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A COINTEGRATION ANALYSIS OF MALAYSIAN TERM STRUCTURE

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ABSTRACT

This paper demonstrates the existence of cointegrating relationships between the Malaysian short and medium interest rates (interbank rates), namely one-week, two-month, six-month and twelve-month rates, with the spread defining the cointegrating vectors, particularly by using the 'pre-crisis' sample period. Using this sample period, the Johansen approach is applied and results of the test imply that the spreads between interest rates form a basis for cointegration space. It is found that two error correction models, which use spreads as the error correction terms, are stable over this 'pre-crisis' sample period. They pass most of the diagnostic tests and it is also found that a non-linear structure existed in one of the models. The result is strengthened with the tests of stability which confirm that there is no structural change between the sample periods. The results of cointegration and error correction analyses also support the validity of the expectation hypothesis. For the long-run, the longer-term interest rates are playing a greater role as equilibrium attractors and this supports the long-to-short version of the expectation hypothesis. Similarly, in the short-run, causal impact runs from long- to short-term interest rates and further confirms the hypothesis.

Key words: Term structure, Expectation hypothesis, Cointegration

JEL classification: C32, E43.

1. INTRODUCTION

Many central banks have increasingly relied on interest rates over the past 15 years, to the almost complete exclusion of monetary or reserve aggregates, both as sources of information for determining policy and as operating instruments for conducting policy. This shift in the conduct of policy from money to interest rates has been taking place by virtue of two developments:

- The breakdown of traditional relationships between money and economic activity largely brought on by innovations in payment and transaction technologies; and
- The increasing sophistication of financial markets and central banks regarding information about the future as embedded in financial instruments, for example, the emergence of derivatives and inflation-indexed debt.

One way in which interest rates appear to be playing an important role in monetary policy is as informational indicators. For example, current expectations about future inflation might help determine how the economy will perform in later years. Thus, central banks are interested in obtaining information about current expectations from forward-looking financial markets in order to help predict future paths for inflation and output. In obtaining such information from financial markets, central banks have relied on the "Expectation Theory" of the term structure. This theory states that longer-term interest rates are set according to market expectations of future shorter-term rates; specifically, rates will be set so that a representative investor is indifferent between holding a long-term bond or a sequence of short-term bonds covering the same length of time. This expectation theory of the term structure is important because it is related to the notion of market efficiency, that is, whether there are profitable arbitrage possibilities to be exploited in the bond market. In addition, the term structure is important in describing the transmission mechanism of monetary policy. If the hypothesis holds, there is a stable one-to-one relationship between short- and long-term interest rates and it implies that the monetary authorities will not be able to permanently 'twist' the term structure by altering the relative supplies of long and short bonds (Engsted and Taggaard, 1994). The expectation theory of the term structure has also been widely used to infer agents' expectations following changes in monetary policy (Mankiw, Miron and Weil, 1987), to evaluate the credibility of economic policy (Andersen and Risager, 1988) and, most importantly, the term structure has been found to be a useful predictor of the future, as the slope of the yield curve has significant predictive value in forecasting future short-term interest rates (Mankiw, 1986; Campbell and Shiller, 1987, 1991), inflation (Mishkin, 1990), and real economic activity (Estrella and Hardouvelis, 1991).

Due to its importance, the expectation theory of the term structure of interest rates has been extensively tested in the literature. Melino (1988) and Shiller (1990), for example, found interest rates to be non-stationary stochastic processes. Thus, it is necessary to transform the data into stationary processes in order to test the expectation theory using conventional methods. Studies by Hall, Anderson an Granger (1992) and Cox, Ingersoll and Ross (1985) indicate that short- and long-term interest rates are subjected to an equilibrium path which ties interest rates movement over time and thus supporting the expectation theory of the term structure. Other recent studies that provide evidence for the expectation theory of the term structure include McFadyen, Pickerill and Devaney (1991), Engsted and Taggaard (1994), Wallace and Warner (1993) and Ghazali and Low (2002). Nonetheless, studies rejecting the theory are from Nourzad and Grennier (1995), Zhang (1993) and Kugler (1996).

However, although most previous studies only investigate interest rates in pairs, a few authors have tested for cointegration between the yield on a long-term bond and a short-term bond and found one. However, they have failed to further apply the theory of cointegration to study the term structure. Nonetheless, the literature which relates cointegration to the Malaysian theory of the term structure is currently very limited. Therefore, in this paper, investigations on the cointegration of interest rates are expanded by using more than two non-stationary interest rates. Most importantly, the paper will employ Malaysian data representing a 'developing' market since analysis employing data from this market is relatively scarce compared to that of the 'developed' financial markets. The paper also reexamines the expectation theory of the term structure using the maximum likelihood approach to estimation and inference on cointegration to test the existence of cointegrating vectors between interest rates of different maturities. The results of the test will be used to estimate an error correction model which is potentially useful for forecasting interest rates in the future. The advantage of this approach is that, unlike Engle and Granger (1987), it allows us to draw inferences about the elements of cointegrating vectors.

The empirical results show that, for the period 1994-2001 (full sample), the test of the hypothesis on the estimated cointegrating vector indicates that the pure expectation theory of the term structure can be rejected. However, when the full sample is split into two subsamples of the 'pre-crisis' period and the 'post-crisis' period, the first subsample (pre-crisis period) confirms/accepts the theory but this is not the case for the second subsample (post-crisis period).

