SHORT- AND LONG-TERM LINKS AMONG EUROPEAN AND US STOCK MARKETS

MBA THESIS

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By

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June, 1995

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Business Administration.

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ABSTRACT

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June, 1995

Recently, national economies are becoming more internationalized because of increased trade and more cooperation between national governments to remove the barriers to free flow of goods, services, and financial, physical and human capital. The relationship between equity markets in various countries have been extensively examined in the literature. This study tests the interdependence between stock prices in Germany, the UK, the Netherlands and the US, using daily closing prices for the period between March 1990 and October 1994. Results of the tests showed that the US exerts a significant impact on the European markets. Moreover, the three European markets influence each other in the short- and long-run. This result implies that these markets move together. Therefore, diversification among those national stock markets will not greatly reduce the portfolio risk without sacrificing expected return.

ÖZET

AVRUPA VE AMERİKA BORSALARI ARASINDA KISA VE UZUN DÖNEM BAĞLANTILAR

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Haziran, 1995

Son yıllarda eşya, hizmet, finansal, fiziksel ve insan sermayesinin akışını serbestleştirmek amacıyla sınırları kaldırmak üzere ulusal hükümetler arasında artan işbirliği ve artan ticaret, ulusal ekonomilerin giderek enternasyonel bir kimlik kazanmalarına yol açmaktadır. Çeşitli ülkelerin borsaları arasındaki ilişki literatürde geniş bir şekilde incelenmiştir. Bu çalışma ise Almanya, İngiltere, Hollanda ve Amerika'daki hisse fiyatları arasındaki bağımlılığı, Mart 1990 - Ekim 1994 tarihleri arasında günlük kapanış fiyatlarını kullanarak test etmektedir. Test sonuçları Amerika'nın Avrupa piyasaları üzerinde önemli bir etkisi olduğunu göstermektedir. Bunun yanısıra, üç Avrupa borsası da kısa ve uzun dönemde birbirlerini etkilemektedir. Böylece, değişik ülkelerin hisse senetlerine yatırım yapmak portföy riskini büyük ölçüde azaltmayacaktır.

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Contents:

1. Introduction

In the last 30 years there has been an increase in diversification at several levels in the world economy. Large firms have discovered advantages in international diversification and have diversified direct investments geographically and across industries to become today's multinational corporations. Smaller investors and professional investment and pension fund managers, who look after their interests, have also become aware of the potential benefits of international diversification. Cross border investment continues its rapid worldwide growth as investors are attracted by the potential opportunities for increased returns and diversification benefits to be gained from an international approach to investment. In response to this phenomenon, banks and financial institutions have multiplied the international products and services they offer, while organized financial markets have tried to cope by adjusting products procedures and trading times. Due to financial deregulation and advances in computer technology, world stock markets have become more integrated. The globalization of markets and economies have resulted in stronger linkages between the markets of the world.

However, at the heart of the concept of international diversification is the notion that economic conditions and shareholders' returns in different (domestic and foreign) markets are less than perfectly correlated. If this is indeed the case, it is possible to reduce portfolio risk without sacrificing expected return by selecting individual securities in such a way that their risk characteristics offset each other.

To examine long-term links and short-run causality for four different capital markets, the subject of my thesis, I will use a vector error correction model. This paper discusses the methodology that will be used to check for short- and long-term links among the markets and will furthermore pay attention to the characteristics and the stationarity of the data-sets.

2. Literature Review

Recently, national economies are becoming more internationalized because of increased trade and more cooperation between national governments to remove the barriers to free flow of goods, services, and financial, physical and human capital. The relationships between equity markets in various countries have been extensively examined in many prior empirical studies. However, many early studies have made a strong case for international portfolio diversification. The benefits of international diversification have been extensively documented (Solnik, 1988). Such diversification allows to reduce the total risk of a portfolio while enhancing the performance opportunities.

