Available online at www.sciencedirect.com
ScienceDirect
Journal of International Money and Finance 26 (2007) 86–103
Journal of International Money and Finance
www.elsevier.com/locate/jimf

Interest rate linkages in the Eurocurrency market: Contemporaneous and out-of-sample Granger causality tests

Zijun Wang [a], Jian Yang [b,c,*], Qi Li [d,e]

[a] Private Enterprise Research Center, Texas A&M University, College Station, TX 77843, USA
[b] Department of Accounting, Finance and MIS, Prairie View A&M University, Prairie View, TX 77446, USA
[c] Lingnan College, Sun Yat-Sen University, Guangzhou, Guangdong 510275, PR China
[d] Department of Economics, Texas A&M University, College Station, TX 77843, USA
[e] Department of Economics, Tsinghua University, Beijing 100084, PR China

Abstract

This paper examines linkages among major Eurocurrency interest rates during 1994–2002. Eurocurrency interest rate causal linkages are found to be much stronger with additional allowance for contemporaneous causality test results than the inference based solely on Granger causality tests. The impact of U.S. interest rates is clearly not dominant in the Eurocurrency markets, while the Japanese interest rates are found to be quite influential. German interest rates both cause, and are caused by, several other Eurocurrency interest rates. By contrast, interest rates on the new currency, the Euro, do not have a substantial influence on other Eurocurrency interest rates, which underscores its emerging status.

JEL classification: F36; F21

Keywords: Interest rate linkages; Granger causality; Forecasting evaluation; Contemporaneous correlation; Directed acyclic graphs

* Corresponding author. Department of Accounting, Finance and MIS, Prairie View A&M University, Prairie View, TX 77446, USA. Tel.: +1 936 857 4014; fax: +1 936 857 2797.
E-mail address: jiyang@pvamu.edu (J. Yang).

0261-5606/$ - see front matter
doi:10.1016/j.jimonfin.2006.10.005

1. Introduction

In the past two decades, linkages among international capital and money markets have been perceived to increase dramatically, while government-imposed barriers to international capital flows have fallen. The extent of interest rate linkages in these markets carries important policy implications for the independence of monetary policies by nations' central banks (Kirchgassner and Wolters, 1987, 1993). If a country is sufficiently large or is isolated from other countries due to idiosyncratic domestic conditions, the country may not be responsive to foreign interest rate changes. This would, in turn, permit the country to pursue an independent monetary policy. Furthermore, enhanced understanding of transmission of (short-term) interest rates across countries can also help to more accurately forecast interest rates in a country, itself a key input to strategic business decisions (Lo et al., 1995). However, the extent of such international interest rate linkages remains an unsettled empirical matter.

Numerous studies have examined (short-term) interest rate linkages across international money markets. Almost without exception, these studies employ in-sample Granger causality tests. Early studies, such as Kirchgassner and Wolters (1987), document the important influence of U.S. interest rates on European interest rates. However, the causal inference from earlier studies did not allow for possible cointegration between nonstationary interest rates. It is widely acknowledged that the existence of cointegration can substantially affect Granger causality testing results (Granger, 1988). Recent studies have generally documented long-run relationships among interest rates across countries (Karfakis and Moschos, 1990; Katsimbris and Miller, 1993; Kirchgassner and Wolters, 1993; Bremnes et al., 1997; Awad and Goodwin, 1998; Hassapis et al., 1999; Uctum, 1999). Many of these studies exploit causal inference within a cointegrated vector autoregression model and focus on the relationship between interest rates between European Monetary System (EMS) members and the rest of the world. The empirical findings are generally mixed, particularly with regard to the influences of U.S. and German interest rates on other EMS members.

This study examines interest rate causal linkages in the Eurocurrency market in the recent period of 1994–2002. The study contributes to the literature in three ways. First, we shed more light on contemporaneous causal relationships among major Eurocurrency interest rates having strong contemporaneous correlations. The existing literature (Kirchgassner and Wolters, 1987, p. 679; Karfakis and Moschos, 1990, p. 393; Uctum, 1999, pp. 781–783) has documented strong contemporaneous correlations of various interest rate innovations (e.g., residuals from a VAR system), and underscored the importance of this phenomenon in understanding instantaneous adjustment across markets. Nevertheless, the existing literature concludes that "with respect to the (contemporaneous causal) direction of instantaneous relations nothing can be derived from the data alone" (Kirchgassner and Wolters, 1987, p. 679). Building on an innovative directed graphs technique (Spirtes et al., 1993; Pearl, 1995; Swanson and Granger, 1997), this study is able to explore a data-determined pattern of contemporaneous causality between VAR innovations. Such an examination of contemporaneous causality is a complement to Granger causality and provides a more comprehensive picture of interest rate causal linkages. As pointed out by Swanson and Granger (1997) and Breitung and Swanson (2002), unidirectional Granger causality in the presence of temporal aggregation can result in such contemporaneous correlations of residuals in a system that has contemporaneously uncorrelated residuals at the "true" time interval. Thus, Swanson and Granger (1997, p. 364) argue for checking both Granger causality and contemporaneous causality to allow for the effects of aggregation.

Second, a multivariate out-of-sample Granger causality test is applied to infer Granger causal inference. Most previous studies in this line of research focus on in-sample Granger causality tests. As noted by Granger (1969), and more rigorously documented in Ashley et al. (1980), a causality test based on forecasting performance brings the maximum amount of information to bear on the Granger causation hypothesis. Ashley et al. (1980, p. 1149) explicitly stated "…a sound and natural approach to such tests [Granger causality tests] must rely primarily on the out-of-sample forecasting performance of models relating the original (non-prewhitened) series of interest." Unfortunately, this important insight has been all but ignored in the literature. Recently, a handful of researchers (e.g., Amato and Swanson, 2001; Chao et al., 2001; Corradi and Swanson, 2002) have forcefully advocated the use of out-of-sample Granger causality tests. As shown in Chao et al. (2001), the choice of out-of-sample versus in-sample Granger causality tests can have a dramatic impact on causal inference. In this study, we utilize recent advances in forecasting evaluation (Diebold and Mariano (1995) test) to more accurately conduct out-of-sample Granger causal inference.

Finally, this study extends previous research to the recent period 1994–2002, and, to our knowledge, presents the first attempt to explore the role of the new currency, the Euro, in the Eurocurrency market in the context of international interest rate transmission. The use of recent data is important, given the finding of Uctum (1999) that a structural break occurred regarding the influences of U.S. and German interest rates on other EMS member interest rates after the German reunification in 1990. The rest of this paper is organized as follows: Section 2 presents econometric methodology; Section 3 describes the data; Section 4 presents major empirical results; and finally, Section 5 concludes the paper.

