**CORRECT COINTEGRATION TESTS OF THE LONG RUN
RELATIONSHIP BETWEEN NOMINAL
INTEREST AND INFLATION**

by

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Correct cointegration tests of the long run relationship between nominal interest and inflation

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The Fisher (1930) hypothesis suggests that a long run equilibrium relationship exists between the nonstationary series: nominal interest and expected inflation. Testing such a cointegrating relationship is complicated by the presence of the unobserved ex ante real rate of interest in residuals from the cointegrating regression. Assumptions concerning the stochastic properties of the expected real rate of interest are examined, and two proxies for the ex ante real rate are employed in multivariate cointegration tests of the Fisher hypothesis.

1.0 Introduction

A large empirical literature exists addressing the measurement and analysis of ex ante real interest rates using the framework originally suggested by Irving Fisher (1930). Equation (1) represents the basic form of the Fisher equation estimated in much of the work on real interest.

$$i_t = \alpha + \beta\pi_t + z_t \quad (1)$$

The constant term, α , represents the 'constant' ex ante real rate of interest, i_t is the nominal rate of interest, and π_t is the actual (ex post) rate of inflation. The error, z_t , is a linear combination of a "rational" forecast error accounting for the difference between actual and expected inflation and a disturbance term accounting for all movements in money interest not explained by variation in expected inflation. A typical test of the Fisher hypothesis involves testing that α is constant and $\beta=1$.¹ However, the nonstationarity of money interest and inflation raises questions regarding the usefulness of much of this literature. Phillips (1986) showed that in least squares regressions with nonstationary regressors, coefficient estimates do not converge in probability as the sample size increases, and the distribution of t-statistics diverge. Although the nominal rate of interest and inflation are generated by nonstationary stochastic processes, estimation of equations such as (1) may still provide information that is useful in studying the Fisher hypothesis; this will occur if the nominal rate of interest and

the rate of inflation are cointegrated.² In a recent article in this journal, R. MacDonald and P. D. Murphy (1989) apply statistical tests for cointegration to the Fisher equation linking the ex ante real rate of interest, the nominal rate of interest, and the expected rate of inflation. By pointing out the possibility of spurious results and recognizing the connection between the Fisher hypothesis and the notion of cointegration, their article represents a useful contribution to this literature. MacDonald and Murphy (MM) conclude that they are unable to reject the null hypothesis of no cointegration using their entire sample period although some evidence of cointegration is found for the United States and Canada for the fixed exchange rate period. Also, no evidence of cointegration is found during the period of floating exchange rates. MM note that the cointegration technique may prove useful in future research while the omission of key information from their model may explain the finding of no cointegration over some periods. However, MM test the cointegration of nominal interest and inflation under the assumption of a stationary ex ante real rate of interest and fail to note that a rejection of cointegration may be a result of the invalidity of this assumption rather than separate and unique trends in money interest and inflation.

This paper extends the work of MM by emphasizing the role of assumptions concerning the stochastic properties of the ex ante real rate of interest in cointegration tests of the Fisher hypothesis. Tests are conducted assuming either a stationary or non stationary ex ante real rate of interest. Under the maintained hypothesis of a stationary real rate of interest we are unable to reject the null hypothesis of no cointegration for either the period studied in MM, 1955:1 to 1986:12, or for an extended sample of data from 1955:1 to 1990:3. Assuming that the real rate of interest is non stationary requires the use of real rate proxies to correctly test the cointegrating Fisher relationship. Two proxies for the real rate of interest are used in multivariate cointegration tests of the Fisher hypothesis, and the null hypothesis of no cointegration is rejected for each sample period studied here. When proper account is taken of the movements in the unobserved ex ante real rate of interest, there appears to be no

difference between the periods prior to and after the adoption of a floating exchange rate system.

Section two of this paper outlines the intuition behind the Fisher hypothesis and its relationship with the concept of cointegration. The next section deals with the econometric issue of testing for cointegration between the nominal interest rate and the rate of inflation under the assumptions of a stationary and a non stationary ex ante real rate of interest. Section four presents results from cointegration tests using two proxies for the expected real rate of interest.