The lack of interdependence across national stock markets has been presented as evidence supporting the benefits of international portfolio diversification. In the causality literature, Granger and Morgenstern (1970) use spectral analysis on weekly data for stock indices in eight countries. Their empirical evidence shows few or no interrelationships between the stock markets examined, except in the cases of the US-Holland and Germany-Holland. Agmon (1972) using weekly or monthly return data, find no significant leads or lags among the common stocks of Germany, Japan, the UK and the USA. Studies, such as Lessard (1976) and Jorion and Schwartz (1986), using regression models to test for the existence but not the degree of market segmentation, suggest that market segmentation does exist in some national equity markets.

The stock market crash of 1987 has provide new insights into the economic nature of globalization of stock markets. Dwyer and Hafer (1988), using daily data for seven months before and after the October 1987 crash, show no evidence that the levels of stock price indices for the US, Japan, Germany and the UK are related. They report statistical evidence, however, that the changes in the stock price indices in these four markets are generally related.

More recent studies, however, examining the stock price indices around the crash by Eun and Shim (1989), von Furstenberg and Jeon (1989), and Bertera and Mayer (1990) report a substantial amount of interdependence among national stock markets.

Eun and Shim (1989) investigate the international transmission mechanism of stock market movements by estimating a nine-market VAR system, including the US, Japan, and Hong Kong. The results show that innovations in the US are rapidly transmitted to the stock market in Japan and Hong Kong market to be independent of one another.

Von Furstenberg and Jeon (1989) used daily data from 1986 to 1988 to analyze the relationships for stock markets in London, Frankfurt, Tokyo and New York during and after the October 1987 market crash. They use a four-variable VAR model for investigating the interdependence of the four markets. They report that the degree of international co-movements in stock price indices had increased significantly after the crash.

Bertera and Mayer (1990) examines the stock price indices and the structure of 23 stock markets including Australia, Hong Kong, Malaysia, Mexico, Singapore, South Africa, New Zealand, Japan, the US and some European countries around the crash of 1987. They compared the size, trading volume and some trade characteristics and analyzed the interdependencies between these markets. Their study showed that the correlations between all regions increased and remained higher after the crash.

Many studies have been made to examine the international linkage between the US and Japan. Gultekin et al. (1989), Becker et al. (1990), Hamao et al. (1990), Kasa (1991), and Smith et al. (1993) find high correlations between the two markets with an asymmetric spillover effect from the US to the Japanese market, while Smith et al. (1993) and Aggerwal and Park (1994), however, find that US equity prices do not lead Japanese equity prices and state that gains from international diversification are obtainable.

Gultekin et al. (1989) focus on Japan and the US to test the integration of capital markets. Weekly stock returns calculated from daily closing prices of the markets are used for two sample periods around the December 1980 liberalization in Japan: 1977 to 1980 and 1981 to 1984. To test the hypothesis of market integration, an international version of a multifactor assets pricing model is used. Using multifactor asset pricing models, they show that the price of risk in the US and Japanese stock markets was different before, but not after, the liberalization. This evidence supports the view that governments are the source of international capital market segmentation.

Becker et al. (1990) study the inter-temporal relation between the US and Japanese stock markets for the period 1985-1988. They use daily opening and closing data the market indexes. Correlations and regression are used for detection of lead-effects and determination of the relation between the two markets. They find a high correlation between the open to close returns for US stocks in the previous trading day and the Japanese equity market performance in the current period. In contrast, the Japanese market has only a small impact on the US return in the current period. In addition, there is no relation between the performance of the Japanese market and the close to open return in the US. High correlations among open to close returns are a violation of the efficient market hypothesis. However, profitable trading on Japanese market based on the movements on New York stock exchange was not possible due to the high trading costs in Japan.

