A multivariate cointegration analysis of interest rates in the Eurocurrency market

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A multivariate cointegration methodology is utilized to analyze relations among interest rates on US dollars, UK pounds, German marks, French francs and Japanese yen in the Eurocurrency market over a period with major capital market deregulations and increasingly globalized money market trading. Three major results appear. It is appropriate to model these interest rates as a multivariate cointegrated system. No interest rate may be excluded from the cointegrating relations. A recursive cointegration approach indicates that the number of cointegration vectors increases in the later part of the sample period. Consequently, this study supports the hypothesis of a substantial increase in Euromarket interest rate comovements. (JEL E40, F02)

This paper analyzes relations among interest rates on currencies in the Eurocurrency market. We utilize the multivariate cointegration methodology developed by Johansen (1988, 1991) and Johansen and Juselius (1990) to investigate the existence of long-run comovements among interest rates of the G5 nations, i.e. The United States, The United Kingdom, France, Germany

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and Japan, for the period from 1984 to 1994. Our data demonstrate that it is appropriate to model these time series of interest rates as a multivariate cointegrated system. No interest rate may be excluded from the cointegrating relations. A recursive cointegrating procedure indicates a substantial increase in Euromarket interest rate comovements during the period of analysis. In particular, after 1987 we find four cointegrating vectors among the five interest rates, indicating that there is only one common stochastic trend underlying the interest rate series.

The voluminous literature on the relations between money markets has mainly provided evidence of international financial market linkages in two respects:

1. comparison of yields on similar assets across national markets, i.e. domestic (onshore) vs. external (offshore) markets;
2. interest sensitivity of financial flows between nations.

Regarding the first question, the early literature, focusing primarily on the causal link between short-term interest rates in the US market and in the Eurodollar market, typically documented segmented markets. For example Hendershott (1967), Kwack (1971), Argy and Hodjera (1973) and Levin (1974) found that US interest rate markets are relatively unaffected by external impacts. Later studies, e.g. Giddy et al. (1979), Schnitzel (1983), Kaen and Hache’y (1983), Hartman (1984), Swanson (1987, 1988) and Fung and Isberg (1992) all documented feedback effects. Furthermore, Lin and Swanson (1993) identified strong bidirectional causalities between the domestic markets (US, UK, West Germany, Switzerland and Japan) and their corresponding Euro- and Asiancurrency markets, respectively. The direct impacts from national markets to the Euromarket in London are immediate and domestic markets are not immune from influences from offshore markets, especially the two most developed ones; the Eurocurrency market in London and the Asiancurrency market in Singapore. They conclude that national governments may lose control over domestic markets if external impacts are from these two offshore markets. However, the causality results are mixed and a less than perfect integration and adjustment between two markets may be attributed to transactions costs, regulatory constraints and other imperfections between domestic and external markets (cf. Aliber, 1978).

With respect to the second question, Kirchgasner and Wolters (1987) tested for an international bivariate linkage of interest rates between the US dollar, German mark and Swiss franc in the short-term Euromarket and in the long-term bond market from 1974 to 1984. They were able to identify a strong linkage in both markets solely for the second half of this decade. In the first half, there was no (bond market) or only a weakly pronounced linkage (Euromarket). The bivariate analysis of Karfakis and Moschos (1990) indicated that the German interest rate plays a dominant and independent role within the European Monetary System (EMS). Reexamining this study, Katsimbris and Miller (1993) failed to support this ‘German leadership’ result when including the US interest rate as a potential third variable in the analysis. Both the US and German interest rates have important causal influences on the
EMS members’ rates. In general, these findings support those of De Grauwe (1989), Fratianni and von Hagen (1990) and Edison and Kole (1995), who concluded that the monetary policies within the EMS respond to each other, as well as to impulses from the rest of the world. With diverse approaches, different methodologies and data sets, these studies have typically documented a substantial increase in comovements among interest rates over time.

Over the past few decades, market deregulations, institutional changes and advances in technology have increased international financial trading. The foundation of the European Monetary System in March 1979 and international policy coordination among the governments and the central banks intend to create monetary stability. In particular, the governments of the G5 nations have taken concerted efforts to maintain parity of exchange and interest rates.