2.0 Cointegration and the Fisher hypothesis

The Fisher hypothesis that the nominal rate of interest adjusts to changes in the expected rate of inflation is a hypothesis regarding the efficiency of the market for financial assets. Optimizing behavior in asset markets implies that the nominal rate of interest and the expected rate of inflation will move in the same direction. Changes in the market expectation of inflation will cause expected rates of return on real assets to change so that the nominal rate of interest must move with expected inflation to equate the expected real yields on nominal and real assets. According to Fisher, the link between the money rate of interest and the expected rate of inflation is money profits. "... if inflation is going on, [agents] will scent rising prices ahead and so rising money profits, and will be stimulated to borrow unless the rate of interest rises enough to discourage them, and their willingness to borrow will itself tend to raise interest."³ In the long run, the nominal rate of interest can not stray too far from the expected rate of inflation and, assuming market efficiency, it can not stray too far from the actual rate of inflation. Or, as Carlson (1977, p. 470) pointed out, "[t]he trend in nominal yields parallels that in expected inflation rates This result is consistent with the notion that financial markets adjust to the real forces of productivity and thrift over fairly long periods of time and that these forces change only gradually." This is the essence of the Fisher hypothesis. In steady state equilibrium the ex ante real rate of interest would be

constant, and a test of the Fisher hypothesis could be achieved by testing whether the nominal rate of interest and the expected rate of inflation share a common stochastic trend.

3.0 Correct Cointegration Tests of the Fisher hypothesis

Following the publication of Eugene Fama's (1975) conclusion that the real rate of interest was constant, Hess and Bicksler (1975), Fama (1976), Nelson and Schwert (1977), Garbade and Wachtel (1978), and Fama and Gibbons (1982) each contributed to the reversal of this conclusion. Nelson and Schwert present evidence that the real rate behaves like a slow moving random walk, and the final two works model the real rate as a random walk. More recently, Mishkin (1981), and Huizinga and Mishkin (1986) have attempted to explain movements in the ex ante real rate of interest using projections from an ex post real rate equation. Given the overwhelming consensus that the real rate of interest is time varying, assumptions about the time series properties of the ex ante real rate play a central role in cointegration tests of the relationship between nominal interest and inflation.

The following equation represents the tax adjusted form of the Fisher equation employed in MM as a basis for their cointegrating regressions.

$$i_t = \frac{1}{1-T} r_t^e + \frac{1}{1-T} \pi_t^e + \frac{1}{1-T} r_t^e \pi_t^e, \quad (2)$$

where i is the nominal rate of interest, r^e is the ex ante real rate of interest, π^e is the expected rate of inflation, and T is the average tax rate on investment income. Before proceeding to test the equilibrium relationship between the nominal rate of interest and expected inflation a number of assumptions must be made. First, using short term assets, the multiplicative term, $r_t^e \pi_t^e$, is approximately equal to zero. "Second, since real expected rates of return are difficult to observe it is commonly assumed that these are constant but subject to random error."⁴

$$r_t^e = r^* + u_t \quad (3)$$

where r^* is a positive constant and u_t is $N(0, \sigma_u^2)$. Using equation (3) and setting $T=0$, produces the following equation referred to by MM as the 'weak form' of the Fisher hypothesis:

$$i_t = r^* + \pi_t^e + u_t \quad (4)$$

In order to estimate equation (4) inflation is assumed to equal its expectation plus a white noise error:

$$\pi_t = \pi_t^e + v_t \quad (5)$$

where v_t is $N(0, \sigma_v^2)$.⁵ The resulting equation represents one form of the cointegrating regression estimated by MM:

$$i_t = r^* + \beta \pi_t + \eta_t \quad (6)$$

The "equilibrium error", $\eta_t = u_t - \beta v_t + e_t$, from the cointegrating regression is actually an unobserved component equal to a linear combination of the mean adjusted, unobserved, ex ante real rate of interest, $u_t = r_t^e - r^*$, a fraction of the unobserved rate of inflation, βv_t , and a disturbance term, e_t , accounting for unexplained movements in money interest.