2. Econometric methodology

The basic empirical framework used in this study is a cointegrated vector autoregression (VAR) model. Let Y_t denote a vector which includes p nonstationary interest rates. Assuming the existence of cointegration, the data generating process of Y_t can be written as an error correction model (ECM) with $(k-1)$ lags:

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta Y_{t-i} + \mu + \varepsilon_t \quad (t = 1, \ldots, T), \tag{1}$$

where Δ is the difference operator $(\Delta Y_t = Y_t - Y_{t-1})$, Π is a $(p \times p)$ coefficient matrix, Γ_i is a $(p \times p)$ matrix of short-run dynamics coefficients, and μ is a $(p \times 1)$ vector of parameters. We apply Johansen's (1991) maximum likelihood estimation procedure to estimate the ECM and to carry out the cointegration tests. The one-step-ahead out-of-sample forecasting computation is based on the ECM of Eq. (1).

2.1. Out-of-sample Granger causality tests

As noted, in-sample Granger causality tests have been widely used in the literature to investigate causal relationships among interest rates. The empirical implementation of such a test employs the standard in-sample F or Wald test. However, as mentioned above, it is preferable to conduct Granger causality tests by comparing out-of-sample forecasting performance, which is more in the spirit of Granger's (1969) original definition of causality. The way that out-of-sample tests are implemented in this study closely follows Amato and Swanson (2001).

Specifically, to test for Granger causality running from y_{jt} to y_{it}, one should examine whether the inclusion of series y_{jt} helps to improve predictability of series y_{it} ($i = 1, \ldots, p$, $i \neq j$), given the inclusion of other relevant economic (e.g., interest rate) series. In this study, allowing for well-documented cointegration between interest rates, we estimate two vector error correction models (Eq. (1)) with (hereafter the U model) and without y_{jt} (hereafter the R model) included in the vector Y_t using, for instance, the first T_1 observations. We then generate one-step-ahead recursive forecasts of y_{it} for the remaining T_2 observations ($T_1 + T_2 = T$) from both the U model (y_{it}^{U}) and the R model (y_{it}^{R}). Denote the corresponding forecast error series as e_{it}^{U} and e_{it}^{R}, respectively. If y_{it}^{U} is a more accurate forecast than y_{it}^{R}, or equivalently, if e_{it}^{U} is smaller than e_{it}^{R}, then y_{jt} Granger-causes y_{it} in an out-of-sample sense. Compared to the bivariate framework used in the existing literature (e.g., Karfakis and Moschos, 1990; Awad and Goodwin, 1998), the multivariate framework in this study allows for the causal influence of the rest of the world on the two interest rate series under consideration, thus excluding the possible spurious (out-of-sample) causal relationship due to omission of important causing variables (Katsimbris and Miller, 1993; Bremnes et al., 1997; Hassapis et al., 1999).

Determining whether there exists a (statistically) significant difference in forecasting accuracy between the U and R models is a fundamental aspect of the out-of-sample Granger causality test. It is possible that, although two sets of forecasts are visually different from each other, they may not differ statistically. In this study, following Amato and Swanson (2001), we apply a testing procedure proposed by Diebold and Mariano (1995). For a pair of h-step-ahead forecast errors (e_{it}^{U} and e_{it}^{R}, $t = 1, \ldots, T_2$), the forecast accuracy can be judged on some specific function $g(\cdot)$ of the forecast error (where Mean Squared Forecast Errors (MSFE) are often used). The null hypothesis of equal forecast performance is:

$$E\left[g\left(e_{it}^{\mathrm{U}}\right) - g\left(e_{it}^{\mathrm{R}}\right)\right] = 0,$$

where $\mathrm{g}(\cdot)$ is a loss function. In this paper we use $\mathrm{g}(u) = u^2$, the square loss function. Define d_t by

$$d_t = g\left(e_{it}^{\mathrm{U}}\right) - g\left(e_{it}^{\mathrm{R}}\right).$$

The Diebold–Mariano test statistic is then

$$\mathrm{DM} = \left[\widehat{V}(d)\right]^{-0.5} d,$$

where d is the sample mean of d_t, $\widehat{V}(d)$ is the Newey–West heteroskedasticity and autocorrelation consistent estimator of the sample variance of d. We use the simulated critical values provided in Table 1 of McCracken (1999) to conduct the DM test.

2.2. DAG contemporaneous causality tests

The instantaneous linkages among major Eurocurrency interest rates can be studied through identifying contemporaneous causal relationships from their corresponding innovation processes. The contemporaneous causal structure on innovations can be identified through a priori structural modeling of observed innovations $\widehat{e}_t$, or, as is done in this study, through the directed acyclic graphs (DAG) analysis of the correlation (covariance) matrix of $\widehat{e}_t$ (Spirtes et al., 1993; Pearl, 1995; Swanson and Granger, 1997). For more discussion on the directed graphs analysis in the context of time series analysis, see Bessler and Yang (2003) and Demiralp and Hoover (2003).

In this study, we apply the directed graphs method to determine contemporaneous causality patterns. A directed graph is an assignment of causal flow (or lack thereof) among a set of variables (vertices) based on observed correlation and partial correlation. Each pair of variables is characterized by an edge relationship representing the causal relationship (or lack thereof) between them. In the context of this study, there are five applicable cases for an edge relationship: (1) no edge ($X\ Y$), which indicates (conditional) independence between two variables; (2) undirected edge ($X—Y$), which signifies a nonzero covariance that is given no particular causal interpretation; (3) directed edge ($Y \rightarrow X$), which suggests that a variation in Y, with all other variables held constant, produces a (linear) variation in X that is not mediated by any other variable in the system; (4) directed edge ($X \rightarrow Y$); (5) bi-directed edge ($X \leftrightarrow Y$), which indicates the bi-direction of causal interpretation between the two variables.

The directed acyclic graphs method provides a PC algorithm for removing edges between markets and directing causal flows of information between markets. The algorithm begins with a complete undirected graph, where innovations from every market are connected with innovations from every other market. It then proceeds in two stages: elimination and orientation.

In the elimination stage, the algorithm removes edges based on vanishing correlation and partial correlation. Edges between variables are removed sequentially based on either vanishing zero order correlations (unconditional correlations) or vanishing conditional correlations, where conditioning is done on all possible sets with members 1, 2, …, $N-2$, where N is the number of variables studied. Specifically, the algorithm removes edges from the complete undirected graph by first checking for (unconditional) correlations between pairs of variables. Edges connecting variables having zero correlation are removed. Remaining edges are then checked for first order partial correlation (correlation between two variables conditional on a third variable). Similarly, edges connecting variables having zero first order conditional correlation are removed. Edges that survive this check of first order conditional correlation are then checked against zero second order conditional correlation, and so on. For N variables, the algorithm continues to check up to order $N-2$ conditional correlation.

