SNF REPORT NO. 54/00

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by

Helge Bremnes
Øystein Gjerde
Frode Sættem

Revised version of SNF Report No. 77/97

SNF-project no. 7465: «Stabilitet i finanssektoren"

The project is financed by the Banking, Insurance and Securities Commission of Norway

FOUNDATION FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION
BERGEN, OCTOBER 2000

ISBN 82-491-0085-9
ISSN 0803-4036

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HELGE BREMNES
Institute of Economics
Molde College
6400 Molde, Norway

ØYSTEIN GJERDE
Department of Finance and Management Science
Norwegian School of Economics and Business Administration
5045 Bergen, Norway

FRODE SÆTTEM
Department of Finance and Management Science and
Foundation for Research in Economics and Business Administration
Norwegian School of Economics and Business Administration
5045 Bergen, Norway

Keywords: Interest rates, Multivariate cointegration methodology
JEL Classification system-number: E43

* The authors would like to thank Jan Tore Klovland and Emil Steffensen for helpful discussions and two anonymous reviewers of the Scandinavian Journal of Economics for constructive comments. Financial support from the Banking, Insurance and Securities Commission of Norway is gratefully acknowledged.

Abstract
The Johansen multivariate cointegration methodology is utilized to analyze relationships among short-term and long-term interest rates in the United States, Germany and Norway. A variance decomposition approach is applied to estimate the proportion of each interest rate's forecast error variance attributable to innovations in the other interest rates. Impulse response functions are plotted to illustrate the speed with which interest rates events are transmitted between capital markets. The analyses illustrate that US interest rates have a significant influence on both German and Norwegian interest rates, while the reverse effect is modest. Norway is also strongly exposed to German interest rates movements, which illustrates the consequences of a small country linking its currency to the value of European currencies.

Linkages among Interest Rates in the United States, Germany and Norway

I. Introduction

Over the past decade, a voluminous literature on the subject of international interest rate comovements has emerged. The research activity has been stimulated by the hypothesis of an increasing international integration between capital markets around the world. We have observed a considerable deregulation of financial markets, which has increased the flow of capital between nations. An extensive use of electronic trading devices has also contributed to this development. The purpose of this paper is to analyze short-term and long-run relationships among interest rates in the US, Germany and Norway utilizing the Johansen multivariate cointegration methodology. In addition, we apply a variance decomposition approach and estimate impulse response functions based on the cointegration results to provide insights into the extent to which, and the speed with which, interest rate changes in one market are incorporated in another national capital market. The paper has three major contributions: First, we use Norway as a proxy for small, open economies heavily dependent upon interest rate events in major world capital markets, and we incorporate this country into a US-German analysis. This provides both country specific evidence as well as evidence of more general interest on the relationships between major and minor world interest rates. For example, Mundaca, Røste and Valseth (1996) report a strong correlation between changes in Norwegian, Swedish and Danish long-term interest rates, respectively, indicating that our results may be of interest for at least other Scandinavian countries as well. Second, the paper provides evidence of interest rate linkages based on recent data from the nineties. Third, we include measures of estimation uncertainty (standard errors and test statistics) when impulse response functions and forecast error variance decompositions are analyzed. In the cointegration literature, these measures are rarely found.

The relationship between US and German capital markets is of special interest. While the most important economy of the world is found in the US, Germany is assumed to be the leader among European countries. Therefore, we utilize interest rates, both short-term and long-term, from these two countries. Removals of official trade barriers along with a general trend of increasing globalization imply that minor countries will import interest and inflation policies from abroad into an economy characterized by high capital mobility. Norway, assumed to be heavily influenced by the interest rate developments in large nations, especially Germany, is a striking example. More specifically, on October 22, 1990, the value of the Norwegian Krone was linked to the ECU, and from December 10, 1992, the Bank of Norway has been seeking to stabilize the international value of the Krone against European currencies.

The methodological approach in this paper permits us to analyze interest rate linkages between Norway and Germany, when we simultaneously control for interest rate impacts from the US. Cointegration methods have been utilized to reveal interest rate linkages based upon both uncovered and covered interest rate parity. Assuming that forecast errors of the change in the exchange rate are stationary, a cointegration relationship can be formed. The cointegration approach is also appropriate in studying the term structure of interest rates. If interest rates are integrated of order one, a long-run relationship between the yield to maturity on a k period discount bond and the return on a bond with one period to maturity, can only be formed when they are cointegrated. To obtain information about our interest rates within a system of variables, we follow the Johansen (1988, 1991) approach and perform multivariate cointegration analyses. We aim at revealing both short-term adjustment mechanisms and long-term comovements to assess the pattern of interest rate transmissions and market linkages within and between our three countries. Following Lütkepohl and Reimers (1992), we construct impulse response functions and carry out forecast variance decompositions to provide further insights into the short-term and long-run interrelationships among variables in cointegrated systems.