The structure of the paper is as follows. Section 2 relates the theory of cointegration and error correction models to models of the term structure. Section 3 describes the data used in this study. Section 4 presents the empirical evidence as to whether the interest rates are cointegrated or not. If the cointegration is traced within the interest rates, an estimated error correction model is developed to illustrate how this information can be utilized and could be useful for forecasting interest rates/yields of different maturities of treasury bills/bonds. The paper concludes with Section 5, which summarizes this work along with some concluding thoughts.

2. THEORETICAL FRAMEWORK

The theory of the term structure holds that the yields on assets of differing maturities will reflect market expectations of future rates. The expectation model states that the long rate is a weighted average of expected short rates over the lifetime of the long asset plus a term premium. This implies that the spread, that is, the difference between the long rate and the short rate, is a weighted average of expected changes in future short rates, plus a function of the term premium (Patterson, 2000). Following Hall, Anderson and Granger (1992), this relationship could be written as

$$(1) \qquad R(k,t) = \frac{1}{k}\left[\sum_{j=1}^{k} E_t[R(1,t+j-1)]\right] + L(k,t)$$

where E_t is the expectations formed on the basis of information available at time *t, R*(*k,t*) is the *k* period rate at time *t* and *L*(*k,t*) is the associated term premium. This equation provides a general linkage between long- and short-term interest rates. It indicates that the yields of bonds with similar maturities will move together. The pure expectation hypothesis, advanced by Irving Fisher, asserts that the *L*(*k,t*) are zero: short-term bonds yield the same expected return as long-term bonds. This means that forward interest rates are unbiased estimates of expected future spot rates. Other assumptions about the premium would lead to different theories about the term structure.[1]

Equation (1) can be rearranged as

$$(2) \qquad R(k,t) - R(1,t) = \frac{1}{k}\left[\sum_{i=1}^{k-1}\sum_{j=1}^{i} E_t \Delta R(1,t+j)\right] + L(k,t)$$

and then we could expect that if the yields are *I*(1), the spreads between the yields would be *I*(0) and that, assuming rational expectations, any set of *n* yields would have a cointegrating rank of (*n*-1) and would take the long-run form [(-1,1,0, . . . , 0), (-1,0,1,0 . . . , 0), . . . , (-1,0,. . . , 1)].

In Engle and Granger (1987), cointegration implies and is implied by an error correction representation. In the case of the series *X*(*t*)' = [*R*(1,*t*), *R*(2,*t*), . . . , *R*(*k,t*)], an error correction model can be expressed by the equation

$$(3) \qquad \Delta X(t) = -\delta[S(t-1) - \mu] + c(B)\Delta X(t-1) + d(B) \in (t)$$

where *ä* is a non-zero *n* x (*n*-1) matrix, *S*(*t*) is an (*n*-1) x 1 vector of spreads, *c*(*B*) and *d*(*B*) are polynomials in the lag operator *B*, and Î *(t)* is a vector white noise, which may be contemporaneously correlated. The vector [*S*(*t*-1)-*ì*] is called the error correction term, while *ä* is a matrix of adjustment coefficients. If the *ä* is statistically significant, it will show that the error correction model is a valid representation of the data and supports the hypothesis that the spreads contained in *S*(*t*) are cointegrating. Equation (3) shows that although yields on bonds of different maturities may diverge in the short-run, the yields will adjust when the spread between them deviate from the equilibrium value *ì* , so that in the long run yields of different maturity will move together.

However, this paper will re-examine the expectations hypothesis of the term structure using a maximum-likelihood system approach to estimation and inference on cointegration and error correction developed by Johansen (1988) and Johansen and Juselius (1990) due to its advantages over the Eagle-Granger approach.[2]

As Campbell and Shiller (1987, 1988) pointed out in the context of their present value models of the term structure, the spread might measure anticipated changes in yields. Using the short yields as an example, this implies that agents have more information in the spread for forecasting changes in short yields, than is available in the history of short yields alone. Therefore, the spreads are useful for forecasting changes in short yields and the error correction model arises because of agents' forward looking behavior.

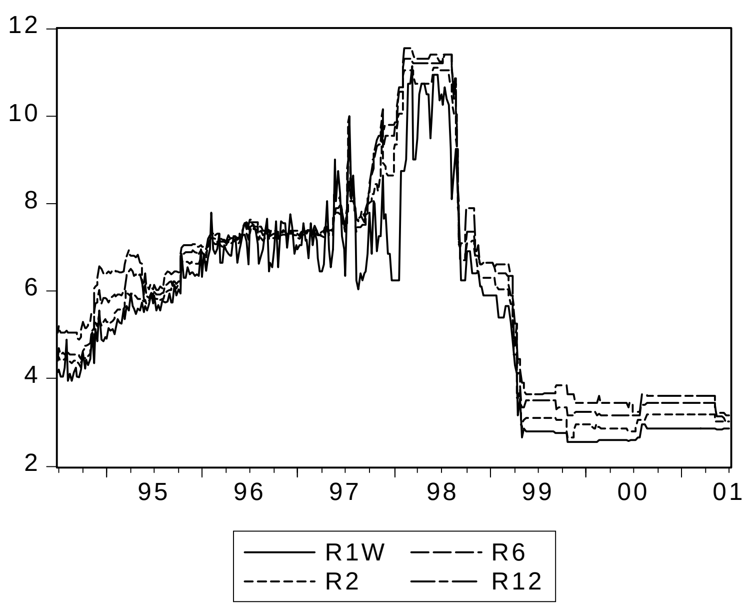
3. THE DATA SET

The analysis has been conducted on four short- and medium-term interest rates, namely the one-week rate (*r1w*), two-month rate (*r2*), six-month rate (*r6*) and twelve-month rate (*r12*). The data obtained are weekly data and the full sample consists of 367 observations for each series, that is, from 29 June 1994 until 4 July 2001. These data of interbank rates are collected from *Datastream* and each interest rate is the average mid-market rate on the third day of each calendar week.