In applications, Fisher's z statistic is used to test whether conditional correlations are significantly different from zero. Specifically, $z((i,j|k)T) = 1/2(T-|k|-3)^{1/2}\ \ln\{(|1+\rho(i,j|k)|)(|1-\rho(i,j|k)|)^{-1}\}$ and T is the number of observations used to estimate the correlations, $\rho(i,j|k)$ is the population correlation between series i and j conditional on series k (removing the influence of series k on each i and j), and $|k|$ is the number of variables in k (that we condition on). If i, j and k are normally distributed and $r(i,j|k)$ is the sample conditional correlation of i and j given k, then the distribution of $z(\rho(i,j|k)T) - z(r(i,j|k)T)$ is also standard normal. Note that although normality is maintained here, Monte Carlo simulation evidence suggests that, in applications, the directed graphs analysis is not sensitive to this assumption so long as the distribution is largely symmetric (Scheines et al., 1994).

Once the elimination stage is completed, the algorithm proceeds to the orientation stage. The notion of *sepset* is used to assign the direction of causal flow between variables that remain connected after all possible conditional correlations have been determined to be nonzero. The conditioning variables on the removed edges between two variables are called the *sepset* (for vanishing unconditional correlation, the *sepset* is the empty set). Edges are directed by considering triples $X—Y—Z$, such that X and Y are adjacent, and so are Y and Z, but X and Z are not adjacent. Direct the edges between triples $X—Y—Z$ as $X \rightarrow Y \leftarrow Z$, if Y is not in the *sepset* of X and Z. If $X \rightarrow Y$, Y and Z are adjacent, X and Z are not adjacent, and there is no arrowhead at Y, then $Y-Z$ should be positioned as $Y \rightarrow Z$. If there is a directed path from X to Y, and an edge between X and Y, then $X-Y$ should be positioned as $X \rightarrow Y$.

The algorithm discussed above is implemented in the program TETRAD II (Scheines et al., 1994), which we use for the empirical analysis below. For applications of the directed graphs analysis on contemporaneous causal ordering of macroeconomic series, see Swanson and Granger (1997) and Demiralp and Hoover (2003); for the contemporaneous causal flow across various financial markets, see Bessler and Yang (2003) and Yang and Bessler (2004).

We highlight the fact that the contemporaneous causality tests may reveal a unidirectional Granger causality pattern in the presence of time aggregation (Swanson and Granger, 1997; Breitung and Swanson, 2002). As is well known, causality can be jumbled once the data are temporally aggregated. If the data are observed at intervals when the dynamics fail to hold, there may not be any Granger causality detected. In the spirit of Granger (1988, p. 206), the true causal lag may be smaller than the aggregation intervals. In this case, the observed or apparent contemporaneous correlation at that interval can be indicative of unidirectional (Granger) causality in the presence of temporal aggregation.[1] Thus, the Granger causality test and the contemporaneous causality test results should be combined to reveal a complete picture of causality, as they are complementary. Uctum (1999) is among the first to suggest this approach. In accord with Swanson and Granger (1997), Uctum (1999, p. 782) argues that the strong and significant correlations of interest rate innovations are possibly a reflection of high responsiveness of some markets to others, which would not be captured in the lagged effects.

3. Data

The data for this study cover a 9-year period from January 2, 1994 to December 31, 2002. The selection of the sample period, starting from 1994, excludes some significant events in the EMS history. These events include the German reunification in 1990, the monetary turmoil and the resulting currency crisis in September 1992, and another currency crisis in August 1993. In particular, the currency crisis in August 1993 resulted in such a dramatic broadening of fluctuation bands for the EMS member countries that many considered the EMS to become a floating-rate system in all but name only. Compared to the previous range of fluctuations of 2.25% around the central cross exchange rate (6% for Spain and Britain), beginning in August 1993, seven EMS currencies could trade within a band of 15% above or below their central rates. Thus, the period of 1994–1998 (before the introduction of the Euro) represents an interesting and unique time period of the EMS, one which has not been fully explored in the existing literature. Except for the introduction of the Euro in 1999, there are no other publicly identifiable events which can conceivably affect the interest rate linkages in Europe.

To allow for the structural break associated with the introduction of the Euro in January 1999, we divide the data into two subperiods. The first period covers a 5-year period of January 1994–December 1998, and includes eight major currencies: the U.S. Dollar, Canadian Dollar, Japanese Yen, U.K. Pound, German Mark, French Franc, Italian Lira and Swiss Franc. The second period covers a 4-year period of January 1999–December 2002, and only includes the six major currencies of the following countries (regions): the U.S., Canada, Japan, U.K., Eurozone,

[1] Theoretically, the observed or apparent contemporaneous correlation could also be due to missing causal variables. Such a possibility is probably hard to clearly rule out. But it is often also hard to specify what missing causal variables exactly are in applied research.

and Switzerland. Note that this division of the sample period is necessitated by data availability: the Eurocurrency interest rates no longer exist for several EMU countries under study (Germany, France, and Italy) after 1999, as a single currency in the EMU (the Euro) replaced the German, French and Italian currencies. Consequently, these Eurocurrency rates were replaced by the interest rates on the new currency, the Euro, the so-called Euroeuro rates.

The daily data for major Eurocurrency interest rates are originally obtained from Datastream. All interest rates are generated from a single market, the London Eurocurrency market, which should minimize distortions caused by differences in taxes, capital control and other regulations. The interest rate data for different Eurocurrencies are recorded synchronously at the end of a trading day in London. An examination of the data shows that, for most Eurocurrency rates (other than Eurodollar rates), there is little variation within a week. Thus, following Lo and MacKinlay (1988), the daily data are converted into weekly observations to address the potential autocorrelation problem, yielding a total of 470 weekly observations.

The data possess the following features over the period of study: (1) prior to the third quarter of 1999, most Eurocurrency interest rates tended to decline with the exception of the U.S. and U.K.; (2) all Eurocurrency interest rates have increased from the third quarter of 1999 to the end of 2000, but they steadily dropped throughout 2002; (3) the Japanese Yen interest rates remained the lowest over the entire sample period; and (4) before the introduction of the Euro, the Italian Lira interest rates were the highest for the majority of the time. Several standard unit root test procedures were applied to test for nonstationarity of the interest rate series in the two periods. Consistent with previous studies, the results (available on request) show that a unit root exists in all series in both periods.

4. Empirical results

The first step required for VAR model specification is the selection of the lag order k.[2] Both Akaike information criterion (AIC) and the likelihood ratio (LR) test, conducted at the 5% significance level, lead us to include two lags for both periods. We report the trace test results along with the appropriate critical values in Table 1. At about 5% significance level, the cointegration rank is 3 for the first period and 1 for the second period.[3] The findings of cointegration

[2] Consistent with all the previous studies cited above, only interest rates are included in the system to examine their causal relationships. As pointed out in Uctum (1999, pp. 784–785), such a practice can be justified based on the assumption that market rates incorporate the information contained in the final policy targets. More generally, such conditioning has to be implicitly used in most causality tests. As discussed in Granger (1988), to make the causality definition operational, we have to conduct causality tests conditional on the information set we define for a particular study. In this context, we may likely investigate prima facie causality rather than the true causal relationship, which can potentially apply to any studies on causal relationships. The prima facie causality is a necessary condition, but not a sufficient condition, for true causality. Nevertheless, the information of one variable as a useful predictor for another conditioning on the defined information set can be inferred and practically important. Practically, many users of Eurocurrency markets probably focus on inferring information from the interaction between various interest rates directly.