Hamao et al. (1990) study the short-run interdependence of prices and price volatility across three major international stock markets. Daily opening and closing prices of major stock indexes for the Tokyo, London and New York stock markets are examined over the period 1985-1988. The analysis utilizes the autoregressive conditionally heteroskedastic (ARCH) family of statistical models to explore these pricing relationships. They find spillover effects from the US and the UK stock markets to the Japanese market. This effect shows an intriguing asymmetry: while the volatility spillover effect on the Japanese market is significant, the spillover effects on the other two markets are much weaker. Unexpected changes in foreign market indices are associated with significant spillover effects on the conditional mean of the domestic market for both open-to-close and close-to-open returns. For the close-to-open returns, this effect on the conditional mean is consistent with international financial integration, while the magnitude of volatility spillover is generally much less.

Kasa (1991) present evidence concerning the number of common stochastic trends in the equity markets of the US, Japan, the UK, Germany, and Canada. Monthly and quarterly indices data from 1974 through 1990 are used. Johansen's tests (1990) and the present value model of asset pricing are applied to the stock markets. The results indicate the presence of a single common trend driving these countries' stock markets. Estimates of the factor loadings suggest that this trend is most important in the Japanese market and least important in the Canadian market. These results imply that to investors with long holding periods the gains from international diversification have probably been overstated in the literature. Specifically, the presence of a single common stochastic trend means that these markets are perfectly correlated over long (infinite) horizons.

In contrast with the previous studies, Smith et al. (1993) and Aggerwal and Park (1994) find evidence supporting the benefits of international portfolio diversification.

Smith et al. (1993) examine the possible market linkages using weekly returns from markets in the US, the UK, West-Germany and Japan, during the 1979-1991 period. Granger causality tests are applied to the weekly data. Evidence of Granger unidirectional causality running from the US to the other countries immediately after the October 1987 world-wide crash is found. For the most part, this linkage appears to be short-lived, with the exception of the linkage from the US to the German market. These are episodes of other countries Granger-causing the US, but these are short-lived as well. Given the results, one can conclude that the market crash in the US caused instability, which was transmitted to other major markets around the world. Other than the crash period, there appears to be a lack of Granger causality from market to market, except the US/German relationship. In terms of their aggregate returns data, the results are consistent with the idea that gains from international diversification are obtainable. for the most part, shocks from one market are not transmitted to other markets around the world.

Aggerwal and Park (1994) presents evidence of the international integration of the US and Japanese equity markets. They used daily opening and closing prices of the stock markets from 1987 to 1991. This paper accounts for the problem of non-synchronous trading associated with the calculated spot opening value of the market index. This study find hat US equity prices do not lead Japanese equity prices. Both US and Japanese opening equity prices reflect overnight price changes in the other market.

The conflicting evidence leads naturally to the question why are there differences in results? Meric and Meric (1989) analyze the inter-temporal stability of the matrix of correlation coefficients among seventeen national stock markets (Spain, Singapore, Australia, the US, Canada, Hong Kong, Italy, Norway, France the UK, Belgium, Austria, Germany, Switzerland, Netherlands, Sweden and Japan). They use month-end closing stock market indices of the different equity markets for the Box's M methodology for the 1973-1987 period. They find empirical evidence that diversification across countries results in greater risk reduction than diversification across industries. Their inter-temporal stability tests indicate that, the longer the time period considered, the better proxies ex post patterns of co-movement can be for the ex ante co-movements of international stock markets. Their seasonality tests show that international stock market co-movements are stable in the September-May period, but relatively unstable in the May-September period.

European countries are also frequently examined for interdependencies between stock exchange markets. Mathur and Subrahmanyam (1990), Arshanpalli and Doukas (1993), and Malliaris and Urrutia (1994) have used the concept of Granger causality, and cointegration and error-correction models to analyze the linkages and dynamic interactions among stock prices.

Mathur and Subrahmanyam (1990) discuss the interdependencies between the US and Nordic stock markets. They used monthly stock price indices for the period between 1974 to 1985. The data was examined by applying the concept of Granger causality. They concluded that the US market affected only one of the four Nordic markets (Denmark). However, a high interdependence was observed between the Nordic markets and they concluded that it was possible to earn extra returns by anticipating stock price changes in one market by observing the changes in others.