Clearly, assumptions made about the stochastic properties of the ex ante real rate of interest are crucial to cointegration tests based on the stochastic properties of η_t . If the first two components of the "equilibrium error" are stationary, as assumed in MM, then tests for a cointegrating relationship are easily performed. However, a stationary real rate of interest is not commonly assumed or empirically discovered in this literature. Following Garbade and Wachtel (1978) and Fama and Gibbons (1982), assume that the real rate of interest follows a random walk without drift. Thus, the error in (3) is no longer a zero mean stationary process. Rather, $u_t = r_{t-1}^e - r^* + a_t$, where a_t is a serially uncorrelated zero mean process with variance σ_a^2 . Under the random walk assumption the "equilibrium error", $\eta_t = (r_t^e - r^*) - \beta v_t + e_t$, is a combination of the mean adjusted random walk real rate of interest, $(r_t^e - r^*) \sim I(1)$, a multiple of the stationary forecast error, $v_t \sim I(0)$, and the

disturbance term, ε_t .⁶ The residuals from equation (6) will be integrated of order one, and tests of the null hypothesis of no cointegration will fail to reject although a long run equilibrium relationship may exist.⁷

Proper tests for cointegration between the nominal rate of interest and expected inflation require the use of proxies for the real rate of interest. Substituting (5) into (2), setting $r_t^e \pi_t^e = T=0$, and using the errors in variables formulation $\hat{r}_t = r_t^e + \varepsilon_t$, produces the following cointegrating regression:

$$i_t = \gamma \hat{r}_t + \beta \pi_t + \eta_t. \quad (7)$$

In equation (7) $\hat{r}_t$ is a proxy for the unobserved ex ante real rate of interest, and the "equilibrium error", $\eta_t = -\gamma \varepsilon_t - \beta v_t + \varepsilon_t$, is a linear combination of the unobserved rate of inflation, v_t , the measurement error associated with the real rate proxy, ε_t , and the equation disturbance term, ε_t . Under the relatively satisfactory assumption that ε_t is white noise, the "equilibrium error" may be tested for stationarity providing a useful test of the hypothesis of no cointegration.

4.0 Empirical Results

Correct tests for cointegration will depend on the availability of quality proxies for the real rate of interest. Fortunately, a number of proxies do exist and have been used in previous work on the Fisher hypothesis. The real rate proxies used here are the expected real rate series (rrhm) presented in Huizinga and Mishkin (1986), and the Standard & Poor's earnings-price ratio (e/p). Inflation is the log difference of the consumer price index, and the nominal interest rate is the three month treasury bill rate. All data are monthly, and with the exception of rrhm are from the Citibase data base. All data are available from the author upon request. The time period considered here, 1955:1 -1986:1, mimics that of MM as far as possible however, the real rate series rrhm ends in 1984:12. Results are also presented based on an extended sample of data ending in 1990:3.

For any real rate proxy to be cointegrated with the nominal rate of interest and the actual rate of inflation all three series must be nonstationary. Table 1 presents standard Augmented Dickey Fuller (ADF) statistics for the null hypothesis of a unit root in each of the series considered in this work.⁸ Selecting the correct lag length for ADF type tests is crucial from the perspective of obtaining consistent small sample coefficient estimates. Schwert (1987) shows that small sample bias in the coefficient of interest may be quite large in the presence of a moving average disturbance term. In addition, assumptions regarding the process generating the series in question are important in the selection of critical values for the unit root hypothesis tests.⁹ This work specifies the lag length in ADF type tests using the rules of thumb $l_4 = [4*(T/100)^{.25}]$ and $l_{12} = [12*(T/100)^{.25}]$ suggested in Schwert (1987). The statistics presented in Table 1 are for the AR(l_4) and AR(l_{12}) tests where a time trend has been included in the regression, and the critical values are tabulated in Table 7 of Schwert under the assumption of a first order moving average representation and a range of values for the moving average coefficient. I concluded that all series are non-stationary in levels and stationary in first differences.