The purpose of this paper is to examine the question of empirical regularities in the movements of interest rates, employing the multivariate cointegration approach. Based on uncovered and covered interest rate parity, respectively, Karfakis and Moschos (1990) and Katsimbris and Miller (1993) suggest that the existence of long-run interest rate linkages can be adequately analyzed within the framework of cointegration. Our study advances the literature in two ways. First, we apply a multivariate cointegration method to investigate long-run trend relations and perform tests to determine whether structural changes in the interest rate market have taken place. The recent literature [see e.g. Karfakis and Moschos (1990); Fung and Isberg (1992); Lin and Swanson (1993); and Katsimbris and Miller (1993)] employs bivariate or trivariate cointegration analysis and error correction models (ECM), as specified in Granger (1986) and Engle and Granger (1987), to assess the existence of long-run equilibrium relations between pairs of interest rates. However, the variation in the results and in the offered explanations of these cointegration and Granger causality tests underscores that a multivariate cointegration analysis may be a more appropriate approach (cf. Phillips, 1991; Gonzalo, 1994). The results of a test within a multivariate system are considerably more general and reliable as compared to bivariate test results, which may be suspect because of the omission of variables. Therefore findings based on bivariate cointegration tests may not be robust in a larger system of variables.

Second, we utilize data from the world’s major countries, the G5 nations, from the Eurocurrency market of London. Domestic markets are not immune from influences from off-shore markets, especially the Euromarket in London (cf. Lin and Swanson, 1993; Kirchgässner and Wolters, 1987). In that sense, empirical regularities and linkages between yields on currencies in the Euro-market may also have consequences for domestic governments in designing interest rate policies. The growth of Eurocurrency trading can be explained by the growth of world trade, government financial regulations and political considerations. Regulation is the major factor behind the continuing profitability of Eurocurrency trading (cf. Krugman and Obstfeld, 1988, pp. 635–638). In formulating bank regulations, governments in the main Eurocurrency centers discriminate between deposits denominated in the home currency and those denominated in foreign. This makes the Eurocurrency market more frictionless and informationally more efficient than the corresponding domestic
interest rate markets. In addition, Eurocurrency futures trading in the IMM of the CME and the growth of the market for interest rate swaps have both enhanced liquidity and thereby the trading activity in the Eurocurrency market.

Our data set of interest rates from 1984 to 1994 covers a period with major capital market deregulations and increasingly globalized money market trading, along with expanding offshore markets. With our data set, we would therefore anticipate the empirical relations between interest rates to be more evident than in previous contributions.

The structure of this paper is as follows. In Section I, we outline the research methodology. In Section II, we describe the data set. In Section III, our results are presented and discussed. First, results from unit root tests of the individual time series are reported. Second, we establish the appropriate number of lags in the VAR model. Third, we estimate cointegration vectors using the multivariate methodology. Fourth, tests are carried out to analyze whether some variables may be excluded from the cointegration vectors. Fifth, intertemporal stability is tested by utilizing a recursive cointegration procedure. A summary of important results is offered in Section IV.

I. Methodology

We give a brief presentation of the multivariate cointegration analysis in this section. For a more rigorous discussion, see Johansen (1988, 1991), Johansen and Juselius (1990) and Hamilton (1994). If two or more variables are cointegrated, then stationary linear combinations of the variables may exist even though the variables themselves are individually non-stationary. Thus, variables that are cointegrated exhibit stable long-run relations. Although the variables may drift apart in the short-run, economic processes force their values back to their long-run equilibrium paths.

Johansen (1988, 1991) and Johansen and Juselius (1990) suggest a maximum likelihood estimation procedure which provides estimates of the cointegration vectors between a set of variables and derive a likelihood ratio test for the hypothesis that there is a given number of these vectors. We consider an n-dimensional vector autoregressive model:

\begin{equation}
X_t = c + \sum_{i=1}^{k} \pi_i X_{t-i} + \epsilon_t,
\end{equation}

where \( X_t \) is an \( n \times 1 \) vector of \( I(1) \) variables, \( \pi_i \) is an \( n \times n \) matrix of parameters and \( c \) is a constant. The vector \( \epsilon_t \) is white noise, which may be contemporaneously correlated. We write the model in error correction form:

\begin{equation}
\Delta X_t = c + \Gamma_1 \Delta X_{t-1} + \ldots + \Gamma_{k-1} \Delta X_{t-k+1} + \Pi X_{t-k} + \epsilon_t,
\end{equation}

where \( \Delta X_t \) is the vector of changes in period \( t \) and:

\begin{align}
\Gamma_m &= -I + \sum_{i=1}^{m} \pi_i, \quad m = 1,2,\ldots,k-1 \\
\Pi &= -I + \sum_{i=1}^{k} \pi_i.
\end{align}
\( \Gamma \) is the short-run dynamics and \( I \) is an identity matrix. \( \Pi \) is known as the long-run matrix and the rank \( r \) determines the number of stationary linear combinations of \( X_r \). For \( 0 < r < n \), there exist \( r \) cointegrating vectors. In that case, \( \Pi \) can be factorized as \( \alpha \beta' \), where both \( \alpha \) and \( \beta \) are \( n \times r \) matrices. This model reflects a dynamic equilibrium relation, in which the expression \( \beta'X_{t-1} \) represents the extent to which the system is ‘out of equilibrium’, or deviates from long-run relative price relations. The series are linked together over time by the long-run relations in \( \beta' \), ensuring that the series never move too far apart. \( \alpha \) are the error-correction parameters and take into account the speed of adjustment.