The full sample covers two important periods, namely the period *before* the eruption of the Asian financial crisis and the period *after* the crisis. The first period covers the date up to and including 25 June 1997, (the last week of the pre-crisis period). The second period covers the date of 2 July 1997 onwards. Plots of the interest rate data and differenced interest rate data for four rates of short- and medium-terms are provided in Figures 1 and 2. In particular, the figures illustrate that the interest rates were considerably more volatile when the crisis occurred than they had been before. Prior to the eruption of the Asian financial crisis, the tools of monetary policy were not under great pressure as inflation rates were at moderate levels and Malaysia had experienced high economic growth. However, when the crisis erupted, monetary policy was conducted in the difficult economic environment of the deflationary contagion effect of the region's financial crisis on domestic financial markets and the real economy. The immediate response from the government to bouts of speculative pressure was to sharply increase interest rates supported by intervention operations. But it was recognized that this would not be a sustainable response. The policy response had evolved according to the changing economic conditions to achieve the objectives of monetary and financial stability in an environment of sustainable growth. In July 1998, the ringgit was, therefore, left to adjust downwards and interest rates were brought down to the levels prior to the currency attack. The view taken was that high interest rates were unlikely to contribute to stabilizing the currency given the factors causing the shifts in flows. While this resulted in an initial 5 percent depreciation in the currency, this policy allowed the international reserves to remain intact and reduced the damage on the financial system and the real sector arising from higher interest rates. The policy continued in 1999 and 2000 and it achieved its objective of controlling inflation while promoting consumption and investment. The reduction in interest rates provided an environment for recovery and financial restructuring.

FIGURE 1

Plots of *r1w*, *r2*, *r6* and *r12*



The first analysis of this paper is based on the full sample. However, in view of the major event of the financial crisis which took place within this full sample period and of the empirical evidence that this caused inconsistency to the expectation theory of term structure, two subsets corresponding to the pre-crisis and the post-crisis periods have also been analyzed.

4. THE EMPIRICAL EVIDENCE

4.1 TESTING FOR UNIT ROOTS

In order to test formally the stationarity and non-stationarity of the series, unit root tests were conducted on both the level and first difference of the series. In this process, the Augmented Dickey-Fuller (ADF) test with lag 7 is used. This number of lag is obtained based on the procedure for maximum lag length developed by Said and Dickey (1984). The full sample test statistics (as shown in Table 1) from the test on the level values of the interest rate series cannot reject the null hypothesis of a unit root at any significance level. This implies that the level series, $r1w_t$, $r2_t$, $r6_t$ and $r12_t$, are probably $I(1)$. The ADF test again is performed on the first difference of the series. The results obtained led us to the rejection of the hypothesis of a unit root for the series. Therefore, the interest rates are stationary in levels.

When the two sub-samples are examined, the same pattern emerges for each of the four interest rate series. Thus, it could be concluded that each interest rate is an $I(1)$ process over each of the sub-sample periods.

4.2 COINTEGRATION ANALYSIS

In this section, we consider the hypotheses of interest, that is, n interest rates are cointegrated with (n-1) cointegrating vectors and that the cointegrating vectors are the spread vectors. Johansen (1988, 1991) and Johansen and Juselius (1990, 1992) have developed likelihood based procedures which test for cointegration, estimate the cointegrating vectors and permit the testing of restrictions on the cointegrating vectors. We will apply these techniques to test the hypotheses.

TABLE 1
Unit Root Tests of Stationarity of Variables

Variable	ADF Test Statistic	95% Critical Value	*p*-value	Variable	ADF Test Statistic	95% Critical Value	*p*-value
Full Sample (lag=7)							
r1w	-1.951510	-3.422252	0.6252	Δ*r1w*	-14.4809	-1.941699	0.0000
r2	-1.691384	-3.422218	0.7334	Δ*r2*	-11.51972	-1.941697	0.0000
r6	-1.742702	-3.422218	0.7302	Δ*r6*	-9.916532	-1.941697	0.0000
r12	-1.689466	-3.422218	0.7542	Δ*12*	-10.59172	-1.941697	0.0000
Sub-sample 1 (pre-crisis period) (lag=5)							
r1w	-3.093013	-3.439461	0.1117	Δ*r1w*	-10.19077	-1.942938	0.0000
r2	-2.425646	-3.438886	0.3649	Δ*r2*	-14.62258	-1.942896	0.0000
r6	-2.027347	-3.438886	0.5815	Δ*r6*	-6.931459	-1.942910	0.0000
r12	-2.365537	-3.438886	0.3961	Δ*12*	-14.83071	-1.942896	0.0000
Sub-sample 2 (post-crisis period) (lag=6)							
r1w	-2.204408	-3.431368	0.4842	Δ*r1w*	-15.00807	-1.942346	0.0000
r2	-1.534353	-3.431368	0.8148	Δ*r2*	-8.588932	-1.942346	0.0000
r6	-1.995787	-3.431368	0.5999	Δ*r6*	-7.453101	-1.942346	0.0000
r12	-2.003143	-3.431368	0.5959	Δ*12*	-7.848738	-1.942346	0.0000

Notes: 1. The ADF tests on the level values of interest rates include trends and intercepts in the test equations. The ADF tests on the first-differenced interest rates do not include any trend or intercept.
2. The number of lags used for different samples is based on the number of observations of each sample. See Said and Dickey (1984) for the procedure of maximum lag length for the ADF test.