[3] We also conducted maximal eigenvalue tests. The eigenvalue test concludes with four (instead of three) cointegrating vectors for the first period. It agrees with the trace test result for the second period (one cointegrating vector at the 5% significance level). As discussed shortly, we use the forecasting performance comparison as a model selection approach to determine the appropriate cointegration rank. Furthermore, in the robustness check section, we find that such slight difference in the cointegration rank basically does not affect the inference either on the Granger causality tests or DAG contemporaneous causality tests.

Table 1
Trace tests for cointegration rank[a]

Rank	Trace statistics	Critical values at 5%
1994–1998		
0	191.66	160.87
1	137.62	127.05
2	100.03	97.26
3	67.28	71.44
4	42.52	49.64
1999–2002		
0	120.31	97.26
1	72.28	71.44
2	45.66	49.64
3	25.98	31.88

[a] Only most relevant part of the trace test results is reported here to conserve space. The critical values are obtained from MacKinnon et al. (1999).

in this study are consistent with those of many previous studies (Katsimbris and Miller, 1993; Kirchgassner and Wolters, 1993; Bremnes et al., 1997; Hassapis et al., 1999; Uctum, 1999).

To test the robustness of the above rank order choices, we also compare the out-of-sample forecast performance of cointegration models with different cointegration ranks (available on request). We find that the models with the cointegration rank chosen above (namely $r = 3$ for the first period, and $r = 1$ for the second period) are the best model specifications in terms of forecasting performance. Specifically, compared to other models with alternative cointegration rank (i.e., $r = 2$, 4 and 5 for the first period, and $r = 0$, 2 for the second period), the cointegration model with $r = 3$ fit to the first period provides the most accurate forecasts in one-, three- and four-steps-ahead forecasts, and the model with $r = 1$ fit to the second period provides the most accurate forecasts in all one-step- to four-step-ahead forecasts. Hence, we confirm the above choices of cointegration ranks. Given the above model specifications, we conducted various causality tests as reported below. In the Appendix, we also report the full information maximum likelihood estimates of α, β, Γ and Σ of the cointegration model for the sample period 1994–1998 ($r = 3$) and 1999–2002 ($r = 1$), respectively.

Note that the theory does not provide unambiguous prediction on the extent and the nature of international money market rate linkages. Short-term money market rates can generally be viewed either as analogous to other asset prices or as policy instruments. With substantially deregulated international financial markets and voluminous capital flows across borders, short-term interest rates in different countries may be expected to move together to some extent, depending on the degree of the remaining barriers to market entry. Furthermore, market-driven comovement of interest rates may be confounded to a varying extent by the degree of monetary policy independence sought by national authorities. As found in Uctum (1999), linkages among national interest rates and intervention rates, which can directly capture the monetary authorities' behavior, may well reflect international transmission of monetary policy. By contrast, national money market interest rates (e.g., T-bill) reflect the markets' perception of the monetary authorities' behavior, and the linkages between them may only be loosely related to the interaction of central banks' monetary policy behavior.

In this regard, similar to national money market interest rates, Eurocurrency interest rates may be better described as a type of asset prices than as a policy instrument. It is well known that compared to national money market interest rates, offshore Eurocurrency markets are not subject to any government regulations. Arguably, such relatively unregulated markets could be better positioned to collect market opinions about interest rate movements, which may not necessarily agree with the opinion of the national monetary authorities. Some researchers (e.g., Lo et al., 1995) have documented evidence that Eurocurrency interest rates often (unidirectionally) Granger-cause domestic money market interest rates in U.S. and Japan. Hence, the nature of Eurocurrency rate linkages can only be determined by empirical testing, since there are no well-justified theoretical priors regarding the cointegration rank among the interest rates (or the exact identification of the cointegration structure).

4.1. First subsample (1994–1998)

4.1.1. Out-of-sample Granger causality test results (1994–1998)

As discussed above, to implement the out-of-sample Granger causality test on the hypothesis that series y_{jt} Granger-causes series y_{it} ($i, j = 1, \ldots, n, i \neq j$) with the inclusion of other relevant series, we obtain the forecasts from both the U and R models. The U model (including all eight variables in Eq. (1) and $r = 3$) is first estimated using observations for the first 4 years (1994–1997) (a total of 209 weekly observations). The first set of one-step-ahead out-of-sample forecasts for all eight series is generated from the estimated model. The model is then re-estimated and new forecasts are generated after each of the first 51 observations in 1998 is sequentially added to the sample (there are 52 weekly observations in 1998). This results in a series of 52 one-step-ahead out-of-sample forecasts. The forecast errors are formed by the difference between observed interest rates of year 1998 and the forecasts. The forecasts based upon the seven R models (omitting series y_{jt} in Eq. (1), $j = 1, 2, \ldots, 8$ for each i, $i = 1, 2, \ldots, 8, j \neq i$) are generated in a similar way. It is worth noting that the cointegration ranks of each of the R models are also re-estimated. We find that the R model, excluding the U.S., the U.K. and Germany, has one fewer rank ($r = 2$) than the U model. The cointegration ranks of the other five R models remain to be 3.

For the first subsample, we have a total of 64 forecast error series. As discussed earlier, for each of eight interest rate series, there is one forecast error series based on the U model and seven based on the R models. With both the U and R model-based forecast error series at hand, we calculate the DM statistic to complete the causality test. The causality test results for the first period are presented in Table 2. There are three interesting possibilities. First, if the U model generates more accurate forecasts (smaller Mean Squared Forecast Errors (MSFE)) than the R model, and the DM test indicates that this difference is statistically significant, then y_{jt} Granger-causes series y_{it}. Second, if the U model generates more accurate forecasts than the R model, but the DM test indicates that this difference is statistically insignificant, then y_{jt} does not Granger-cause series y_{it}. Third, if the U model generates less accurate forecasts (larger MSFE) than the R model, then y_{jt} does not Granger-cause series y_{it}, and no further test is conducted. It should be noted that if the U model has much more parameters than the R model and/or the ratio of T_2/T_1 is large, forecasts from the U model can still be more accurate than those from the R model in terms of DM test, even if the U model has a larger MSE than the R model (McCracken, 1999). Nevertheless, neither of the two conditions applies here.