Irrespective of approach, methodology and data set, a large body of research documents a significant increase in comovements among interest rates over time. Most papers focusing on the interest rate sensitivity of financial flows between nations are devoted to causal relationships between *nominal* interest rates. In addition to the US influence, the importance of German policies on other European countries has been investigated. A number of papers are therefore concerned with interest rate linkages within the European Monetary System (EMS). Kirchgässner and Wolters (1987) include both the short-term Eurocurrency market of London and the long-term bond market to establish interest rate linkages between the US dollar, the German mark and the Swiss franc over 1974-1984. Using Granger causality tests, they identified a strong linkage in both the short-term and the long-term market for the second half of that period only, i.e. an indication of an increasing economic integration. Karfakis and Moschos (1990) perform a bivariate vector autoregression analysis on short-term domestic interest rates from 1977-1988 and find that German interest rates have prediction abilities for future interest rates in other EMS membership countries. They hence conclude that Germany has a pivotal and independent role within the EMS. However, Hafer et al. (1997) find a general integration of interest rate behavior across the EMS, and raise doubts about the concerns that Germany will occupy a dominant position, if and when the EMU takes place. Other authors point out the necessity of a more general framework to deal with these issues, such that one may control for factors that influence the interest rate level in a particular EMS nation. Fratianni and von Hagen (1990) incorporate domestic inflation and output growth and find that Germany is a vital player, although not necessarily the dominant force in the monetary policies of the EMS member countries. This result coincides with the one of Katsimbris and Miller (1993). They reexamine the study of Karfakis and Moschos (1990) in a trivariate Granger causality analysis by including US interest rates, and it turns out that these rates have a substantial influence on the rates of the EMS member countries. This is consistent with de Grauwe (1989), Edison and Kole (1995) and Borio and McCauley (1996), who concluded that the monetary policies within the EMS respond to each other, as well as to impulses from the rest of the world.

Linkages and comovements between *real* interest rates of various countries have been analyzed by Modjtahedi (1988), who assumes a unidirectional causality from the US to the other OECD real rates. He shows that real interest differentials converge to their long-run values over a period of at most six months. Equal real rates in the long run along with a correct causality assumption imply that they are tied to the US. On the other hand, Throop (1994) applies a cointegration analysis on data from 1974-1993 and is unable to establish a link from the US to Canada, Germany or the UK. There is some support for cointegration between US and Japanese real rates, but the evidence for long-run convergence is weak. Fujihara and Mougoué (1996) extend this analysis by including interest data from France and Italy over approximately the same period of time. Their Granger causality tests reveal no significant linkages between the countries' real rates, although subperiod analyses indicate that this phenomenon may be sensitive to the US monetary policy regime. Furthermore, Germany seems to provide some information on real interest rates in France and in the UK.

Since both short-term and long-term interest rates are utilized in our study, this paper is also related to the studies of Campbell and Shiller (1987) and Engle and Granger (1987), who have tested for and found cointegration relationships between the yield on long-term and short-term bonds. Moreover, Hall et al. (1992) analyze one- and up to twelve-months interest rates for US Treasury bills and their study suggests that the belonging term structure is well modelled as a multivariate cointegrated system. They find that a single nonstationary common factor underlies the time series behavior of each yield to maturity, and this factor may be related to economic variables such as monetary growth and/or inflation. We have no ambitions towards detailed explanations of causes of the established relationships between short-term and long-term interest rates, partly because our data stem from two different markets, the short-term Eurocurrency market and the long-term national bond market. Using e.g. Norwegian Treasury bills to calculate short-term interest rates for Norway would have yielded biased results, since a huge liquidity premium can be found in these data, especially in the beginning of the sample period, cf. Section II Data.

The paper is organized as follows. Section II describes the data set. In Section III, results from the stationarity tests of the time series are reported and the appropriate number of lags in the VAR model is established. Second, cointegration vectors using the Johansen multivariate methodology are estimated. In addition, Johansen cointegration tests between pairs of interest rates are performed. Third, an innovation accounting analysis based on a decomposition of forecast error variances from the multivariate cointegration model is performed, and impulse response functions are plotted. In Section IV, we offer a summary of important results.

II. Data

We use short-term and long-term nominal interest rates for the US, Germany and Norway. The long-term series are interest rates on 10-year governmental bonds in those countries, denoted USDL, DEML and NOKL, respectively. For the money market we employ the three-month currency yields from the Eurocurrency market of London, denoted USDS, DEMS and NOKS, respectively. The sample comprises the period from November 1990 to April 1997, i.e. the starting point is the month after the international value of the Norwegian Krone was linked to the ECU. The series consist of monthly average interest rates provided by the Bank of Norway. Averages as a simple smoothing technique may reduce the effects of outliers, and may thus lead to a frequency distribution closer to the normal distribution.

As pointed out in the Introduction, using e.g. Norwegian Treasury bills to calculate short-term interest rates for Norway would have yielded biased results. Market frictions and low trading activity, especially in the beginning of the sample period, have caused a huge, stochastic liquidity premium in these data. Instead, we utilize the Eurocurrency yield for the NOK, and correspondingly for the USD and DEM short-term yields, as this market is in general more informationally efficient and has less frictions than the corresponding domestic markets. For example, 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. Furthermore, the high correlation between domestic and Eurocurrency yields, documented by e.g. Lin and Swanson (1993) and Kirchgässner and Wolters (1987), justifies the use of Eurocurrency data to represent a country’s short-term interest rates.

In some periods, the Norwegian Krone has been exposed to comprehensive speculation in the foreign exchange market, leading to extraordinary high interest rates, in both the domestic and the Eurocurrency market. During the autumn of 1992, the turbulence in the market led to a temporary 5 per cent increase in the (monthly average) three-month NOK interest rate in the Euromarket. To circumvent the problems associated with this event, we have interpolated the NOKS series over the months 1992(9), 1992(11) and 1992(12), respectively. In addition, we have interpolated the NOKL series over the month 1994(6), due to the bond market turbulence associated with the forthcoming EU referendum in Norway. Alternatively, a number of dummy variables could have captured the effects of these incidents. However, the characteristics of the error term turned out to be less favorable in these model specifications. There has not been any such speculation against the USD or the DEM in the period, and hence, no smoothing of these series has been carried out. Moreover, the instability in the foreign exchange market during the autumn of 1992, did also strike e.g. Sweden and Finland. The situation illustrates in general the limited ability of small, open economies to maintain a stable interest rate level when the international capital market moves into the currency.