The concept of cointegration is closely related to that of common trends. Stock and Watson (1988) illustrate that when there are \( (n - r) \) linearly independent cointegration vectors for a set of \( nI(1) \) variables, then each of these \( n \) variables can be expressed as a linear combination of \( rI(1) \) common trends or factors and an \( I(0) \) component. Consequently, the higher the number of cointegration vectors, the more stable the system.

Johansen (1988, 1991) proposes two methods for estimating the number of cointegration vectors; the trace test and the maximal eigenvalues test (max test), respectively. The trace test is a likelihood ratio test for maximum \( r \) cointegration vectors against the alternative equal to \( n \). The max test has an identical null hypothesis, while the alternative is \( (r + 1) \) cointegration vectors. Both tests have a non-standard asymptotic distribution and the critical values for the rank test are tabulated in Johansen and Juselius (1990) and Osterwald-Lenum (1992).

The constant term \( c \) is included in the regression to take care of possible trends. Two options arise. An unrestricted \( c \), i.e. \( c \neq 0 \), implies a linear trend in the non-stationary part of the model, while a restriction of the form \( c = \alpha \beta_0 \), implies an intercept term and, hence, absence of trend in the non-stationary part. Furthermore, since the critical values of the test statistics and estimators depend on which assumption is maintained, it is important to choose the appropriate model formulation. Thus, the restriction \( c = \alpha \beta_0 \) will be tested using an ordinary likelihood ratio test as described in Johansen and Juselius (1990).

The Johansen procedure also allows for testing a variety of restrictions on the elements of \( \alpha \), \( \beta \), or both. In our context, we will investigate whether some of the interest rates may be excluded from the long-run relation of the system. These hypotheses are of the form \( \beta = H\varphi \), where \( H \) is a design matrix, imposing linear restrictions on \( \beta \) like exclusion of certain variables in the cointegration vectors. The restrictions may be tested by a likelihood ratio test (cf. Johansen, 1988, 1991).

A problem in time series analyses is the existence of possible shifts in the mean and in the trend of the variables. The consequences of this problem are well documented for univariate series (cf. Perron, 1989). To test for the significance of intertemporal changes in the interest rate relations, we could have split the data set into subperiods, performing cointegration tests for each of them. However, to obtain more information about the stability over time, we will implement a recursive cointegration procedure.
II. Data

The data are the logarithms of 1 plus the 3-month yield on the five major currencies US dollar (West) German mark, British pound, French franc and Japanese yen; bid rates quoted Tuesday at 11.00 h (Greenwich Mean Time) from the Eurocurrency market of London. The total sample comprises the period from January 1984 to October 1994 and consists of 138 four-weekly observations for each data series. We collect them from the currency data base ‘Cumix’ at the Norwegian School of Economics and Business Administration.

III. Empirical results

The stationarity characteristics of the individual time series are controlled for by an augmented Dickey and Fuller (1979, 1981) test. We include a constant term and exclude trend considerations, as no trend pattern could be revealed in the individual time series. Table 1 presents results for our five time series. We learn from the table that the null hypothesis of a unit root in interest rate levels cannot be rejected, while the hypothesis that there is a unit root in the differences is rejected, i.e. the series tested are non-stationary in the levels, but stationary in differences. Thus, the interest rate is an $I(1)$ process for all countries and the series are expedient in a cointegration analysis.

To determine the appropriate lag length, we apply two different test procedures; the Akaike’s Information Criterion (AIC) and likelihood ratio tests for reduction in the number of lags in the VAR model, respectively. The tests

<table>
<thead>
<tr>
<th>Table 1. Augmented Dickey-Fuller tests for stationarity of the individual time series of interest rates</th>
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<tbody>
<tr>
<td>DEM</td>
</tr>
<tr>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>(a) Levels</td>
</tr>
<tr>
<td>−1.24</td>
</tr>
<tr>
<td>−1.05</td>
</tr>
<tr>
<td>−0.88</td>
</tr>
<tr>
<td>−0.71</td>
</tr>
<tr>
<td>(b) Differences</td>
</tr>
<tr>
<td>ΔDEM</td>
</tr>
<tr>
<td>ΔDEM</td>
</tr>
<tr>
<td>−3.34***</td>
</tr>
<tr>
<td>−3.89***</td>
</tr>
<tr>
<td>−6.01***</td>
</tr>
<tr>
<td>−10.38***</td>
</tr>
</tbody>
</table>

* *** and ****, significant at the 10, 5 and 1% levels, respectively.