In this analysis, there is a set of p = 4 endogenous variables, z = [*r1w,r2,r6,r12*]. Following Johansen (1988, 1991) and Johansen and Juselius (1990, 1992), we consider a p-dimensional vector time series z_t and model it as an Unrestricted Vector Autoregression (VAR) involving up to k-lags of z_t.

$$z_t = A_1 z_{t-1} + ... + A_k z_{t-k} + \mu + \varepsilon_t, \quad \varepsilon_t \sim niid(0, \Sigma) \tag{4}$$

where z_t is a (px1) matrix and each of the A_i is a (pxp) matrix of parameters. The Johansen approach is used with the consideration that it enables hypotheses tests concerning the matrix and the number of equilibrium relationships to be carried out.

Before the test of cointegration could be conducted, we have to choose the maximum lag length, k, in the Unrestricted VAR Model. Choosing the appropriate lag length is important since a k which is too small will invalidate the tests, whereas a k which is too large may result in a loss of power (Kanioura, 2001). The appropriate lag is chosen by performing the VAR lag order selection criteria with several tests suggesting different lag lengths. In this analysis, we adopt the sequential modified LR test statistic (each test at 5 percent level), Final Prediction Error (FPE) and Akaike Information Criterion (AIC) which suggest 6 lags for the full sample as well as each sub-sample, since this number of lags is absent of serial correlation in the residuals. Except sub-sample 1, the other samples, however, suffer heteroskedasticity problems in the residuals and all samples also face the problem of normality.

Being aware of the lag order, we then construct the long-run equations (Unrestricted VAR model) for the 4 interest rate series. Table 2 reports the diagnostic tests for the four equations, using a lag length of k=6 and allowing for the intercept term to enter the cointegrating space, since the series have a non-zero drift term.

The results of the diagnostic tests indicate that all four equations in all samples have no problem of serial correlation since the hypothesis of the non-presence of serial correlation in residuals is not rejected at the 1 percent, 5 percent and 10 percent significance levels. However, all equations in all samples have the problem of normality failures in residuals. With the exception of sub-sample 1, all equations in the full sample and sub-sample 2 suffer the heteroskedasticity and the ARCH

TABLE 2
Diagnostic Tests on Four Equations of Unrestricted VAR:
z = [*r1w, r2, r6, r12*]

Statistic	*r1w*	*r2*	*r6*	*r12*
		Full sample		
Far	0.605056	0.445015	0.418278	0.770833
	(0.546641)	(0.641194)	(0.658524)	(0.463449)
Farch	69.63790	57.18346	42.23859	57.54253
	(0.00000)	(0.00000)	(0.00000)	(0.00000)
JB normal	371.7502	8509.806	6680.924	6321.888
	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Fhet	3.529471	3.519552	7.679904	6.927470
	(0.00000)	(0.00000)	(0.00000)	(0.00000)
		Sub-sample 1 (pre-crisis period)		
Far	0.840412	0.251936	0.453072	1.613179
	(0.433976)	(0.777691)	(0.636720)	(0.203406)
Farch	0.099738	0.354231	0.448526	0.002076
	(0.752589)	(0.552636)	(0.504079)	(0.963724)
JB normal	53.63105	883.9362	411.8687	548.1779
	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Fhet	1.363363	1.019635	0.806265	1.047046
	(0.097010)	(0.456946)	(0.795416)	(0.414753)
		Sub-sample 2 (post-crisis period)		
Far	0.666959	0.149543	0.159125	0.995831
	(0.514510)	(0.861206)	(0.853007)	(0.371409)
Farch	69.38168	30.36761	25.91932	34.17492
	(0.00000)	(0.00000)	(0.00000)	(0.00000)
JB normal	394.3377	2812.220	1482.703	1958.406
	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Fhet	3.214679	3.541195	5.278441	5.232406
	(0.00000)	(0.00000)	(0.00000)	(0.00000)

effect in residuals. These failures might be due to several outliers in the series, which may have been caused by the changes in the monetary policy regime in the central bank's operating policy.

This analysis is carried out further by doing the Johansen cointegration test with 5 lags (k-1 lag). The determination of the number of cointegrating vectors is based on the *maximal eigenvalue* and the *trace* tests. Table 3 reports the results of the tests to determine the cointegrating rank of these 4 interest rates for the full sample and the two sub-samples. For the full sample, the statistics of trace test support r=1 cointegrating vector at the 5 percent level and the maximal eigenvalue test indicates no cointegration at the 5 percent level. These results reject the theory developed by Hall, Anderson and Granger (1992) who suggest that there should be n-1 cointegrating vectors

TABLE 3
Johansen Cointegration Tests on *r1w, r2, r6* and *r12* to Determine the Cointegrating Rank

Sample	Null Hypothesis about Rank (r)	*Λ-max* Test Statistic	5% Critical Value	*trace* Test Statistic	5% Critical Value
Full Sample	r=0	37.97108	28.14	70.28498	53.12
(29/06/1994 -	r ≤ 1	24.66025	22.00	32.31390	34.91
04/07/2001)	r ≤ 2	6.831203	15.67	7.653652	19.96
	r ≤ 3	0.822449	9.24	0.822449	9.24
Sub-Sample 1	r=0	39.17496	28.14	64.64840	53.12
(29/06/1994 -	r ≤ 1	30.91170	22.00	37.72787	34.91
25/06/1997)	r ≤ 2	18.20843	15.67	20.22760	19.96
	r ≤ 3	7.816671	9.24	7.816671	9.24
Sub-Sample 2	r=0	36.37230	28.14	73.23240	53.12
(02/07/1997 -	r ≤ 1	25.40279	22.00	36.86010	34.91
04/07/2001)	r ≤ 2	10.51022	15.00	11.45731	19.96
	r ≤ 3	0.947092	0.924	0.947092	9.24

between n interest rates. This means that there should be 3 cointegrating vectors between 4 interest rates. We suspect that the inconsistency of the cointegrating results with the theory probably has to do with the impact of the Asian financial crisis on the volatility of the interest rates series. Therefore, an attempt is made to split the full sample into two sub-samples: the pre-crisis period (from 29 June 1994 until 25 June 1997) and the post-crisis period (from 2 July 1997 until 4 July 2001).