Arshanapalli and Doukas (1993) use recent developments in the theory of cointegration to study the linkages and dynamic interactions among stock prices in Germany, UK, France, Japan, and the US, using daily closing data from 1980 to 1990. Cointegration and the error-correction model is applied in this study. For the pre-crash period they find that France, Germany, and UK stock markets are not related to the US stock market. For the post-crash period, however, their results show that the three major European stock markets (i.e. Franc, Germany and UK) are indeed strongly linked (cointegrated) with the US stock market. The US stock market is found to have a substantial impact on the French, German and UK markets. Stock market innovations in any of the three European stock markets have no impact on the US stock market. In addition, they find no evidence of interdependence among stock price indices between US and Japan. Furthermore, the results show that the US and Japan stock markets have drifted far away from each other since the October crash. The pattern of interactions among France, Germany, UK, and Japan suggests that Japanese stock market innovations are unrelated to the performance of the major European stock markets.

Malliaris and Urrutia (1994) uses a vector error correcting (VEC) model to examine long-term and short-run causality for five major European capital markets: the UK, France, Italy, Belgium and Germany. The data consists of daily closing prices of the equity market indexes for the time period 1989 through 1992. The empirical results of the VEC model show statistically significant long-term links and short-term causal relationships. There is a two way long-term relationship between each pair of European equity indexes. These findings show that these markets are not independent but move together. They adjust to each other in the long-run and they lead or lag each other in the short-run. The results imply limitations in the role of portfolio diversification and confirm a high degree of integration among European equity markets.

Recently, considerable attention is given to possible linkages and interdependencies in major Asian countries. Lee et al. (1990), Chan, Gup and Pan (1992), Chowdhury (1994), Rogers (1994), and Kwan (1995), using cointegration tests and vector autoregression analyses, report that international diversification in those countries can be effective.

Lee, Pettit, and Swankoski (1990) provides evidence on the issue of seasonal characteristics of international equity markets through an analysis of stock market returns in Hong Kong, Korea, Singapore, Taiwan, and the US during 1980-1988. The results show that important day-of-the-week effects can be identified in Hong Kong, Korea and Singapore. Moreover, the returns indicate a significant amount of underlying independence between the various equity markets studied, thus providing strong arguments for investor diversification beyond country boundaries.

Chan, Gup and Pan (1992) analyzed stock prices in the US and major Asian countries (Hong Kong, South Korea, Singapore, Taiwan) using daily and weekly data. First they tested pairwise correlation among these markets. The obtained correlation coefficients were low indicating that international diversification among these markets could be effective. Second, to test for the random walk, they applied Perron-Phillips unit root tests. The null hypotheses for unit roots in all markets were not rejected indicating the random walk behaviour of indices. Lastly, they applied co-integration tests and no evidence for con-integration between these markets was found. They concluded that international diversification among the tested markets will be effective.

Chowdhury (1994) analyzes the relationship among the stock markets of Hong Kong, Korea, Singapore, Taiwan, Japan and the US, using daily stock market indices at closing time from 1986 to 1990. A six-variable vector autoregressive (VAR) model is used to investigate the strength and persistence of the effects of shock or innovation in one market on the other markets in the model. The results show that innovations in the US are rapidly transmitted to the stock market in Japan and Hong Kong, whereas neither of these two markets can explain the US market movements. Moreover, the results indicate that a significant link exists between the stock markets of Hong Kong and Singapore and those of Japan and the US. On the other hand, the markets with severe restrictions on cross-country investing, that is, Korea and Taiwan, are not responsive to innovations in foreign markets. Finally, the US stock market influences but is not influenced by the four Asian markets.

