these residuals, the likelihood function can be concentrated and estimates of α, μ, Γ and Λ can be found as functions of β.

Three product moment matrices of these residuals, S_{ij}, are calculated as

$$S_{ij}=T^{-1}\sum_{t=1}^{T}\hat{r}_{it}\,\hat{r}_{jt}' \tag{15}$$

for i,j=0,k and T being the number of observations.

Johansen shows that the likelihood-maximising solution for $\hat{\beta}$ is found by solving the eigenvalue problem

$$|\lambda S_{kk}-S_{k0}S_{00}^{-1}S_{0k}|=0 \tag{16}$$

This results in the eigenvalues $\hat{\lambda}_1>\hat{\lambda}_2>...>\hat{\lambda}_p$. The estimate of β is obtained as the normalised eigenvector associated with the relevant eigenvalue. Estimation of the remaining parameters is done by substituting $\hat{\beta}$ for β in the functions obtained from the concentrated likelihood function.

There are two likelihood ratio tests which test the number of stationary combinations of the variables under consideration. The maximum eigenvalue test, or ‘lambdamax’ for short, tests the null hypothesis of r cointegrating vectors against the alternative of r+1 cointegrating vectors. It is given as

$$-T\ln(1-\hat{\lambda}_{r+1})) \tag{17}$$

where the $\hat{\lambda}_i$ are the eigenvalues obtained from estimating $\hat{\beta}$. The second likelihood ratio test statistic is the trace test which tests the null that there are at most r cointegrating vectors against the alternative that all the series are stationary, namely that r=p. The trace test statistic is given as

$$-T\sum_{i=r+1}^{p}\ln(1-\hat{l}_i) \tag{18}$$

Critical values are provided in Table D2, Osterwald-Lenum (1992). The maximum likelihood procedure developed by Johansen and Juselius also allows for linear restrictions on α and/or β to be tested.

REFERENCES

Baba, Y., D.F. Hendry and R.M. Starr (1992), "The Demand for M1 in the USA 1960-1988", *Review of Economic Studies*, 59, pp. 25-61.

Battellino, R. and N. McMillan (1989), "Changes in the Behaviour of Banks and their Implications for Financial Aggregates", in I. Macfarlane and G.S. Stevens (eds.), *Studies in Money and Credit*, Reserve Bank of Australia, Sydney, pp. 124-146.

Bewley, R.A. (1979), "The Estimation of the Equilibrium Response in a Linear Dynamic Model", *Economic Letters*, 3, pp. 357-361.

Blundell-Wignall, A. and S. Thorp (1987), Money Demand, Own Interest Rates and Deregulation, Reserve Bank of Australia Research Discussion Paper No. 8703.

Blundell-Wignall, A., P. Lowe and A. Tarditi (1992), "Inflation, Indicators and Monetary Policy", in A. Blundell-Wignall (eds.), *Inflation, Disinflation and Monetary Policy*, Reserve Bank of Australia, Sydney, pp. 249-313.

Bullock, M., D. Morris and G. Stevens (1989), "The Relationship between Financial Indicators and Activity: 1968-1987", in I. Macfarlane and G. Stevens (eds.), *Studies in Money and Credit*, Reserve Bank of Australia, Sydney, pp. 53-88

Coelli, M. and J. Fahrer (1992), Indicators of Inflationary Pressure, Reserve Bank of Australia Research Discussion Paper No. 9207.

Cooley, T.F. and S.F. LeRoy (1981), "Identification and Estimation of Money Demand", *American Economic Review*, 71(5), pp. 183-199.

Cuthbertson, K. (1991), "Modelling the Demand for Money", in C.J. Green and D.T. Llewellyn (eds.), *Surveys in Monetary Economics Volume 1: Monetary Theory and Policy*, Blackwell, Oxford.

de Haan, J. and D. Zelhorst (1991), "Financial Deregulation and the Stability of the Demand for Money in Australia", *Kredit und Kapital*, 24(3), pp. 317-331.

Dickey, D.A and W.A. Fuller (1981), "Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root", *Econometrica*, 49, pp. 1057-1072.

Emery, K.M. (1991), "Modeling the Effects of Inflation on the Demand for Money", *Federal Reserve Bank of Dallas Economic Review,* March, pp. 17-29.

Engle, R.F. and C.W.J. Granger (1987), "Co-integration and Error Correction: Representation, Estimation and Testing", *Econometrica,* 55, pp. 251-276.

Ericsson, N.R., J. Campos, and H. Tran, (1991), "P-C Give and David Hendry’s Econometric Methodology", Board of Governors of the Federal Reseve System, *International Finance Discussion Paper,* 406.

Fuller, W.A. (1976), *Introduction to Statistical Time Serie*s, Wiley, New York.

Goldfeld, S.M. (1973), "The Demand for Money Revisited", *Brookings Papers on Economic Activity,* 3, pp. 577-638.

Goodhart, C. (1989), "The Conduct of Monetary Policy", *The Economic Journal,* 99, pp. 293-346.

Gregory, A.W. and J.M. Nason (1991), Testing for Structural Breaks in Cointegrated Relationships, University of British Columbia, Department of Economics Working Paper No. 91-31.

Grenville, S. (1990), "The Operation of Monetary Policy", *Australian Economic Review*, 2, pp. 6-16.

Hall, S.G., S.G.B. Henry, and J.B. Wilcox (1989), The Long-Run Determination of the UK Monetary Aggregates, Bank of England Discussion Paper No. 41.