Over sub-sample 1, the tests accept the null hypothesis that the rank of the cointegrating space is not more than and equal to 3, but reject the null hypothesis that the rank is not more than and equal to 2.

This confirms, as the theory predicts, that the 4 short- and medium-term interest rates are cointegrated and the cointegrating rank is 3. In sub-sample 2, during the period when the crisis was taking place, the tests suggest that the cointegrating rank is 2. Similar to the full sample results, the theory is also rejected in sub-sample 2. A reasonable explanation is that the uncertainty caused by the enhanced volatility in monetary growth, interest rates and economic activity in the crisis, makes the term premium non-stationary over this period, causing a breakdown of the cointegrating relationships.

The analysis, therefore, proceeds with the use of sub-sample 1 which confirms the hypothesis that the set of 4 interest rates has 3 cointegrating vectors. These cointegrating vectors, however, require identification. Exact identification of *â*, in Ð = *áâ'*, requires at least *r* restrictions (including the normalization restrictions) on each of the *r* cointegrating relationships. Before we could make any restriction, we should speculate on the equilibrium relationship of the variables. Based on the expectation theory, which is discussed in the previous section, we speculate that the long rate is determined by the short rate and this implies that the spread (difference between the long rate and short rate) is determined by changes in expected future short rates plus a function of term premium. Since each of the three vectors found by Johansen's normalization is an arbitrary linear combination of the possible theoretical long-run relationships, we need to identify these theoretical cointegrating vectors. There are only three linearly independent combinations from six possible pairs. In this case, we choose to impose the cointegrating vectors to be the spread between r1w and the other interest rates, based on equation (2). Under the null hypothesis, the three cointegrating vectors are assumed to be:

$$
\begin{aligned}
(5) \qquad & r1w = r2 + c1 \\
& r1w = r6 + c2 \\
& r1w = r12 + c3
\end{aligned}
$$

In other words, the null hypothesis is that the spreads form a basis for the cointegration space. Table 4 displays the results of testing the hypothesis of the existence of spreads over sub-sample 1.

This method of identifying and testing for overidentification on the cointegrating vectors has been developed by Pesaran and Shin (1994).

TABLE 4
Vector Error Correction Estimates with Restricted Cointegrating Relations (Test that Spread Vectors are Cointegrating)

Variable	Vector 1	Vector 2	Vector 3
r1w	-1	-1	-1
r2	1	0	0
r6	0	1	0
r12	0	0	1
Intercept	-0.123071	-0.009787	0.152282
	(0.03623)	(0.13000)	(0.25839)
Test of imposing the restrictions: $\chi^2(3) = 4.392937$ [prob.= 0.222041]			

Notes: 1. Standard errors of estimates in parentheses where appropriate.
2. Column one lists the interest rates (m=4). The null-hypothesis is that (m-1=3) linearly independent spreads from these interest rates belong in the cointegrating space. The test statistic is conditional on there being 3 cointegrating vectors and the test statistic has a Chi-square distribution with 3 degrees of freedom.

In this method, general nonlinear restrictions on cointegrating relations are imposed in order to identify them. Since there are 3 cointegrating vectors suggested, we need to impose at least 3 restrictions on each cointegrating relation where one of the restrictions on each relation should be the normalization restriction. As there are 4 restrictions imposed in each of the vectors above, the number of degrees of freedom of the likelihood ratio test is 3, which is the number of the overidentifying restrictions imposed on all the vectors. The Likelihood Ratio test statistic for testing the over-identifying restriction is distributed as $X^2(3)$ under the null hypothesis, giving a value of 4.392937 (p-value = 0.222041) which significantly accepts the restrictions and, therefore, accepts the hypothesis that the spreads form a basis for the cointegration space. This result is consistent with the predictions of the theory.

Imposing the above restrictions provides us with the following restricted cointegrating vectors:

(6) $CV1 = r2 - r1w - 0.123071$
$CV2 = r6 - r1w - 0.009787$
$CV3 = r12 - r1w + 0.152282$

These cointegrating vectors represent the spreads of long-term and short-term interest rates, which are indicators of term premium. The ADF and/or Phillips-Perron tests on these cointegrating vectors are performed to ensure the cointegrating relationships. The results of both tests confirm that the cointegrating relationships are $I(0)$.

4.3 ERROR CORRECTION MODEL (ECM)

In this section, we will present an estimated error correction model using the 4 interest rates to illustrate how the cointegration results might be utilized. The spreads are used to define the cointegrating vectors, but the estimation of the model is only based on the period of sub-sample 1 since the cointegration results are not consistent with the data of the full sample and sub-sample 2. The vector error correction model (VECM) restricts the long-run behavior of the endogenous variables to converge to their cointegrating relationships while allowing for short-run adjustment dynamics. In this case, the cointegration terms are the correction terms since a series of partial short-run adjustments gradually correct the deviation from long-run equilibrium. The VECM corresponds to a restricted VAR of order k-1=*5* for the first differenced series, with the inclusion of error-correction terms for the cointegrating vectors.