From Table 2 we can see that the U models generate more accurate forecasts than the R models in 17 out of 56 cases studied. Further DM tests show that Granger causality is statistically significant at the 10% significance level in nine cases (of which six are significant at the 5% level). There

Table 2
Out-of-sample Granger causality tests (1994−1998)[a]

	U.S.	Canada	Japan	U.K.	Germany	France	Italy	Switzerland
U.S.								
Canada			0.577			0.836*		
Japan								
U.K.		1.748**	1.134**					0.120
Germany							0.297	
France			1.431**				0.740*	
Italy	0.844*	0.233	1.639**			0.580		
Switzerland	0.330	0.507		2.078**	0.103		1.731**	

[a] Each entry reports the result of a Diebold−Mariano test. The null hypothesis is that each series in the first row does not Granger-cause any particular series in the first column (given existence of other series in the first column). The symbols "**" and "*" indicate that the null is rejected at a 5% and 10% significance level, respectively. Empty entries on off-diagonal elements represent cases where an unrestricted model has a larger MSFE than a restricted model. The null of no Granger causality cannot be rejected for the insignificant or empty entries. The critical values of Diebold−Mariano test are provided in McCracken (1999).

are no Granger causal relationships between many pairs of Eurocurrency interest rates. Although not directly comparable, the strength of causal linkages in the Eurocurrency market in this study appears much weaker than what is reported in Awad and Goodwin (1998), where the causality in at least one direction is detected in 31 out of the 90 cases (34%), in contrast to nine out of 56 cases (16%) in this study. In addition to different data sets, such a difference might be attributable to our use of a different test of forecast accuracy (i.e., the DM test) and a multivariate (rather bivariate) VAR framework that incorporates cointegration relations.[4]

As shown in Table 2, three major Eurocurrency interest rates, U.S., Japan and Germany, were not Granger-caused by any other interest rates. On the other hand, Japanese rates caused changes in the U.K., French and Italian rates. U.S rates appeared to Granger-cause Italian rates. German rates did not Granger-cause any other Eurocurrency interest rates. By contrast, the other five Eurocurrency interest rates were caused by at least one of other interest rates. Canadian interest rates were caused by French rates but not the U.S. rates. The U.K. interest rates were caused by two other interest rates (Canada, Japan) but not the U.S. rates. Italian Lira interest rates were also caused by two other interest rates (U.S. and Japan) while Swiss interest rates were caused by the U.K. and Italy. Overall, the Granger causality test results alone do not suggest a strong causal linkage between the Eurocurrency markets during 1994−1998. However, as mentioned earlier, in the case of temporal aggregation, Granger causality tests may not provide a complete picture of causality (Swanson and Granger, 1997). Below, we turn to contemporaneous causality tests that complement Granger causality tests.

4.1.2. DAG contemporaneous causality test results (1994−1998)

As reported in the Appendix, we find strong contemporaneous correlations among the innovations in major Eurocurrency interest rates. Strong contemporaneous correlations of various

[4] Out-of-sample Granger causality tests may be misleading if cointegrating relations are wrongly omitted from the model. Omitting the error correction terms in Eq. (1), we conduct the out-of-sample causality test in VAR in first difference. For the first period of 1994−1998, we find that the non-causality hypothesis can be rejected 12 times (compared to nine times based upon the ECM model). The major difference is that the U.K. and German rates are mistakenly found to cause the U.S. rates. Similarly, we also find more rejections of the null hypothesis in the second period of 1999−2002 (eight times compared to five times using the model that incorporates cointegration relation(s)).

interest rate innovations have been reported in previous studies, including Kirchgassner and Wolters (1987), Karfakis and Moschos (1990) and Uctum (1999). It is also well recognized (Kirchgassner and Wolters, 1987, p. 679; Uctum, 1999, pp. 781–783) that the contemporaneous correlations among interest rate innovations may reflect the phenomenon that new information in one market is transmitted and shared by other markets in contemporaneous time, due to immediate response to price changes between markets. In such a case, however, both Kirchgassner and Wolters (1987) and Uctum (1999) assume that the currency of the larger country dominates the smaller one, such as the contemporaneous causal flow running from Germany to other European markets. Uctum (1999) pointed out that strong contemporaneous correlations might also be consistent with the existence of a common factor.

We conduct DAG contemporaneous causality tests for the period of 1994–1998. We form the starting undirected graph by connecting all of the pairs of the eight interest rates under consideration, which results in a total of 28 edges. These edges are then subject to sequential removal based upon unconditional or conditional zero correlations. In removing edges, the simulation evidence in Scheines et al. (1994) shows that one should choose a 10% significance level for moderate sample sizes such as those studied here. Thus, we choose a 10% significance level in this study. Less than half of the edges remain in the final graph indicating that the causal relationships are present in these pairs. The causal flows in eight edges, specifically, Germany–U.S., Germany–Canada, Canada–France, Japan–Germany, U.K.–Germany, Germany–Italy, Switzerland–Germany, and Italy–France, are explicitly directed at the chosen significance level. However, three other edges, U.S.–Canada, U.S.–Switzerland, and Canada–Italy remain undirected, perhaps because of the instability of such edge relationships.

As mentioned previously, contemporaneous causality test results can be treated to reveal hidden information on Granger causal relations due to time aggregation (Swanson and Granger, 1997). In this study, contemporaneous causality test results can thus be interpreted meaningfully only when combined with Granger causality test results. Hence, Fig. 1 is a graphical representation, which reports the causal relations from both tests, where DAG causality results are represented by solid lines (—) and Granger causality test results by dashed lines (----). Most importantly, different from the inference from using Granger causality test results alone, Fig. 1 suggests much stronger causal linkages between these Eurocurrency markets than the Granger causality tests reveal. Almost every pair of markets is connected with unidirectional or bidirectional causal edges. As discussed below, it should also be clear that causal roles of various Eurocurrency markets, as suggested by Fig. 1, can be quite different from those of the Granger causality test results alone (at least in some cases).

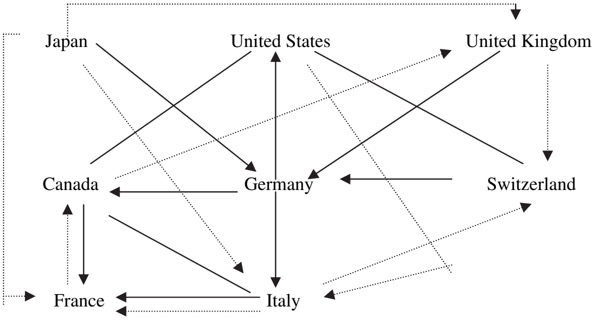

Fig. 1. The combined causal pattern between eight Eurocurrency rates (1994–1998).

Specifically, the U.S. was caused by Germany, which is not found in Granger causality tests. As the U.S. only possibly caused Canada and Switzerland, there is little evidence for U.S. dominance in the Eurocurrency market. It is also now found that the Japanese market caused Germany, in addition to several European markets (France, U.K., and Italy). This provides stronger evidence for the influence of Japan on European markets, which is a bit surprising and has not yet been documented in the literature. Nevertheless, Japan is not found to cause the U.S. and other markets during the period. We also have new evidence for the importance of the U.K. market as an international money center, which sent the information to the two European markets including Germany, after collecting information from Asia (i.e., Japan) and North America (i.e., Canada). The German market was the only market which is clearly identified to cause the U.S., Canadian and Italian markets. Noteworthy, such an informational role of Germany is revealed only in the DAG contemporaneous tests, as German is otherwise considered an isolated market from all other markets based on Granger causality test results. On the other hand, the German market was also caused by such markets as Japan, U.K. and Switzerland, which again is only revealed in the DAG tests. Finally, three European markets, i.e., France, Italy and Switzerland, did not have much influence on other markets, as they caused only one of the other markets but were caused by two or three other markets.