III. Empirical Results

Cointegration analysis

The stationarity characteristics of the individual time series are controlled for by an augmented Dickey and Fuller (1979, 1981) test. Consistent with previous findings, we find that the interest rate is an $I(1)$ process for all countries, and, consequently, the series are expedient in a cointegration analysis. Prior to the cointegration analysis, two different tests were carried out in order to determine the appropriate lag length of the VAR system, the Akaike's Information Criterion and likelihood ratio tests for reduction in the number of lags in the VAR model. The autocorrelation structure of residuals was also examined. It turned out that the VAR(2) model is the most appropriate alternative in our case. In addition, neither the normality nor the heteroscedasticity assumption could be rejected at the 5 per cent level in any series in this model.

Contributions relating the cointegration approach to the theory of the term structure of interest rates include Campbell and Shiller (1987), Engle and Granger (1987) and Hall et al. (1992). In the latter study, the yield to maturity of a *k* period discount bond $R(k,t)$ is linked to the yield of a bond with one period to maturity $R(1,t)$ by the general relationship:

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

where E_t denotes expectations based on information available at time t and $L(k,t)$ are premia, which may account for risk considerations or for investors' preferences for liquidity. By assuming that yields to maturity are integrated $I(1)$ processes, the possibility that they might be cointegrated is seen by rearranging Equation (1) to obtain:

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

Equation (2) describes a relationship between the term structure of interest rates and the cointegration approach. The right hand side of Equation (2) is stationary provided that $\Delta R(1,t)$ and the premia $L(k,t)$ are stationary. Given these conditions, it follows that the left hand side of Equation (2) is stationary and that (1 –1)' is a cointegrating vector for $X_t = \left[R(k,t), R(1,t)\right]'$. Hence, the term structure hypothesis can be analyzed by testing the null hypothesis that the variables enter the cointegration relationship with coefficients of identical size and opposite signs, i.e. that $(\beta_1\ \beta_2) = (1\ -1)$. Furthermore, the model predicts that any yield series is cointegrated with the one period yield and, hence, in a set of n yield series there are (n-1) cointegration relationships and one common trend which drives the system, cf. Hall et al. (1992, pp. 116-118). The cointegration parameters may be expressed as $\beta' = \left[-i \quad I\right]$, where i is an $(n-1)\times 1$ vector with 1 in all elements and I is an $(n-1)\times(n-1)$ identity matrix.

Interest arbitrage ensures that the interest rate differential between two countries must conform to the following relationships:

$$R_h(k,t) - R_f(k,t) = E_t(S(t+k)) - S(t) + \psi_t, \tag{3}$$

where $R_h(k,t)$ and $R_f(k,t)$ denote domestic and foreign interest rates, respectively, on bonds with k periods to maturity, $S(t)$ is the logarithm of the spot exchange rate (domestic currency per foreign currency unit), and ψ_t represent risk premia. The existence of a risk premium implies a departure from uncovered interest rate parity.

If the expected exchange rate change and the risk premium, i.e. the right hand side of Equation (3), are both stationary, then the interest rate differential, i.e. the left hand side of Equation (3), is also stationary, in which case there exists a long-run equilibrium relationship between domestic and foreign interest rates with the cointegration vector (1 –1)'. Again we can test the hypothesis that the variables enter the cointegration relationship with coefficients (β_1 β_2) = (1 –1). There are several papers dealing with this type of cointegration relationship, and our presentation follows e.g. Fratianni and von Hagen (1990), Karfakis and Moschos (1990, p. 339) and Hansen (1996, p. 676). As pointed out by Karfakis and Moschos (1990), the reason for allowing the second cointegration parameter to deviate from unity can be explained by interest income taxation and/or the possibility of measurement errors.

The analysis of the appropriate rank of the multivariate cointegration system is presented in Table 1, Panel A. The null hypothesis that $r = 0$ is rejected both by the *trace* and the *max* test, while the *trace* test also rejects that $r \leq 1$. Consequently, the *max* test indicates one cointegration vector, while the *trace* test indicates two. The observation that the two test procedures do not give the same result and thus introduce ambiguity when choosing the number of cointegration vectors, is quite common. Furthermore, 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 prefer two cointegration vectors over one in our study, which is in line with the common view on this matter. In fact, some researchers even assume more independent cointegration vectors than the number of significant eigenvalues, e.g. Johansen and Juselius (1992) themselves. We find no support for the existence of five cointegration vectors, indicating that the term structure hypothesis and the hypothesis about international interest rate parity are not valid within a system of US, German and Norwegian short-term and long-term interest rates. This result is replicated for other VAR orders. The standardized cointegration vectors in the multivariate system for r = 2 are given in Table 1, Panel B.

Table 1, Panel A
Multivariate Johansen cointegration tests for interest rates in the VAR (2) model

r	*Max* Test Statistic	Crit. Value (5%)	*Trace* Test Statistic	Crit. Value (5%)
0	42.68*	40.30	125.54**	102.14
1	33.52	34.40	82.86*	76.07
2	22.14	28.14	49.34	53.12
3	12.25	22.00	27.20	34.91
4	10.82	15.67	14.95	19.96
5	4.13	9.24	4.13	9.24

* and **: Significant at the 5 and 1 per cent levels, respectively.
Source: Osterwald-Lenum (1992).