From equation (4), a Vector Error Correction Model (VECM) can be reformulated as follows:

(7) $$\Delta z_t = \sum_{i=1}^{k-1} \Gamma_i \Delta z_{t-i} + \Pi z_{t-1} + \mu + \varepsilon_t, \qquad t=1,.......,T$$

where D is the first difference operator, z_t is the set of $I(1)$ variables discussed above, *å*$_t$ ~ *niid*(*0,Ó*)*,ì* is a drift parameter, and Ð is a (*p*x*p*) matrix of the form Ð = *áâ'*, where *á* and *â* are (*p*x*r*) matrices of full rank, with *â* containing the *r* cointegrating vectors and *á* carrying the corresponding adjustment coefficients in each of the *r* vectors.

The results obtained previously show the estimates of the adjustment coefficients, *á*, on *r1w*, *r2*, *r6* and *r12* after the restrictions are imposed and are shown below (standard errors are in parentheses):

$$(8)\qquad \alpha = \begin{bmatrix} 1.082720 & 0.085998 & -0.085574 \\ (0.52072) & (0.60035) & (0.26579) \\ 0.049427 & -0.085119 & 0.080843 \\ (0.20921) & (0.24121) & (0.10679) \\ 0.278479 & -0.466013 & 0.226780 \\ (0.17171) & (0.19797) & (0.08765) \\ 0.244302 & -0.389174 & 0.176305 \\ (0.19227) & (0.22167) & (0.09814) \end{bmatrix}$$

The restricted cointegrating coefficients, *â'*, could be written as

$$(9)\qquad \beta' = \begin{bmatrix} -1.000000 & 1.000000 & 0.000000 & 0.000000 \\ (0.000000) & (0.000000) & (0.000000) & (0.000000) \\ -1.000000 & 0.000000 & 1.000000 & 0.000000 \\ (0.000000) & (0.000000) & (0.000000) & (0.000000) \\ -1.000000 & 0.000000 & 0.000000 & 1.000000 \\ (0.000000) & (0.000000) & (0.000000) & (0.000000) \end{bmatrix}$$

where the standard errors are in parentheses and with restricted intercepts equal to

-0.123071, -0.009787 and 0.152282.
(0.03623) (0.13000) (0.25839)

The adjustment coefficients in matrix *á* refer to the coefficients of the Error Correction (ECM) terms. The restricted vectors as mentioned before are *CV1* = *r2*-*r1w*-0.123071, *CV2* = *r6*-*r1w*-0.009787 and *CV3* = *r12*-*r1w*+0.152282.

We could proceed by forming 4 short-run equations for D*r1w*, D*r2*,D*r6* and D*r12*, respectively. These short-run equations are as follows:

(10) $\Delta r1w_t =$

(11) $=$

(12) $\Delta r6_t =$

(13) $=$

By using the general-to-specific approach, we dropped all the insignificant variables based on their *t*-statistics (or *p*-value) and the parsimonious short-run equations are as follows (standard errors are in parentheses):

(14)
$$\Delta r1w_t = \quad 0.884422CV1_{t-1} - 0.2$$
$$(0.103680) \qquad (0.090305) \qquad (0.399730)$$
$$-0.893350\Delta r6_{t-3} - 0.014646$$
$$(0.402140) \qquad (0.029439)$$

(15)
$$\mathrm{D}r2t = -0.065039\mathrm{D}r1w_{t-3} - 0.210146\mathrm{D}r2_{t-1} + 0.026759$$
$$(0.026316) \qquad (0.080421) \qquad (0.011424)$$

(16)
$$\mathrm{D}r6t = 0.190697CV1_{t-1} - 0.307345CV2_{t-1} + 0.148639CV3_{t-1}$$
$$(0.098017) \qquad (0.140117) \qquad (0.067298)$$
$$+0.160114\mathrm{D}r6_{t-2} + 0.004262$$
$$(0.080513) \qquad (0.019458)$$

(17)
$$\mathrm{D}r12_t = -0.049543\mathrm{D}r1w_{t-3} + 0.570478\mathrm{D}r6_{t-1} - 0.542582\mathrm{D}r12_{t-1}$$
$$(0.024253) \qquad (0.138803) \qquad (0.115100)$$
$$+0.015100$$
$$(0.010561)$$

The ECM terms enter significantly only in two equations, namely equation D*r1w* and D*r6*. The estimate of the ECM term in the short-run equation for D*r*1*w* suggests that when the spread between *r*1*w* and *r*2 (i.e., r2 – r1w), namely *CV1*, is above equilibrium the growth of the one-week interest rate increases by 88 percent in order to obtain its equilibrium position. However, when the spread is below equilibrium the interest rate growth reduces by 88 percent. The short-run equation for D*r6* suggests that when the spread between *r1w* and *r2*, i.e., *CV1*, and the spread between *r*1*w* and *r*12, i.e., *CV3*, are above equilibrium, the growth of the six-month interest rate increased by 19 percent and 15 percent, respectively, in order to achieve the equilibrium position, and vice versa. But when the spread between *r1w* and *r6*, i.e., *CV2*, is above equilibrium, the growth of the two-month interest rate decreased by 31 percent and vice versa. However, the negative sign of the ECM

TABLE 5
Diagnostic Tests on the Error Correction Models

Statistic	$\Delta r1w$	$\Delta r6$
Far	1.797060 (0.169433)	0.126090 (0.881631)
Farch	3.88E-05 (0.995036)	0.141603 (0.707221)
JB normal	75.73438 (0.000000)	484.8162 (0.000000)
Fhet	2.866788 (0.005469)	0.539426 (0.825247)
FChow	1.701007 (0.124994)	0.571528 (0.989994)

Notes: 1. *p*-values are in parentheses.
2. *Far* is the *F*-statistic of Breush-Godfrey Serial Correlation LM Test; *Farch* is the F-statistic of ARCH Test; *JB normal* is the Jarque-Bera Statistic of Normality Test; *Fhet* is the *F*-statistic of White Heteroskedasticity Test; *FChow* is the *F*-statistic of the Chow Stability Test.

terms or cointegrating vectors is rather a better result to be considered since it is the correct sign of the error correction as it now is on the right-hand side.