Hargreaves, C. (1991), Modelling Money Demand in Australian Economy-Wide Models: Some Preliminary Analysis, University of New England Working Paper No. 55.

Harper, I. (1988), "Monetary Policy in a Deregulated Financial System", *Australian Economic Review,* 4, pp. 58-63.

Hendry, D.F. and N.R. Ericsson (1991), "Modeling the Demand for Narrow Money in the United Kingdom and the United States", *European Economic Review*, 35, pp 833-886

Inder, B. (1991), Estimating Long-Run Relationships in Economics: A Comparison of Different Approaches, Monash University, Department of Econometrics Working Paper, 18/91.

Johansen, S. (1988), "Statistical Analysis of Cointegrating Vectors", *Journal of Economic Dynamics and Control*, 12, pp. 231-254.

Johansen, S. and K. Juselius (1990), "Maximum Likelihood Estimation and Inference on Cointegration with Application to the Demand for Money", *Oxford Bulletin of Economics and Statistics*, 52, pp. 169-210.

Juselius, K. (1991), Long-Run Relations in Australian Monetary Data, Australian National University, Department of Economics Working Paper No. 238.

Kremers, J.J.M., N.R. Ericsson and J.J. Dolado (1992), "The Power of Cointegration Tests", *Oxford Bulletin of Economics and Statistics*, 54(3), pp 325-348.

Leong, S.M. and S. Ouliaris (1991), Applying the Econometrics of Cointegration to Time Series Data in Marketing Research, National University of Singapore, Working Paper No. 91-52.

Lim, G.C. (1991), The Demand for the Components of Broad Money: Error-Correction and Generalised Asset Adjustment Systems, University of Melbourne, Department of Economics Working Paper No. 304.

Lim, G.C. and V.L. Martin (1991), Is the Demand for Money Cointegrated or Disintegrated: the Case for Australia?, University of Melbourne, Department of Economics Working Paper No. 289.

Lim, G.C. and V.L. Martin (1992), Efficient Estimation of Long-Run Relationships: A Comparison of Alternative Cointegration Estimation with an Application, University of Melbourne, Department of Economics Working Paper No. 343.

Lim, G.C. and R. Dixon (1991), "The Long and Short Run Demand for Currency by the Non-Bank Private Sector", *Applied Financial Economics,* 1, pp. 159-163.

McTaggart, D. and C. Rogers (1990), "Monetary Policy and the Terms of Trade: A Case for Monetary Base Control in Australia?", *Australian Economic Review,* 2, pp. 38-49.

Mehra, Y.P. (1991), "An Error-Correction Model of US M2 Demand", *Federal Reserve Bank of Richmond Economic Review,* 77/3, pp. 3-12.

Orden, D.A. and L.A. Fisher (1993), "Financial Deregulation and the Dynamics of Money, Prices and Output in New Zealand and Australia", *Journal of Money, Credit and Banking,* 25(2), pp. 273-292.

Osterwald-Lenum, M. (1992), "A Note with Quantiles of the Asymptotic Distribution of the Maximum Likelihood Cointegration Rank Test Statistics", *Oxford Bulletin of Economics and Statistics,* 54(3), pp. 461-472.

Park, J.Y., S. Ouliaris and B. Choi (1988), Spurious Regressions and Tests for Cointegration, University of Maryland, Working Paper No. 20.

Perron, P. (1989), "The Great Crash, the Oil Price Shock, and the Unit Root Hypothesis", *Econometrica,* 57(6), pp. 1361-1401.

Perron, P. (1990), "Testing for a Unit Root in a Time Series with a Changing Mean", *Journal of Business & Economic Statistics,* 8(2), pp. 153-162.

Phillips, P.C.B. (1987), "Time Series Regression with Unit Roots", *Econometrica,* 55, pp. 277-302.

Phillips, P.C.B. and P. Perron (1988), "Testing for a Unit Root in Time Series Regression", *Biometrika* , 75(2), pp. 335-345.

Phillips, P.C.B. and B. Hansen (1990), "Statistical Inference in Instrumental Variables Regression with I(1) Processes", *Review of Economic Studies*, 57, pp. 99-125.

Phillips, P.C.B. and S. Ouliaris (1990), "Asymptotic Properties of Residual Based Tests for Cointegration", *Econometrica,* 58, pp. 165-193.

Porter, M. (1989), "Monetary Policy" in J. Freebairn, M. Porter and C. Walsh (eds.), *Savings and Productivity Incentives for the 1990s,* Allen and Unwin, Sydney, 44-72.

Reserve Bank of Australia Bulletin, various issues.

Said, S.E. and D.A. Dickey (1984), "Testing for Unit Roots in Autoregressive-Moving Average Models of Unknown Order", *Biometrika,* 71, pp. 599-608.

Sieper, E. and G.M. Wells (1989), Macroeconomics on the Left, Centre for Economic Policy Research Conference, ANU, Canberra, 27-28 November, mimeo.

Stevens, G.R., S.J. Thorp and J.S. Anderson (1987), The Australian Demand Function for Money: Another Look at Stability, Reserve Bank of Australia Research Discussion Paper No. 8701.

Stevens, G.R. and S.J. Thorp (1989), The Relationship between Financial Indicators and Economic Activity: Some Further Evidence, Reserve Bank of Australia Research Discussion Paper No. 8903.

Yoshida, T. and R.H. Rasche (1990), The M2 Demand in Japan: Shifted and Unstable?, *BOJ Monetary and Economic Studies,* 8(2), pp. 9-30.