Table 1, Panel B
Standardized cointegration vectors in the multivariate system for r = 2

USDS	DEMS	USDL	DEML	NOKS	NOKL	CONS
1.00	0.95	-1.98	-2.19	-0.71	1.88	8.87
-2.00	1.00	-1.97	0.77	-3.97	5.24	-1.63
-0.62	-0.53	1.00	0.43	0.74	-1.49	2.98
-0.06	-0.14	-0.22	1.00	0.09	-0.45	-1.40
-0.79	-1.43	-0.31	2.22	1.00	-0.77	-1.99
-0.55	0.42	1.03	-1.28	-0.49	1.00	-1.77

Since the term structure and the international interest rate parity hypotheses both describe a relationship between a pair of variables, bivariate cointegration tests can be utilized to provide information about the structural relationships among the variables, i.e. the bivariate tests may provide a guidance for imposing restrictions on the variables and/or the coefficients in the multivariate system. E.g., if the interest parity hypothesis is supposed to hold only for the long-term interest rates between the three countries, exactly two cointegration vectors are required. The reason for this is that if (USDL-DEML) and (NOKL-USDL) are $I(0)$, then a linear combination of these $I(0)$ variables will also be $I(0)$. Hence (NOKL-DEML) is $I(0)$. Following the same type of reasoning, the interest parity hypothesis for *both* short-term and long-term interest rates requires four cointegration vectors, while support for only the term structure hypothesis in one country requires one cointegration vector. In addition, mixing the interest parity hypothesis between countries and the term structure hypothesis within countries may result in any number of cointegration vectors. Since the two models, given by Equations (2) and (3), describe the relationship between a pair of variables, bivariate cointegration tests can be utilized as a route to separate tests of the two hypotheses.

The results of these bivariate tests are presented in Table 2, Panel A. From the *max* and the *trace* tests we see that the hypothesis of zero cointegration vectors is rejected at the 5 per cent level for four and five interest rate pairs, respectively. Although the *trace* test reports five cointegration relationships among the 15 pairwise interest rate relationships, there are only four *independent* cointegration vectors. Since (DEMS, NOKL) and (DEMS, USDL) are cointegrated, the cointegration vector (USDL, NOKL) will only be a linear combination of the two former. Furthermore, the bivariate tests support the conclusion from the multivariate test that less than five cointegration vectors exist in the multivariate system, as we would expect all of the 15 possible pairwise combinations to show cointegration relationships if five cointegration vectors were present. Table 2, Panel B, presents the bivariate cointegration equations for the five relationships of Panel A where cointegration was supported by the *max/trace* tests, along with the tests for the hypothesis that the pairwise variables enter the cointegration relationship with coefficients $(\beta_1\ \beta_2) = (1\ -1)$. We observe from the last column of the table that the null hypothesis is rejected in all cases, suggesting that a level dependent risk premium is present. Hence, no strong support has been found for the international interest rate parity and for the term structure hypothesis, and the bivariate cointegration tests provide no guidance for imposing restrictions on the variables and/or the coefficients in the multivariate system. Moreover, likelihood ratio tests for exclusion of variables in the multivariate system illustrate that no variable may be omitted in the cointegration relationship. Consequently, we end up with restricting the multivariate cointegration space to two, but otherwise we impose no restrictions on the variables or on the coefficients of the two vectors. In any case, this is likely to have had only a marginal effect on our forthcoming impulse-response analysis. E.g. Lütkepohl and Reimers (1992) demonstrate the their impulse responses from a system without constraints on the cointegration vectors are practically identical to those with such constraints.

Table 2, Panel A
Bivariate Johansen cointegration tests for interest rates in the VAR (2) model

Model	*Max* Test $r = 0$	*Trace* Test $r = 0$	*Max*/*Trace* test $r \leq 1$
USDS,DEMS	22.06*	30.16*	8.10
USDS,NOKS	15.39	18.50	3.11
DEMS,NOKS	12.48	18.09	5.61
USDL,DEML	13.48	19.86	6.38
USDL,NOKL	13.96	21.26*	7.30
DEML,NOKL	13.12	18.42	5.30
USDS,USDL	9.02	10.98	1.96
DEMS,DEML	19.46*	24.13*	4.67
NOKS,NOKL	8.30	12.02	3.72
USDS,DEML	11.43	13.22	1.79
USDS,NOKL	11.17	13.22	2.05
DEMS,USDL	24.32*	27.98*	3.66
DEMS,NOKL	17.86*	21.43*	3.57
NOKS,USDL	10.13	15.43	5.30
NOKS,DEML	9.91	15.18	5.27

*: Significant at the 5 per cent levels. Source: Osterwald-Lenum (1992).

Table 2, Panel B

Bivariate cointegration equations and parameter tests

Model	β_1	β_2	Constant	$(\beta_1\ \beta_2) = (1\ -1)$
USDS, DEMS	1.00	0.3376	-7.212	13.30*
USDL, NOKL	1.00	-0.3939	-3.809	5.41*
DEMS, DEML	1.00	-4.041	23.48	13.13*
DEMS, USDL	1.00	-11.64	77.87	18.08*
DEMS, NOKL	1.00	-2.320	13.43	10.46*

*: Significant at the 5 per cent levels. Source: Osterwald-Lenum (1992).

We offer two explanations for the conflicting results between the bivariate and the multivariate cointegration tests. Asymptotically, the two cointegration procedures should yield identical results, because the $I(1)$ properties of the variables ensure that $I(1)$ variables converge at rate T, while stationary variables converge at rate $\sqrt{T}$, where T is the sample size. For a sufficiently large T, excluding $I(0)$ variables should therefore have no influence on the cointegration tests. However, in our case, as in most empirical work, omitting $I(0)$ variables does matter, since T is finite. Furthermore, since the bivariate cointegration procedure only differs from the multivariate case by omitting some of the dependent variables in each of the equations, the discussion of inconsistency between the two procedures, is, in fact, a discussion of how adequate the two model specifications are in explaining data. Does e.g. the short-run adjustment of DEMS have an impact on all the other variables? We believe that the short-run adjustments do matter, and our parameter tests of the short-run parameters also suggest they do. Consequently, we prefer to explore the relationships between all the six interest rates within the context of a multivariate system. In addition, since it is difficult to interpret the cointegration relationships directly, cf. Lütkepohl and Reimers (1992, pp. 53-54), we carry out a variance decomposition and an impulse-response analysis. These time paths of the variables may give interesting insights into the short-term and the long-term relationships among the variables in a multivariate dynamic system.