The speed of adjustment for equation D*r1w* is very good. It takes 1 week for *r1w* to converge to equilibrium. On the other hand, it takes 5 or/and 3 or/and 6 weeks for *r6* to converge to equilibrium and this is considered a slow speed of adjustment. Thus, it seems that *r6* is rather more inflexible than *r1w*. We keep the intercept in these short-run equations and the fact that they are all insignificant illustrates that there is an absence of a linear trend in each equation. We also perform the diagnostic tests on these two error-correction models, which are depicted in Table 5.

The results indicate that the short-run equations of D*r1w* and D*r6* pass the autocorrelation and ARCH tests but fail the normality test at the 5 percent significance level. Only equation D*r6* has no heteroskedasticity problem in residuals. The failure of the heteroskedasticity and normality tests on the models might probably be due to the presence of nonlinearities in the models. Therefore, in order to examine the presence of non-linear structure in the behavior of the error correction models, we adopt the methodology of Escribano and Granger (1998) and Escribano and Aparicio (1999). They allow for the square, $CV1^2_{t-1}$, $CV2^2_{t-1}$ or $CV3^2_{t-1}$ and the cubic error correction terms, $CV1^3_{t-1}$, $CV2^3_{t-1}$ or $CV3^3_{t-1}$ to enter the short-run equations. This type of non-linear adjustment allows for the possibility of more than one equilibrium point.

As expected, the square error term enters the short-run equation $\Delta r1w$ significantly with low p-value but both square and cubic error terms enter the equation $\Delta r6$ insignificantly. Thus, the new short-run equation for $\Delta r1w$ is the following:

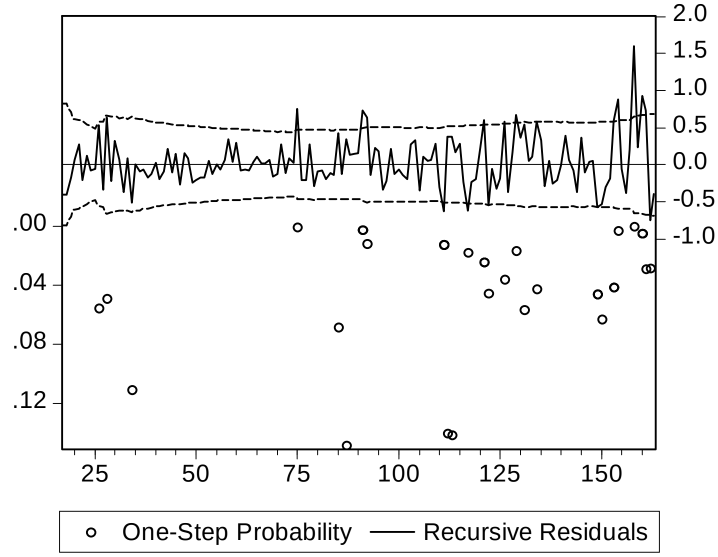
$$
\begin{aligned}
(18) \quad \Delta r1w_t = {} & \underset{(0.102198)}{0.842711}CV1_{t-1} - \underset{(0.225917)}{0.654877}CV1_{t-1}{}^2 - \underset{(0.088900)}{0.298408}\Delta r1w_{t-3} \\
& + \underset{(0.404370)}{1.218103}\Delta r2_{t-3} - \underset{(0.394701)}{1.015483}\Delta r6_{t-3} + \underset{(0.033405)}{0.034761}
\end{aligned}
$$

These results are expected as equation $\Delta r1w$ had more residual problems than equation $\Delta r6$ in the diagnostic tests before. Most importantly, the coefficient of the squared error term entered in equation $\Delta r1w$ has the negative sign as required. Thus, we conclude that there is a non-linear structure in the $\Delta r1w$ model but not in the $\Delta r6$ model. To check the robustness of the model we perform the Chow Breakpoint test and the Chow Forecast test on both the short-run equations, i.e., equation (16) and equation (18) (which includes the squared error term). After observing the residuals, we test the stability of the model with the biggest outlier, that is observation 100 (date of 10 April 1996). The Chow Breakpoint test and the Chow Forecast test do not reject the null hypotheses of no structural change between the sample period (29/06/1994 until 10/04/1996, and 17/04/1996 until 04/07/2001). These results provide no evidence that the estimated models are unstable.