Overall, the combined causality test results during 1994–1998 are largely consistent with the finding of Uctum (1999) that the influence of German interest rates on other European interest rates was weakened, and the international interest rate linkage between several major European countries and the U.S. broke down after the German reunification (during the period of 1990–1997).[5] As pointed out in Uctum (1999), such a possible breakdown between several major European markets and the U.S. can be traced back to the divergence between European and U.S. monetary policies after 1990. In 1990, the West German government decided, on political grounds, to convert East German savings, wages and prices at vastly overvalued exchange rates of the East German mark. This resulted in an expansion in the German money supply, which contributed to the inflationary pressures facing reunified Germany. At the same time, the combination of East and West Germany caused huge increases in welfare expenses. The Bundesbank responded to unification-induced inflation and deficits by raising real interest rates and keeping them high. Its final target was shifted from reducing unemployment and stimulating growth in the 1980s to combating inflation in the 1990s. By contrast, the sole objective for the Fed continued to be stimulating growth, as is evidenced by a stepwise decline in interest rates to simulate the U.S. economy in the early 1990s.

The Bundesbank's response also explains why the influence of Germany on other European markets may be weakened after 1990. It is well known that the EMS was essentially based on Germany's continuing ability to deliver low inflation rates and low real interest rates. With the German government running huge and inflationary deficits and high interest rates since 1990,

[5] We thank a referee for bringing up the point that the comovements in business cycles or inflation between the countries, as measured by the correlations of unemployment rates and inflation rates, are likely to explain to some extent the Eurocurrency rate causal linkages. As pointed out in Uctum (1999), these two are the two final targets of central bank policies for most industrialized countries in 1990s. Many pairs of causal links shown in Figs. 1 and 2 are characterized with rather high correlations in either unemployment rates or inflation rates. Some of the most relevant correlations are as follows. During 1994–1998, the correlations of unemployment rates among these countries are 0.62 (Canada–France), 0.88 (Canada–U.K.), and 0.49 (Japan–Germany). During 1999–2002, the correlations of unemployment rates are 0.92 (Japan–U.S.), and the correlations of inflation rates are 0.61 (Canada–Euro), 0.49 (Canada–U.K.), 0.65 (Canada–U.S.), 0.41 (U.S.–U.K.), and 0.46 (U.S.–Euro).

the cost of other EMS member countries following a Bundesbank's monetary policy increased dramatically and might have exceeded the benefit. As observed in Uctum (1999), to make the EMS viable, Germany had to respond to its partners' monetary policies after its reunification. The currency crises in 1992 and 1993 are a manifestation of the severe lack of such effective monetary policy coordination in this new era. Hence, not surprisingly, our results are also partly consistent with Hassapis et al. (1999), who find that the German interest rates were caused by, rather than cause, the interest rates of several major European countries. However, we do not find evidence that the U.S. has a strong influence on most European rates, although the former is indeed not much influenced by the latter (Awad and Goodwin, 1998; Hassapis et al., 1999).

4.2. Second subsample (1999–2002)

4.2.1. Out-of-sample Granger causality test results (1999–2002)

Applying out-of-sample Granger causality tests to the second period, we also find some differences in the cointegration ranks between the U and R models. No cointegration relation is found if either Euro or Switzerland is omitted from Eq. (1). For these R models, a VAR in first difference is used. The number of forecast error series in the second period is 36 for the six interest rates. The out-of-sample Granger causality test results for the second period 1999–2002 are reported in Table 3.[6]

The Granger causal relations are found to be significant between nine pairs of interest rates, although the U model prevailed in 16 out of 30 cases. The U.S. market did not cause any other markets and was caused by Canada and the U.K. As will be clear shortly, such a puzzling result may be largely due to failure to allow for more rapid information transmission from the U.S. to other markets, as captured by the contemporaneous causality tests. The impact of Japanese Yen persisted in this period, as it significantly caused Canadian and Euro rates. The Euro rate only caused the Canadian rate and was only caused by the Japanese rate. The Granger causality between U.K. and Canada is bi-directional. The U.K., rather than the Euro, seemed to have a bigger effect on other rates following the adoption of the European Monetary Union.

4.2.2. DAG contemporaneous causality test results (1999–2002)

For the six markets in the second period, we remove seven edges out of the total of 15. Among the eight remaining edges, four of them are undirected: Canada–Euro, Euro–Switzerland, Euro–U.K., and U.K.–Switzerland. Interestingly, if only the first 2-year (1999–2000) sample observations are used, the contemporaneous causal relationships between Canadian and Euro, and between Euro and Swiss markets are directed as Canada → Euro, Euro → Switzerland. This may suggest, among other things, that contemporaneous causal flows between these markets might be unstable due to the unsettled role of the new currency Euro. The result

[6] Based on recursive cointegration tests, we find evidence that adding the data of year 2003 consistently increases the cointegration rank from 1 to 3 (or higher). As further evidence of such a break, none of the edges can be directed with the data of 2003 added to the second subsample. Interestingly, such a break between Eurocurrency interest rates (roughly) beginning in 2003 coincides with a new trend of the Euro exchange rates. Since its inception in January 1999, the Euro had mostly fallen against the U.S. dollar throughout much of the year 2002 (from about $1.2 in early 1999 down to about $0.85). Only until January 2003, the exchange rate of the Euro against the U.S. dollar turned around and exceeded 1.0 again and it continued to appreciate up to $1.2 until early 2004. Since there is only 1-year data in 2003 available at the time of writing, we cannot meaningfully conduct a separate analysis. Thus, we decide to leave this for future research and drop it from the second period.

Table 3
Out-of-sample Granger causality tests (1999–2002)[a]

	U.S.	Canada	Japan	U.K.	Euro	Switzerland
U.S.		0.933*		1.412**		
Canada	0.095		1.566**	2.699**	1.897**	1.573**
Japan	0.019	0.132				
U.K.	0.207	2.252**				1.218**
Euro	0.222	0.339	0.821*			
Switzerland	0.429					

[a] See the note in Table 2.

on contemporaneous causal relationships in the second period is presented in Fig. 2. Again, similar to the finding in the first period, with the DAG contemporaneous causality test result added, the causal linkages among these markets are stronger than what is revealed based on using the Granger causality tests alone.