Variance decomposition and impulse response analysis

We utilize an innovation accounting approach based on decomposing forecast error variances from the multivariate cointegration model, i.e. we investigate the extent to which an interest rate series responds to shocks in other interest rate series in the multivariate system. In addition, our impulse response functions address the question of how rapidly events in a single interest rate series are transmitted to other interest rate markets.

Table 3 presents the results of the decomposition procedure by reporting the ratio of the *h*-th month forecast error variance accounted for by innovations in each of the six interest rates series in the system. We estimate standard errors by utilizing the procedure explained in Lütkepohl (1990) and Lütkepohl and Reimers (1992), and the values are reported in parentheses. Significant estimates under a two-standard error criterion are printed in bold. The analysis is based on the assumption of two cointegration vectors. As explained, no restrictions have been put on the parameters. Contemporaneous correlations from the error covariance matrix of the VAR(2) model are removed by carrying out an orthogonalizing transformation. Regarding the ordering of variables, we have put last those that we do not expect to have any predictive value for other variables. Consequently, Norwegian interest rates are ordered last and long-term rates precede short-term ones.

Table 3

Variance decomposition: proportion of the forecast error variance explained by innovations in other interest rates with standard errors in parentheses

Market explained		By Innovations in					
	Horizon	USDL	DEML	USDS	DEMS	NOKL	NOKS
USDL	1	**1.000**(0.000)	0.000(0.000)	0.000(0.000)	0.000(0.000)	0.000(0.000)	0.000(0.000)
	3	**0.930**(0.047)	0.010(0.017)	0.000(0.001)	0.005(0.012)	0.050(0.036)	0.005(0.011)
	6	**0.842**(0.083)	0.024(0.036)	0.000(0.000)	0.005(0.017)	0.117(0.075)	0.012(0.026)
	12	**0.802**(0.093)	0.028(0.048)	0.000(0.001)	0.004(0.018)	0.150(0.092)	0.015(0.035)
	18	**0.790**(0.096)	0.030(0.053)	0.000(0.001)	0.004(0.018)	0.160(0.099)	0.017(0.039)
	24	**0.784**(0.098)	0.030(0.056)	0.000(0.002)	0.003(0.019)	0.166(0.104)	0.017(0.041)
	36	**0.777**(0.100)	0.030(0.060)	0.000(0.002)	0.003(0.019)	0.172(0.109)	0.018(0.043)
DEML	1	**0.234**(0.084)	**0.766**(0.084)	0.000(0.000)	0.000(0.000)	0.000(0.000	0.000(0.000)
	3	**0.394**(0.112)	**0.584**(0.111)	0.009(0.012)	0.000(0.002)	0.011(0.017)	0.001(0.004)
	6	**0.495**(0.125)	**0.479**(0.126)	0.007(0.013)	0.000(0.003)	0.017(0.028)	0.003(0.011)
	12	**0.540**(0.126)	**0.431**(0.131)	0.004(0.012)	0.000(0.003)	0.023(0.037)	0.002(0.010)
	18	**0.557**(0.126)	**0.415**(0.132)	0.003(0.011)	0.000(0.003)	0.024(0.040)	0.001(0.008)
	24	**0.564**(0.126)	**0.407**(0.132)	0.003(0.011)	0.000(0.002)	0.025(0.042)	0.001(0.008)
	36	**0.572**(0.126)	**0.400**(0.133)	0.003(0.010)	0.000(0.002)	0.025(0.043)	0.001(0.007)
USDS	1	**0.451**(0.083)	0.001(0.006)	**0.548**(0.083)	0.000(0.000)	0.000(0.000)	0.000(0.000)
	3	**0.642**(0.091)	0.001(0.002)	**0.322**(0.076)	0.025(0.027)	0.007(0.012)	0.003(0.002)
	6	**0.680**(0.107)	0.021(0.030)	**0.221**(0.074)	0.043(0.048)	0.003(0.004)	0.033(0.036)
	12	**0.679**(0.133)	0.051(0.061)	**0.153**(0.074)	0.056(0.067)	0.001(0.001)	0.060(0.063)
	18	**0.688**(0.143)	0.064(0.074)	0.127(0.075)	0.056(0.072)	0.001(0.003)	0.065(0.071)
	24	**0.693**(0.147)	0.070(0.080)	0.114(0.076)	0.056(0.074)	0.001(0.004)	0.066(0.074)
	36	**0.698**(0.152)	0.076(0.087)	0.103(0.077)	0.055(0.076)	0.001(0.005)	0.068(0.077)
DEMS	1	0.000(0.003)	0.087(0.061)	0.000(0.004)	**0.912**(0.061)	0.000(0.000)	0.000(0.000)
	3	0.013(0.027)	0.079(0.069)	0.010(0.022)	**0.847**(0.083)	0.005(0.011)	0.046(0.036)
	6	0.081(0.085)	0.076(0.076)	0.019(0.034)	**0.741**(0.110)	0.003(0.012)	0.079(0.060)
	12	0.157(0.135)	0.089(0.095)	0.024(0.040)	**0.644**(0.152)	0.001(0.002)	0.085(0.076)
	18	0.189(0.163)	0.097(0.107)	0.026(0.041)	**0.604**(0.180)	0.001(0.003)	0.083(0.083)
	24	0.206(0.180)	0.102(0.115)	0.026(0.042)	**0.583**(0.198)	0.001(0.005)	0.081(0.087)
	36	0.223(0.198)	0.107(0.123)	0.026(0.042)	**0.563**(0.217)	0.001(0.007)	0.080(0.091)
NOKL	1	0.083(0.060)	**0.205**(0.078)	0.036(0.035)	0.023(0.028)	**0.654**(0.087)	0.000(0.000)
	3	0.109(0.082)	**0.259**(0.103)	0.026(0.033)	0.013(0.025)	**0.591**(0.109)	0.002(0.007)
	6	**0.214**(0.122)	**0.274**(0.115)	0.025(0.034)	0.008(0.023)	**0.472**(0.119)	0.007(0.018)
	12	**0.332**(0.143)	**0.277**(0.122)	0.022(0.034)	0.005(0.020)	**0.359**(0.126)	0.005(0.019)
	18	**0.376**(0.150)	**0.278**(0.126)	0.021(0.034)	0.004(0.019)	**0.318**(0.133)	0.004(0.017)
	24	**0.396**(0.153)	**0.278**(0.127)	0.020(0.034)	0.004(0.019)	**0.299**(0.137)	0.003(0.016)
	36	**0.415**(0.157)	**0.278**(0.129)	0.019(0.034)	0.003(0.020)	**0.282**(0.143)	0.003(0.015)
NOKS	1	0.025(0.035)	0.026(0.035)	0.084(0.059)	0.052(0.046)	**0.358**(0.081)	**0.457**(0.076)
	3	0.021(0.038)	0.096(0.076)	0.098(0.067)	0.053(0.055)	**0.460**(0.105)	**0.272**(0.079)
	6	0.014(0.011)	**0.197**(0.114)	0.106(0.071)	0.037(0.052)	**0.458**(0.116)	**0.188**(0.084)
	12	0.089(0.088)	**0.292**(0.136)	0.096(0.070)	0.022(0.041)	**0.386**(0.118)	0.115(0.079)
	18	0.145(0.126)	**0.324**(0.143)	0.087(0.069)	0.016(0.036)	**0.346**(0.123)	0.083(0.075)
	24	0.175(0.144)	**0.337**(0.147)	0.082(0.069)	0.013(0.034)	**0.325**(0.127)	0.068(0.074)
	36	0.203(0.162)	**0.348**(0.151)	0.078(0.070)	0.010(0.032)	**0.306**(0.133)	0.055(0.073)