Cointegration tests are conducted under two assumptions: a stationary ex ante real rate of interest, equation (6); and a nonstationary real rate, equation (7). The cointegrating regressions along with DF and ADF statistics for the null hypothesis of no cointegration are presented in Table 2. Estimation is conducted using ordinary least squares and a semiparametric correction is employed to produce asymptotically median-unbiased estimators as described in Phillips (1988) and Hansen and Phillips (1990). This approach is asymptotically equivalent to full information maximum likelihood estimation of the system of equations describing each variable in the cointegrating vector. Fully modified standard errors described in Phillips (1988) are presented below the estimated parameters of the cointegrated vectors. Results are presented to correspond as closely as possible to each of the three sub-periods considered in MM: full period- 1955:1 to 1986:12 (or 1984:12 for rrhm); period 1- 1955:1 to 1973:3; and period 2- 1973:4 to 1986:12/84:12. Results are

also presented for a full sample cointegration test using data from 1955:1 to 1990:3. The critical values used in all CI tests are from Engle and YOO (1987), tables 2 and 3.

The results from estimating equation (6), assuming a stationary real rate of interest, are consistent with those of MM although the data is of different periodicity. It is not possible to reject the null hypothesis of no cointegration for the full period from 1955:1 to 1986:1. This conclusion also holds for period 2. The null of no CI is rejected at the five percent level for period 1. MM were only able to reject the null of no cointegration for period 1 at the ten percent level.

The cointegrating regressions obtained from estimating equation (7) using proxies for the ex ante real rate of interest are substantially different from those obtained from equation (6). With the exception of period 1, the fit of the equation always improves with the inclusion of a real rate proxy. The hypothesis of no cointegration is rejected in the full period and in period 1 using either of the real rate proxies. In period 2, the hypothesis of no cointegration is rejected only using the proxy $rrhm$.

The final panel of Table 2 contains results based on data from 1955:1 to 1990:3. These results reject the null hypothesis of no cointegration using the e/p real rate proxy while the same hypothesis is not rejected under the assumption of a stationary real rate of interest. Therefore, I find evidence for a long run equilibrium relationship between the nominal rate of interest, the rate of inflation, and the ex ante real rate of interest that is independent of the sample period examined.

Conclusions

MacDonald and Murphy (1989, p. 446) state that "....the cointegration technique should prove useful in determining why nominal interest rates and inflation drift apart. Thus future research could usefully add other variables, which influence real interest rates, to the cointegrating vector." The purpose of this paper is to emphasize the importance of carefully considering the stochastic properties of the ex ante real rate of interest when

conducting these tests. The first variable to be added to the cointegrating vector must be some measure of the expected real rate of interest. When proxies for the real rate are added to the cointegrating relationship tested in MM, the null hypothesis of no cointegration is rejected in every sample period considered here. When proper account is taken of the movements in the unobserved ex ante real rate of interest, there appears to be no difference between the periods prior to and after the adoption of a floating exchange rate system.

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Notes

¹ For examples see Gibson (1970), Fama (1975), Garbade and Wachtel (1978), or Fama and Gibbons (1982). More recently, Huzinga and Mishkin (1986) employ an ex post real rate equation to forecast the ex ante real rate of interest and test for changes in the stochastic properties of the real rate of interest. Survey data has also been used to generate real rate series which are then analyzed for instance in Gibson (1972), Carlson (1977), Tanzi (1980), and Bonham (1989).

² Nelson and Plosser (1982) find evidence of a stochastic trend (nonstationarity) in annual bond yields and prices. Schwert (1987) finds that nominal bond yields and the rates of growth of the CPI or GNP deflator may contain a unit root. The original works of Granger (1983), and Engle and Granger (1987) introduced the concept of cointegrated series. Pagan and Wickens (1989) provides a useful survey of the literature on unit root and cointegration tests.

³ Fisher (1930, p. 400).

⁴ MacDonald and Murphy (1989, fn 2.) state that they recognize the short-coming of both of these assumptions and are simply trying to keep their specification in line with those common in the literature. While the first assumption is certainly common, the second is not.

⁵ This approach, applied first in studies of the Fisher hypothesis by Fama (1975), is due originally to Reuben Kessel (1966) where it was applied to the study of the term structure of interest.

⁶ Evidence that inflation forecast errors are stationary series is found by Bonham and Dacy (1988). Five out of seven inflation forecast errors are found to be serially uncorrelated.

⁷ The random walk assumption is not a necessary condition for $\eta_t \sim I(1)$. Any non stationary real rate process will result in a rejection of the null hypothesis of no CI.