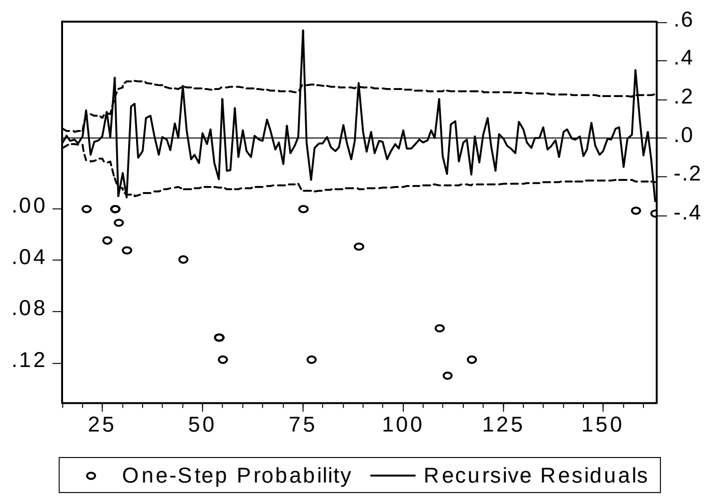
To further confirm our results, we performed the one-step forecast test for the recursive residuals. The one-step forecast test produces a plot of the recursive residuals and standard errors and the sample points whose probability value is at or below 15 percent. The upper portion of the plot repeats the recursive residuals and standard errors, whereas

FIGURE 2
One-step Forecast Test on Short-run Equations

a. $\Delta r1w$: Equation 18



b. $\Delta r6$: Equation 16



the lower portion of the plot shows the probability values for those sample points at the 5, 10 or 15 percent levels. The test is depicted in Figure 2.

The plot reinforces the results of the Chow Breakpoint tests that the models are stable. This is because, in general or most of the time, the recursive residuals lie inside the two standard error bounds. There are only two periods, September/October 1995 and April/May 1997, where the equations are less successful. Generally, however, there is strong evidence of parameter consistency.

It is interesting to note the manner in which the cointegrating vectors enter into each short-run equation. The spread is not relevant in the model for changes in the two-month and twelve-month interest rates but they are relevant to the model for changes in the one-week and six-month interest rates. Interestingly, more spreads are needed to explain changes in the six-month interest rates compared to the one-week interest rates. Comparison between the relative size of absolute error correction coefficients of equation $Dr1w$ and equation $Dr6$ lead us to the interest rates that act as the attracting force. Since the absolute coefficients of error correction terms/cointegrating vectors in equation $Dr1w$ are *larger* than the coefficients of error correction terms in equation $Dr6$, then long-term interest rate assumes a stronger role as an attractor that determines the long-run equilibrium path. Movement in short-term interest rate adjusts more significantly to its deviation from the equilibrium path driven by the long-term interest rates. This relative strength of the speed of adjustment is in favor of the long-to-short version of the expectation hypothesis. The ECM can also be used to represent the short-run causal impact between short- and long-term interest rates as defined by Granger (1969). The significance of the coefficients for lagged differences of long-term rates in equation (18) provides evidence of causality from long- to short-term interest rates. The result, again, is parallel to the long-to-short hypothesis of the expectation theory.

5. CONCLUSION

In this paper, we reexamined the expectation theory of the term structure using Johansen cointegration tests and error correction models. We began by testing for unit roots in the data used in this study. We found that in the full sample period and the two sub-sample periods (the pre-crisis and post-crisis periods), all 4 interest rates used in this study, namely one-week, two-month, six-month and twelve-month interest rates, contained unit roots.

Next, we tested for cointegration using Johansen's trace and maximal eigenvalue tests for each of the samples and found that only the interest rates in subsample 1 (the pre-crisis period) are cointegrated with 3 ranks as expected by the theory. This suggests that, within this period, there is a long-run equilibrium relationship between these interest rates. Tests on the hypothesis that the spreads are contained in the cointegration space are conducted in this sub-sample 1. The result accepts the hypothesis that the spreads form a basis for the cointegration space and, therefore, is consistent with the predictions of the theory. We then develop error correction models which include cointegrating vectors, representing the spreads of different maturity in them. Two error correction models implied by this cointegration are estimated and found to be significant, namely equation $Dr1w$ and equation $Dr6$. However, we trace the non-linear structure in equation $Dr1w$. Diagnostic statistics of these two error correction models reveal little evidence of misspecification. The Chow Breakpoint and Forecast tests on the models provide no evidence that the estimated models are unstable. The one-step forecast test also confirms this result.

The significance of error correction terms in the error correction models confirm the cointegration found earlier and the validity of the error correction representation. Interestingly, the comparison between the relative size of absolute error correction coefficients between these two models leads to the final conclusion that the long-term interest rate assumes a stronger role as the attractor that determines the long-run equilibrium path. This result supports the long-to-short hypothesis of the expectation theory. This long-to-short hypothesis is also supported by the Granger short-run causal impact between short- and long-term interest rates.

Thus, all results from the analysis show that it is appropriate to model the term structure of Malaysian interest rates as a cointegrated system, particularly for the period before the financial crisis. During this period of stabilizing monetary regime, the tests broadly support the prediction theory. Moreover, the existence of an error correction model, which implies some Granger-causality in the system, suggests that the error correction model may be a useful forecasting tool and that the model can also be used to clarify some issues of market efficiency, which need further research.

ENDNOTES

1. The 'strong form' of the expectation hypothesis assumes that the term premium is time-invariant (Cook and Hahn, 1990; Russell, 1992; Nourzad and Grennier, 1995). The 'weak form' of the expectation hypothesis assumes that the term premium is not constant, rather, it varies with changes in such variables as the level of interest rates, fiscal and monetary policy, and cyclical factors (Dua, 1991).

2. Johansen's approach has several advantages over the more traditional Eagle-Granger procedure. Unlike the Eagle-Granger cointegration test, the Johansen test enables one to determine the number of cointegrating relations. Moreover, the Johansen test, which utilizes maximum likelihood, does not depend on arbitrary normalization rules, whereas in the Eagle-Granger approach, which uses OLS to estimate the cointegrating vectors, the results depend on the normalization implicit in the choice of the regress and in the cointegrating regression. In addition, in the Johansen approach one can use classical likelihood-ratio statistics to test structural restrictions implied by economic theory (Nourzad and Grennier, 1995).

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