The results render a distinct pattern of how interest rate impulses are transmitted among the three countries. The US turns out to be the dominant force, as shocks in the long-term interest rate have a significant impact on the German and the Norwegian long-term, as well as on the US short-term rate. In addition, the German long-term rate has a substantial influence on both the Norwegian long-term and short-term rates. Beside variances accounted for by innovations in the same variable, found in the diagonal of Table 3, only one additional effect occurs. The Norwegian long-term rate explains the Norwegian short-term rate. However, opposed to all the other findings, the latter result depends completely on the ordering of the variables. E.g., with short-term rates before long-term ones the reverse relationship is found. Hence, only the US and the German long-term interest rates have significant impacts. There are no effects running from short-term rates to long-term rates or to other short-term rates. In this sense, the monetary policy of one country cannot be evaluated as more credible than that of the others.

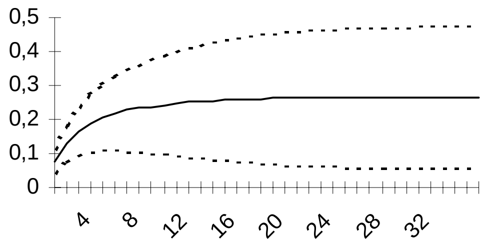
We come up with several important results. From a US point of view, our analysis gives strong support to the opinion that US interest rate markets have a substantial impact on European interest rate markets, while the US itself is little affected by European impulses. In particular, shocks in the USDL have a significant influence on the DEML and on the NOKL, and also on the USDS. The USDS seems to play no active role in explaining German or Norwegian interest rates. The US bond market typically react heavily on underlying economic indicators related to e.g. employment, real production, retail sales, increases in wages and inflation. The empirical analyses illustrate that monetary policy actions on US short-term rates have an insignificant impact on movements in US long-term interest rates, and have no significant transmission effects on foreign interest rates. Consequently, international interest rate impulses arise in the US bond market and influence both German and Norwegian bond market interest rates. On the other hand, we identify no causal effect from German or, of course, Norwegian interest rates on the US yields, suggesting that US interest rates are exogenous in our system.

Furthermore, Germany imports US interest rate changes and influences Norwegian interest rates. The analysis illustrates that shocks in the DEML have a significant influence on both the NOKL and the NOKS, while the DEML is significantly influenced by shocks in the USDL. In fact, the USDL is much more important than the DEMS in explaining movements in the DEML. In Germany, much of the debt of households and firms is linked to long-term rates. Therefore, the US influence combined with the lack of importance of domestic short-term rates could have substantial macreconomic consequences, cf. Hammersland and Vikøren (1997).

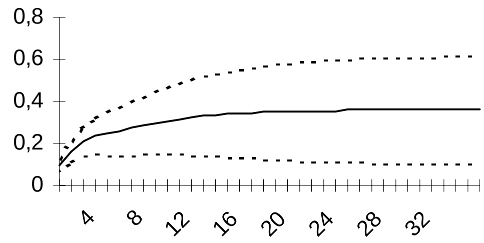
Finally, Norwegian interest rates are endogenous in the model. As expected, shocks in the Norwegian interest rates have no significant influence on any other interest rate. The NOKL is significantly influenced by both the USDL and the DEML. The DEML seems to have a significant influence over the whole horizon of 36 months, while the USDL contributes to explain Norwegian bond yield movements at the horizon of 6 to 36 months. Moreover, the NOKS is significantly influenced by the DEML also at the horizon of 6 to 36 months.