Critical values: 10% −2.57, 5% −2.88, 1% −3.48.

provide different guidelines and may therefore yield different conclusions. The Akaike's Information Criterion scores were estimated for VAR models spanning from 13 lags to one lag and the optimal AIC-value was obtained for the VAR (1) representation. On the other hand, the sequential likelihood ratio test rejected the null hypothesis of the VAR (4) model being preferable to the VAR (5) model, i.e. indicating that the fifth lag contains significant information. To choose among VAR (1) to VAR (5) representations, the autocorrelation structure of residuals in the models was examined. For example it turned out that the VAR (1) model fails to pass an $F$ test for uncorrelated residuals, while there are no autocorrelation problems for the VAR (5) model at the 5% level. Consequently, we select the VAR (5) model in our study.

The analysis of the appropriate rank of the cointegration vectors is presented in Table 2. The Johansen max test statistic accepts the restriction that the rank of the cointegration space is not beyond one and rejects the hypothesis that the rank is maximum null at a 5% level. The trace test statistic accepts the restriction that the rank of the cointegrating space in not more than three, but rejects the hypothesis that the rank is not more than two. Since the power of the tests is low for cointegration vectors with roots close to but outside the unit circle (cf. Johansen and Juselius, 1990), we follow their procedure and include the third cointegration vector in the analysis.

Conditional on the existence of three cointegration vectors, we test the null hypothesis of no linear trend in the data. The methodological issues raised in this test are discussed in Section I. The likelihood ratio test statistic is estimated at 0.34 ($\chi^2$ distribution) and the hypothesis of no linear trend is not rejected.

Next, we investigate whether some interest rates may be excluded from the long-run relation of the system. The methodological issues raised in this test are also discussed in Section I. With three cointegrating vectors, this likelihood ratio test statistic is distributed as a $\chi^2$ random variable with three degrees of freedom. The results from these exclusion tests are presented in Table 3. At a 5% significance level none of the variables may be excluded from the long-run relation, i.e. all interest rate series contribute significantly to the cointegration relation or comprise a basis for the cointegration space.

<table>
<thead>
<tr>
<th>Null hypothesis about rank $r$</th>
<th>Test statistic Max (95%)</th>
<th>Test statistic Trace (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r = 0$</td>
<td>34.44 (34.40)</td>
<td>95.13 (76.07)</td>
</tr>
<tr>
<td>$r \leq 1$</td>
<td>25.32 (28.14)</td>
<td>60.70 (53.12)</td>
</tr>
<tr>
<td>$r \leq 2$</td>
<td>20.92 (22.00)</td>
<td>35.38 (34.91)</td>
</tr>
<tr>
<td>$r \leq 3$</td>
<td>12.59 (15.67)</td>
<td>14.46 (19.96)</td>
</tr>
<tr>
<td>$r \leq 4$</td>
<td>1.87 (9.24)</td>
<td>1.87 (9.24)</td>
</tr>
</tbody>
</table>

Source: Osterwald-Lenum (1992), Table 1*.
With a different, more general, methodology, our empirical findings support those of Katsimbris and Miller (1993), who found that the US interest rate has important causal influences on the EMS members’ rates in addition to the German rate and those of De Grauwe (1989), Fratianni and von Hagen (1990) and Edison and Kole (1995), who concluded that the monetary policies within the EMS respond to each other, as well as to impulses from the rest of the world. In fact, we document that yields on currencies in the Euromarket can be considered as a multivariate system of cointegrating vectors, where no interest rate is redundant.

A common problem with time series is shifts in the mean and in the trend of variables. To test for the significance of intertemporal changes in the interest rate relations, we could perform conventional cointegration tests for subperiods. However, to obtain more information about the structural stability over time, we implement a recursive cointegration procedure. Our hypothesis is that comovements among yields in the Eurocurrency market has increased over time, i.e. we expect to find a larger number of cointegration vectors in the most recent years.