⁸ See Dickey and Fuller (1979), Fuller (1976) for descriptions of the standard tests for unit roots. Pagan and Wickens (1989) provide a thorough survey of the recent developments in testing for unit roots and cointegration.

⁹ For series such as the CPI rate of inflation or the real rate proxy, $rrhm$, which apparently are generated by $ARIMA(0,1,1)$ processes with moving average coefficients near unity, Schwert shows that the critical values tabulated in Fuller (1976) will lead to a rejection of a unit root far too often. For example, the critical values reported in Schwert for a $IMA(1,1)$ process with moving average parameter $\theta = 0.8$ (the estimate for inflation is 0.78 for the 55:1-86:12 period) is $\tau_{\tau 4} \approx -5.09$ as compared with $\tau_{\tau 4} \approx -3.42$ for a pure autoregressive process.

Table 1: Unit Root Tests

SERIES	AR(l ₄)	AR(l ₁₂)
<i>55:1-73:3</i>		
i	-3.47†	-3.34
π	-4.16†	-2.45
rrhm	-4.94†	-1.88
e/p	-3.34	-2.41
<i>55:1-86:12</i>		
i	-2.92	-3.17
π	-3.28	-2.35
rrhm	-2.23	-1.60
e/p	-2.95	-1.68
<i>55:1-90:3</i>		
i	-3.08	-3.33
π	-3.64†	-2.53
e/p	-2.87	-1.79

Note: All series are as defined in the text. AR(l₄) and AR(l₁₂) are test statistics from ADF type regressions where the number of lagged differences of the dependent variable (equal to 5 and 16 respectively for the 55:1-86:12 sample) are determined using the rules of thumb discussed in the text. Assuming a pure autoregressive process, five percent critical values are given by $\tau_{\tau 4} \approx -3.42$ and $\tau_{\tau 12} \approx -3.40$ for the 55:1-86:12 sample. † indicates significance at the 5% level using Dickey-Fuller critical values (i.e. a pure autoregressive process) but insignificant using the critical values for a moving average process as reported in Schwert.

Table 2: Cointegrating Regressions and Unit Root Tests*

equation	proxy	α	β	γ	RSQ	DF	ADF	QMSL
<i>PERIOD 1: 55-86/84</i>								
(6)	*	3.816	.437	*	.342	-6.362	-2.322	.241
(7)	rrhm	*	.844 (.024)	1.113 (.066)	.470	-15.20	-10.345†	.180
(7)	e/p	*	.230 (.062)	.512 (.038)	.561	-4.559	-3.597†	.046
<i>PERIOD 2: 55-73</i>								
(6)	*	3.026 (.202)	.291 (.052)	*	.247	-5.258	-3.562†	.561
(7)	rrhm	*	.599 (.038)	2.035 (.142)	-.239	-10.575	-6.265†	.035
(7)	e/p	*	.309 (.058)	.395 (.031)	.028	-5.337	-3.649†	.359
<i>PERIOD 3: 73-86/84</i>								
(6)	*	6.936	.208	*	.104	-2.199	-1.649	.117
(7)	rrhm	*	.880 (.030)	1.040 (.078)	.143	-7.501	-7.501†	.256
(7)	e/p	*	.063	.655	.261	-2.385	-2.806	.101
<i>PERIOD 4: 55-90</i>								
(6)	*	3.946	.430	*	.331	-6.758	-2.588	.191
(7)	e/p	*	.234 (.060)	.524 (.037)	.537	-4.826	-3.803†	.064

* α , β , and γ , are coefficient estimates from equations (6) and (7) with corrected standard errors in parentheses below cointegrated parameters. RSQ is the squared correlation coefficient corrected for degrees of freedom. Five and ten percent critical values for the ADF cointegration tests are: two CI series- $\tau(\text{adf}) \approx -3.37$ and -3.02 ; three CI series- $\tau(\text{adf}) \approx 3.78$ and 3.47 . The number of lags used in the ADF tests is chosen to minimize the Schwarz Bayesian criterion and whiten the residuals from the ADF regression. QMSL is the marginal significance level of a Ljung-Box Q statistic for the null hypothesis of serially uncorrelated residuals from the ADF regression. † indicates significance at the five or ten percent level.