Our empirical findings support those of Katsimbris and Miller (1993), who found that the US interest rate has an important influence on the EMS members' rates, and those of e.g. 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. The strong relationship between US and German long-term interest rates, with the direction of causality going from the US to Germany, is also found in Hammersland and Vikøren (1997). Finally, our results clearly indicate that Norway is strongly influenced by impulses from the US and Germany, which is consistent with our *a priori* hypothesis of a small and open economy's dependency on changes in international capital markets. The official exchange rate policy of the Norwegian government, executed by the Central Bank of Norway, has been to stabilize the NOK against important foreign currencies, leading to a strong connection between Norwegian and foreign interest rates. Hence, the monetary authorities have limited abilities to protect private real investments and private consumption from changes in the important foreign interest rate markets. As pointed out by Akram og Frøyland (1997), actual domestic demand and real activity level may hence deviate from the desired level relative to the domestic Norwegian price and/or activity development per se. As long as the operative aim of the monetary policy is maintained, the results indicate that policy actions on price and activity level in the Norwegian economy have to be carried out through the fiscal policy. To illustrate the dynamic responses and the transmission mechanism of information among the time series, we plot normalized impulse response functions. Figure 1 depicts the simulated effect of an innovation in one interest rate variable on future values of another variable in the system. We visualize impulse effects from the USDL on the other five interest rates and from the DEML on the two Norwegian interest rates, which were the most important effects in our variance decomposition analysis.

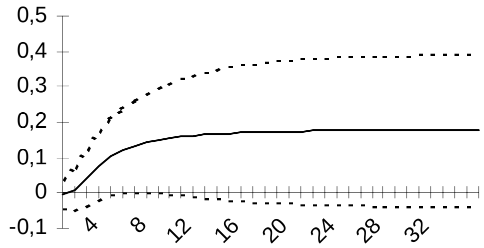
a) Response in DEML to a Shock in USDL



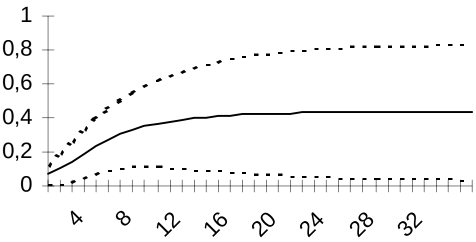
b) Response in USDS to a Shock in USDL



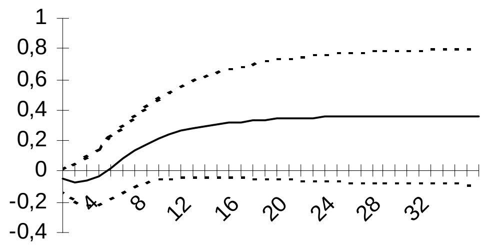
c) Response in DEMS to a Shock in USDL



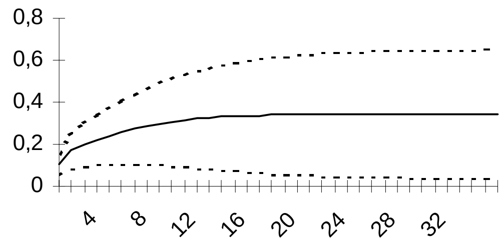
d) Response in NOKL to a Shock in USDL



e) Response in NOKS to a Shock in USDL



f) Response in NOKL to a Shock in DEML



g) Response in NOKS to a Shock in DEML

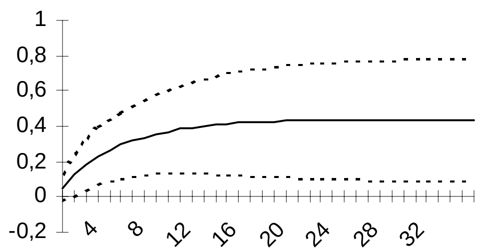


Fig. 1. Impulse responses to shocks in other interest rates with two-standard error bounds.

As regards impulse response functions, we follow the convention of Lütkepohl and Reimers (1992, p. 70) and distinguish between transitory and permanent transmission effects. An effect of a one-time impulse on a variable is called transitory if the variable returns to its previous equilibrium value of zero after some periods. If it does not return to zero and settles at a different equilibrium value, the effect is called permanent. Figure 1 traces the response in an interest rate series to an orthogonalized impulse in another interest rate series of one standard deviation with the estimated two-standard error bounds, using the approach described in Lütkepohl (1990) and Lütkepohl and Reimers (1992). For this type of impulse response, the difference to the stationary case is that the effects of a shock in one variable will in general not die out in the long run, i.e. the variables may not return to their initial values even if no further shocks occur. In other words, a one-time impulse may have a permanent effect in the sense that it shifts the system to a new equilibrium. In fact, we observe in Figure 1 that the typical effect in our study turns out to be of a permanent nature.

At the horizon of only a few months, the graphs clearly visualize a significant positive transmission effect of an interest rate shock, except, of course, in Figure 1c and 1e, where no signficant effects have been established in the variance decomposition. (The lower two-standard error bound is below zero in these cases.) Note that after about 12 months, the interest rate variables are close to reaching their long-term positions in the sense that they remain constant if no further shocks hit the system.

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 utilized the Johansen multivariate cointegration methodology to analyze relationships among short-term and long-term interest rates in the United States, Germany and Norway spanning the period from November 1990 to April 1997. Within the system of selected interest rates, the hypothesis about the term structure of interest rates and the hypothesis about international interest rate parity are not satisfied. Utilizing Johansen bivariate cointegration tests, this result is repeated and may in part be explained by the fact that our interest rate series stem from two different markets, the London Eurocurrency market and the domestic bond market, respectively.