More importantly, several pairs of causal relationships added from the DAG tests in Fig. 2 are particularly helpful in better understanding the nature of causal roles of various currencies. Specifically, we now find that the Euro is not only caused by Japan, but also by the U.S., which is consistent with the fact that the Euro was not a strong currency in its first few years as the EMU struggled with the macroeconomic problems and policy coordination among its member countries. We also document the causal flow from Japan to the U.S., which further strengthens the impression of the influence of Japan in the Eurocurrency markets. We find that the causal linkage between the U.S. and U.K. is bi-directional instead of unidirectional. Finally, as three edges related to the Euro are not directed, we can only infer that Euro did not appear to have had much influence on the rest of the world. The Euro only clearly caused the Canadian market.

4.3. Robustness check

We have conducted many robustness tests for the results reported here (results available on request). In particular, although the division of subperiods is mandated by the nature of the data, we examine the potential structural break within each subsample. We find some evidence for the instability of cointegration rank in the first subsample but little for the second subsample. Thus, for the first period, the cointegration rank could be 3 or 4, although 3 is considered the best fit based on the out-of-sample test. We repeated both types of causality tests based on the assumption of cointegration rank equal to 4 for the first period. The out-of-sample Granger causality tests yield a similar inference and the DAG contemporaneous tests yield an identical pattern to what is reported here. Furthermore, we consider an alternative cointegration rank of 2 for

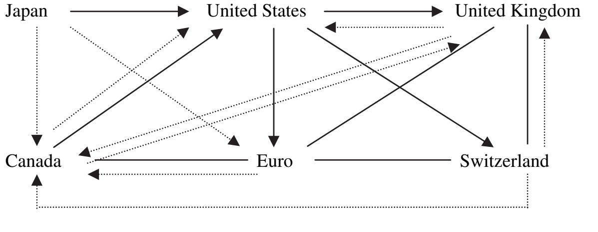

Fig. 2. The combined causal pattern between six Eurocurrency rates (1999–2002).

the second period. As might be well expected, the inference is qualitatively the same. Nevertheless, as discussed previously (footnote 4), failure to impose cointegration constraints (if such exists) would lead to misleading Granger causality test results.

We also conducted robustness checks based on alternative windows of in-sample estimation period and out-of-sample forecasting period. Such a check is expected to shed more light on how the potential instability might affect the causality test results. In particular, we conducted both types of causality tests using 3 years (1994–1996) for in-sample estimation and 2 years (1997–1998) for out-of-sample forecasting in the first period, and 2 years (1999–2000) for in-sample estimation and 2 years (2001–2002) for out-of-sample forecasting in the second period. In such an experiment, DAG tests again produce similar patterns, consistent with the Monte Carlo evidence of its reasonable reliability in identifying the correct causal structures (Demiralp and Hoover, 2003). Although Granger causality tests result in somewhat more significant causal relationships, we again find that the basic inference, particularly about the causal roles of the U.S., Japan and Germany in the first period and those of the U.S., Japan and Euro in the second period, is qualitatively unchanged.

5. Conclusions

In this study, we investigate the contemporaneous and Granger causal relationships among major Eurocurrency interest rates from 1994 to 2002. The sample period enables us to assess the informational role of the recently introduced Euro in the Eurocurrency market. Both out-of-sample Granger causality tests within the framework of multivariate cointegrated VAR models and DAG contemporaneous causality tests are conducted and combined to yield inference on causal linkages between Eurocurrency markets. The study underscores the importance of exploiting both Granger causality tests and contemporaneous causality tests in causality analysis, as recently advocated by Swanson and Granger (1997). Compared to inference based on Granger causality test results alone (which is typically applied in this line of the literature), the combination produces a more complete picture of causality, suggests stronger causal linkages between the markets, and results in more sensible results. Similarly, Uctum (1999) also found that the inference based on Granger causality tests alone appears to be counterintuitive for the analysis of interest rate causal linkages, while additional allowance for high contemporaneous correlations yields much more intuitively appealing findings.

The overall results suggest that the U.S. dollar interest rate does not exert a dominant influence on other currencies in both periods, which is not in line with some recent studies (Awad and Goodwin, 1998; Hassapis et al., 1999). Nevertheless, the impact of U.S. dollar interest rates appears to be strengthened after the introduction of the Eurocurrency in 1999. The interest rates on the German mark (the currency commonly considered as a predecessor of the Euro) Granger-caused the U.S. dollar and some other interest rates, and meanwhile were caused by other interest rates. This evidence is consistent with Uctum (1999) and suggests the decline of German dominance in Europe. Furthermore, there is only rather weak evidence for the influence of the Euro interest rates on other Eurocurrency interest rates. A possible explanation might be the heterogeneity of EMU member countries and lack of flexibility in interest rate adjustments as constrained by accomplishing the common economic and monetary union goals.

Finally, there is strong evidence from both tests and across both periods that Japanese interest rates were influential on other interest rates, but had no noticeable response to the outside world. Such a finding is a bit surprising, and has not been documented in the literature. Nevertheless, it is well known that the Euroyen is the second most important Eurocurrency market in the world. Furthermore, Japan has become the biggest net capital exporter, particularly since the late 1980s when bubbles in its economy and stock market burst. On the other hand, Germany and some other European countries were in great need of foreign capital in the 1990s. Thus, it seems possible that interest rates offered on other currencies are particularly sensitive to changes in the money market rates in Japan to attract the Japanese and other international investors. Little causal influence of other markets on Japan might be an indication of the fact that the Japanese monetary policy targets differ from most other countries during the sample period due to its focus on fighting against recession and deflation rather than inflation, or that the Japanese financial markets are the least open to international investors among major industrialized economies (Bessler and Yang, 2003). Future research is warranted to further explore this issue and provide more clear-cut explanations.

Acknowledgements

We would like to thank Thomas R. Saving, Andrew J. Rettenmaier, session participants at the 2004 Financial Management Association annual meetings, and particularly two anonymous referees for many helpful comments and suggestions. Li's research is partially supported by the Private Enterprise Research Center, Texas A&M University.

Appendix

The estimated error correction model (1994–1998)[7]

$$\alpha' = \begin{pmatrix} .023 & .065 & .001 & .017 & .006 & .044 & .027 & .007 \\ -.002 & .004 & .010 & -.006 & .000 & .017 & -.016 & .007 \\ -.015 & .008 & -.003 & .019 & .028 & .032 & -.002 & -.007 \end{pmatrix},$$

$$\beta = \begin{pmatrix} 1.000 & -.633 & .904 & .026 & 2.254 & -.972 & .243 & -.295 \\ -.525 & 1.000 & -1.967 & -.207 & 6.349 & -3.526 & .675 & -2.527 \\ .018 & -.382 & 1.000 & 1.135 & -1.611 & .048 & .130 & .773 \end{pmatrix},$$

$$\Gamma = \begin{pmatrix} -.242 & .010 & -.010 & .063 & -.091 & -.010 & .028 & .037 \\ -.174 & -.159 & -.161 & -.148 & -.098 & .082 & -.058 & .166 \\ .126 & .048 & -.435 & -.051 & -.108 & -.011 & .007 & .145 \\ -.050 & -.001 & -.051 & -.086 & .059 & -.023 & .012 & -.038 \\ -.016 & -.038 & -.033 & -.018 & -.092 & .013 & -.021 & .034 \\ .022 & -.224 & .160 & -.249 & .085 & -.229 & .321 & .067 \\ -.056 & -.068 & .005 & -.305 & .372 & .041 & -.049 & -.043 \\ .033 & -.042 & -.061 & .159 & .106 & .004 & -.054 & -.115 \end{pmatrix},$$