In Figure 1, we plot the estimated trace test statistics along with the 5% critical values. The test is a likelihood ratio test for maximum r cointegration vectors among the five variables against the alternative equal to n vectors, c.f. Section I. The test statistic is estimated on an increasing number of observations over time. First, we initialize the test procedure by estimating the test statistic on the set of observations from January 1990 to October 1994. The test statistic appears on the right hand side in Figure 1, Panels (a)–(e), for the null hypothesis of the rank being not more than 0–4, respectively. Next, the estimation period is widened by recursively cumulating observations to the initial observation set, i.e. the second test statistic is estimated on the period from December 1989 to October 1994, the third test statistic is estimated on the period from November 1989 to October 1994 etc. Finally, the last test statistic is estimated on the complete data set, i.e. from January 1984 to October 1994. The test statistics appear when moving to the left in the graphs. Consequently, Fig. 1 clearly illustrates the intertemporal structure among the five interest rates.

The figure visualizes interesting trends of development in the Eurocurrency market. In Panel (a), we see that the trace test statistic rejects the hypotheses

<table>
<thead>
<tr>
<th>Variable</th>
<th>Test statistic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEM</td>
<td>9.79</td>
<td>0.0205</td>
</tr>
<tr>
<td>FRF</td>
<td>9.90</td>
<td>0.0194</td>
</tr>
<tr>
<td>GBP</td>
<td>9.50</td>
<td>0.0234</td>
</tr>
<tr>
<td>JPY</td>
<td>7.84</td>
<td>0.0494</td>
</tr>
<tr>
<td>USD</td>
<td>15.01</td>
<td>0.0018</td>
</tr>
</tbody>
</table>
that the rank is null over the full test sample period; i.e. at any time of observation there is at least one cointegration vector.

Panel (b) illustrates that the hypotheses of the rank being not more than one are generally rejected, with the exception of a period of a few weeks during the first half of 1985.
The hypotheses of the rank being not more than two are rejected from September 1987, see Panel (c).

Panel (d) shows that the hypotheses of the rank being not more than three are rejected from December 1987.

Finally, from Panel (e) we see that the hypotheses of the rank being not more than four are never rejected, indicating that the cointegration rank of the set of five interest rates is four from the end of 1987, i.e. we find \((n - 1)\) cointegrating vectors among the \(n\) interest rates. An exclusion test, c.f. Section I, carried out for the subperiod from January 1988 to October 1994 indicates that no variable can be excluded from the cointegration vectors at a 1% significance level.

In general, since a rise in the number of cointegration vectors indicates a more stable system, we conclude that the empirical results are consistent with the hypothesis of stronger interest rate linkages in the Eurocurrency market over time. In that sense, our findings support those of Kirchgassner and Wolters (1987), who, based upon a bivariate analysis, identified a strong linkage between US, German and Swiss interest rates in the Euromarket during the period from 1979 to 1984, but only a weakly pronounced linkage during the period from 1974 to 1979.

Furthermore, if we focus on the relation between cointegration and common trends or factors, four cointegration vectors for a set of five variables indicate that there is only one single non-stationary common factor underlying the time series behavior of each interest rate. The common factor cannot be uniquely identified and it could be a linear combination of several \(I(1)\) variables. It may be appropriate to explain this common non-stationary factor as an exogenous impact to the system of interest rates such as an exchange rate, inflation, a measure of monetary growth etc. (cf. Hall et al., 1992).

**IV. Conclusions**

During the past few decades, market deregulations, institutional changes and advances in technology have increased international financial integration. In this paper, we have employed the multivariate cointegration framework to analyze long-run relations among US dollars, UK pounds, German marks, French francs and Japanese yen in the Eurocurrency market spanning the period from January 1984 to October 1994. Our study covers a period with increasingly globalized money market trading, including the growth of the important Euromarket.

Three major results appear. First, our empirical findings indicate that it is appropriate to model time series of yields on currencies in the Euromarket as a multivariate cointegrated system, reflecting long-run relations among the interest rate series. Second, we find that no interest rate may be excluded from the cointegrating relations. Thus, our findings underscore that previous results and explanations of bivariate and trivariate cointegration and Granger causality tests may not be robust in a larger system of variables. Finally, our study indicates that the structural relations between Euromarket interest rates have changed. A recursive cointegration approach indicates that a higher number of...
cointegration vectors are present in the later part of the sample period. In particular, after 1987 we find four cointegrating vectors among the five interest rates, indicating that there is only one common stochastic trend underlying the interest rate series. Consequently, this study supports the hypothesis of a substantial increase in Euromarket interest rate comovements during the period of analysis. These findings might be the result of high substitutability between the five currencies, indicating that national governments cannot expect to design interest rates policies independently.

Notes
1. The models were also estimated using interest rates in levels rather than logarithms. These estimations yielded similar results and are not reported here.

References
A multivariate cointegration analysis of interest rates in the Eurocurrency market: H Bremnes et al.