To investigate the interrelationships among the variables in the multivariate cointegrated system, a variance decomposition approach has been applied to estimate the proportion of each interest rate's forecast error variance attributable to innovations in the other interest rates. In addition, impulse response functions have been plotted to illustrate the speed with which interest rate events are transmitted between capital markets. We have found that US long-term interest rates influence both German and Norwegian long-term rates. Our study thus supports the view that the US has a dominant global role, and that European countries have to recognize possible effects of the US economic policy in conducting their own. For the small, open Norwegian economy, this point is of special relevance. Norway has chosen to stabilize the international value of the NOK against European currencies, thereby importing European interest and inflation policies. Our study reports that Norway is strongly exposed to both US and German long-term interest rate movements. The empirical results may not only be considered as Norwegian pecularities, but may enrich the understanding of how shocks in the world's major interest rates in general influence the much smaller interest markets, e.g. the Scandinavian ones. Moreover, our findings underscore that a European focus alone is too narrow. Impulses from the rest of the world, especially from the US, have to be included to obtain a representative picture of interest rate flows among nations.

References

Akram, Q.F. and Frøyland, E. (1997), Empirical modelling of Norwegian money-market and bond-market interest rates. *Working Paper no. 1*. Bank of Norway (in Norwegian).

Borio, C.E.V. and McCauley, R.N. (1996), The economics of recent bond yield volatility. *BIS Economic Papers no. 45*. Bank for International Settlements, Basle.

Campbell, J.Y. and Shiller, R.J. (1987), Cointegration and tests of present value models. *Journal of Political Economy* 95, 1062-1088.

De Grauwe, P. (1989), Is the European Monetary System a DM zone? *Working Paper no. 297*. Center for Economic Policy Research, London.

Dickey, D.A. and Fuller, W.A. (1979), Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association* 74, 427-431.

Dickey, D.A. and Fuller, W.A. (1981), Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica* 49, 1057-1072.

Edison, H.J. and Kole, L.S. (1995), European monetary arrangements: Implications for the Dollar, exchange rate variability, and credibility. *European Financial Management* 1, 61-86.

Engle, R.F. and Granger, C.W.J. (1987), Cointegration and error correction: Representation, estimation and testing. *Econometrica* 55, 251-276.

Fratianni, M. and von Hagen, J. (1990), German dominance in the EMS: The empirical evidence. *Open Economic Review* 1, 67-87.

Fujihara, R.A. and Mougoué, M. (1996), International linkages between short-term real Interest rates. *The Quarterly Review of Economics and Finance* 36, 451-473.

Hafer, R.W., Kutan, A.M. and Zhou, S. (1997), Linkages in EMS term structures: Evidence from common trend and transitory components. *Journal of International Money and Finance* 16, 595-607.

Hall, A.D., Anderson, H.M. and Granger, C.W.J. (1992), A cointegration analysis of treasury bill yields. *The Review of Economics and Statistics* 74, 116-126.

Hamilton, J.D. (1994), *Time Series Analysis*. Princeton: Princeton University Press.

Hammersland, R. and Vikøren, B. (1997), Long-term interest rates in the US and Germany. *Working Paper no. 10.* Bank of Norway, Oslo.

Hansen, G. (1996), The domestic term structure and international interest rate linkages: A cointegration analysis. *Weltwirtschaftliches Archiv* 132, 675-689.

Johansen, S. (1988), Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control* 12, 231-254.

Johansen, S. (1991), Estimation and hypothesis testing of cointegration vectors in gaussian autoregressive models. *Econometrica* 59, 1551-1580.

Johansen, S. and Juselius, K. (1990), Maximum likelihood estimation and inference on cointegration - with applications to the demand for money. *Oxford Bulletin of Economics and Statistics* 52, 169-210.

Johansen, S. and Juselius, K. (1992), Testing structural hypotheses in a multivariate cointegration analysis of the PPP and UIP for UK. *Journal of Econometrics* 53, 211-244.

Karfakis, C.J. and Moschos, D.M. (1990), Interest rate linkages within the European Monetary System: A time series analysis. *Journal of Money, Credit, and Banking* 22, 388-394.

Katsimbris, G.M. and Miller, S.M. (1993), Interest rate linkages within the European Monetary System: Further analysis. *Journal of Money, Credit, and Banking* 25, 771-779.

Kirchgässner, G. and Wolters, J. (1987), U.S. European interest rate linkage: A time series analysis for West Germany, Switzerland, and The United States. *The Review of Economics and Statistics* 69, 675-684.

Lin, A. and Swanson, P.E. (1993), Measuring global money market interrelationships: An investigation of five major world currencies. *Journal of Banking and Finance* 17, 609-628.

Lütkepohl, H. (1990), Asymptotic distributions of impulse response functions and forecast error variance decompositions of vector autoregressive models. *The Review of Economics and Statistics* 73, 116-125.

Lütkepohl, H. and Reimers, H.E. (1992), Impulse response analysis of cointegrated systems. *Journal of Economic Dynamics and Control* 16, 53-78.

MacKinnon, J.G. (1991), Critical values for cointegration tests. In *Long Run Economic Relationships*. edited by Granger, C.W.J. pp. 267-276. Oxford: Oxford University Press.

Modjtahedi, B. (1988), Dynamics of real interest differentials. *European Economic Review* 32, 1191-1211.

Mundaca, B.G., Røste, O.B. and Valseth, S. (1996), The dynamics of the correlations between short- and long-run interest rates in the Nordic countries and Germany. *Working Paper no. 7*. Bank of Norway.

Osterwald-Lenum, M. (1992), A note with quartiles of the asymptotic distribution of the maximum likelihood cointegration rank test statistics. *Oxford Bulletin of Economics and Statistics* 54, 461-472.

Stock, J.H. and Watson, M.W. (1988), Testing for common trends. *Journal of the American Statistical Association* 83, 1097-1107.

Throop, A.W. (1994), International financial market integration and linkages of national interest rates. *Federal Reserve Bank of San Francisco Economic Review* (No. 3), 3-18.