[7] The original value of each element has been multiplied by 1000 for the ease of presentation.

$$\Sigma = \begin{pmatrix} 7.798 & & & & & & & \\ 3.283 & 43.600 & & & & & & \\ 1.098 & -1.174 & 18.200 & & & & & \\ .753 & .682 & .324 & 7.389 & & & & \\ 1.338 & 2.852 & 1.017 & 1.216 & 5.117 & & & \\ .435 & 9.725 & -2.108 & 1.377 & 1.465 & 59.900 & & \\ .535 & 9.643 & -.818 & 1.138 & 2.458 & 19.700 & 38.100 & \\ 1.552 & .021 & -.648 & -.090 & 2.972 & -.560 & .263 & 13.900 \end{pmatrix}.$$

The estimated error correction model (1999–2002)[7]

$$\alpha' = (.043 \quad .053 \quad .016 \quad .006 \quad .021 \quad .049)',$$

$$\beta = (1.000 \quad -2.032 \quad -4.181 \quad 2.003 \quad 2.743 \quad -2.377),$$

$$\Gamma = \begin{pmatrix} -.012 & .132 & -.047 & -.036 & -.051 & .088 \\ .028 & -.027 & .151 & .091 & -.118 & .111 \\ .007 & -.035 & -.079 & -.025 & .007 & .012 \\ -.076 & .133 & -.003 & -.001 & .048 & .116 \\ -.028 & .102 & .160 & .130 & -.106 & .108 \\ .033 & .030 & -.040 & .110 & .022 & -.068 \end{pmatrix},$$

$$\Sigma = \begin{pmatrix} 9.511 & & & & & \\ 3.881 & 6.506 & & & & \\ .706 & -.062 & 2.322 & & & \\ 3.671 & 1.459 & .182 & 5.892 & & \\ 2.948 & 1.916 & .017 & 1.800 & 5.714 & \\ 3.862 & 1.238 & .262 & 2.252 & 2.531 & 11.300 \end{pmatrix}.$$

References

Amato, J.D., Swanson, N.R., 2001. The real-time predictive content of money for output. Journal of Monetary Economics 48 (1), 3–24.

Ashley, R., Granger, C.W.J., Schmalensee, R.I., 1980. Advertising and aggregate consumption: an analysis of causality. Econometrica 48 (5), 1149–1168.

Awad, M.A., Goodwin, B.K., 1998. Dynamic linkages among real interest rates in international capital markets. Journal of International Money and Finance 17 (6), 881–907.

Bessler, D.A., Yang, J., 2003. The structure of interdependence in international stock markets. Journal of International Money and Finance 22 (2), 261–287.

Breitung, J., Swanson, N.R., 2002. Time aggregation and spurious instantaneous causality in multiple time series models. Journal of Time Series Analysis 23 (6), 651–665.

Bremnes, H., Gjerde, O., Saettem, F., 1997. A multivariate cointegration analysis of interest rates in the eurocurrency market. Journal of International Money and Finance 16 (5), 767–778.

Chao, J., Corradi, V., Swanson, N.R., 2001. Out-of-sample tests for Granger causality. Macroeconomic Dynamics 5 (4), 598–620.

Corradi, V., Swanson, N.R., 2002. A consistent test for nonlinear out of sample predicative accuracy. Journal of Econometrics 110 (2), 353–381.

Demiralp, S., Hoover, K.D., 2003. Searching for the causal structure of a vector autoregression. Oxford Bulletin of Economics and Statistics 65, 745–767.

Diebold, F.X., Mariano, R.S., 1995. Comparing predictive accuracy. Journal of Business and Economic Statistics 13 (3), 253–263.

Granger, C.W.J., 1969. Investigating causal relations by econometric models and cross-spectral methods. Econometrica 36 (3), 424–438.

Granger, C.W.J., 1988. Some recent developments in a concept of causality. Journal of Econometrics 39 (1–2), 199–211.

Hassapis, C., Pittis, N., Prodromidis, K., 1999. Unit roots and Granger causality in the EMS interest rates: the German dominance hypothesis revisited. Journal of International Money and Finance 18 (1), 47–73.

Johansen, S., 1991. Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. Econometrica 59 (6), 1551–1580.

Karfakis, C.J., Moschos, D.M., 1990. Interest rate linkages within the European Monetary System: a time series analysis. Journal of Money, Credit and Banking 22 (3), 388–394.

Katsimbris, G.M., Miller, S.M., 1993. Interest rate linkages within the European Monetary System: further analysis. Journal of Money, Credit and Banking 25 (4), 771–779.

Kirchgassner, G., Wolters, J., 1987. US–European interest rate linkage: a time series analysis for West Germany, Switzerland, and the United States. Review of Economics and Statistics 69 (4), 675–684.

Kirchgassner, G., Wolters, J., 1993. Does the DM dominate the Euro market? An empirical investigation. Review of Economics and Statistics 75 (4), 773–778.

Lo, A.W., Mackinlay, A.C., 1988. Stock market prices do not follow random walks: evidence from a simple specification test. Review of Financial Studies 1 (1), 41–66.

Lo, W.C., Fung, H.G., Morse, J.N., 1995. A note on Euroyen and domestic yen interest rates. Journal of Banking and Finance 19 (7), 1309–1321.

MacKinnon, J.G., Haug, A.A., Michelis, L., 1999. Numerical distributions of likelihood ratio tests for cointegration. Journal of Applied Econometrics 14 (5), 563–577.

McCracken, M.W., 1999. Asymptotics for out of sample tests of causality. Working paper, Louisiana State University.

Pearl, J., 1995. Causal diagrams for empirical research. Biometrika 82 (4), 669–710.

Scheines, R., Spirtes, P., Glymour, C., Meek, C., 1994. Tetrad II: User's Manual and Software. Lawrence Erlbaum Associates, Inc., Mahwah, NJ.

Spirtes, P., Glymour, C., Scheines, R., 1993. Causation, Prediction, and Search. Springer-Verlag, New York.

Swanson, N., Granger, C.W.J., 1997. Impulse response functions based on a causal approach to residual orthogonalization in vector autoregression. Journal of the American Statistical Association 92 (437), 357–367.

Uctum, M., 1999. European integration and asymmetry in the EMS. Journal of International Money and Finance 18 (5), 769–798.

Yang, J., Bessler, D.A., 2004. The international price transmission in stock index futures markets. Economic Inquiry 42 (3), 370–386.