Rogers (1994) sheds light on the issue of international capital mobility by examining the effectiveness of entry barriers to foreign investment in several stock markets (the US, Japan, Germany, the UK, Mexico, Chile, Argentina, Taiwan, Korea and Thailand). The daily closing data is analyzed over three different sub-periods: (1) before the 1987 crash, 1986-1987, (2) immediately after the crash (first 95 days), and (3) well after the crash (months 9 to 18). A vector autoregression (VAR) analysis is used for the markets during the three sub-periods. Co-movements between major and emerging market stock prices around the 1987 crash reveal a relationship between foreign entry barriers and stock price transmission. For most countries, individual market return volatility and price spillovers among markets increase immediately after the crash. However, in markets with stiff entry barriers, volatility rises but there are no price spillovers. Price-spillovers into emerging markets are found only from the US to Chile and Thailand, the countries where the weakest entry barriers, but not from Japan or the US to Taiwan or Korea. In addition, all of the major markets exhibit increased volatility and price spillovers. The evidence that several emerging-market countries are poorly integrated financially with the industrialized countries has important macroeconomic welfare implications.

Kwan et al. (1995) apply the Engle and Granger cointegration analysis and Granger causality tests to monthly data of nine major stock market indices (Australia, Hong Kong, Japan, Singapore, South Korea, Taiwan, the UK, the US and West-Germany) from 1982 to 1991 to examine for causal links. The result of their pairwise and higher-order cointegration tests reveal that international stock market indices are not weak-form efficient individually and collectively in the long run. In addition, their 'bivariate' causality results indicate the existence of significant lead-lag relationships between equity markets. The US stock market leads four markets: Australia, Japan, Hong Kong and the UK. However, in regard to the US, the results suggest that none of the other eight markets Granger-cause the US stock market.

Another group of studies have modified existing models and frameworks to analyze the existence of short- or long-term linkages among national stock exchange markets.

Koutoulas and Kryzanowski (1994) have modified the domestic and international arbitrage pricing theories (IAPT and APT models) to encompass the hypotheses that the Canadian and global North American equity markets are completely or partly integrated (segmented). For the period from March 1969 through March 1988 both models indicated that the Canadian equity market is only partly integrated (or equivalently, partly segmented) with the American equity market.

Ammer and Mei (1994) have developed a new framework for measuring financial and real economic linkages between countries, using US and UK data from 1957 to 1989. They employ a variant of the Campbell and Shiller log-linearization method. Both real and financial linkages are found to be greater after the Bretton Woods currency arrangement was abandoned in the early 1970s. A common interest rate news component accounts for only a small part of the return covariance because of the lack of predictability of short-term real interest rates. In a further application of their methodology, they find that both real and financial integration typically contribute to the (consistently positive) correlations between the returns on national stock markets. In most cases, news about future dividend growth in two countries is more highly correlated than contemporaneous output measures. This suggest that there are lags in the international transmission of real economic shocks.

The literature review has shown that there is conflicting evidence for possible international stock market linkages. This report will make another contribution to the discussion of the benefits of international portfolio diversification as a result of the lack of interdependence across national stock markets. In this thesis, the linkages among stock prices in the stock exchanges of Germany, Holland, the UK, and the US are studied, using daily closing data from March 1990 through October 1994. Cointegration tests and the vector error correction model, VEC, are used for the analysis of a possible existence of short- and long-term linkages among the equity markets.

3. Data

The data used to investigate short-run and long-run interdependencies consist of the daily closing prices for the following equity market indexes: London (FTSE 100 Price Index - FTSE100), Frankfurt DAX, Amsterdam EOE, and New York (Dow Jones Industrial Average - DJIA). Daily closing data for all four indices have been collected over the period beginning March 1, 1990 and ending October 5, 1994. The sample consists of 1188 observations. When national stock exchanges were closed due to national holidays, bank holidays or severe weather conditions, the index level was assumed to remain the same as that on the previous trading day.

The Financial Times - Stock Exchange 100 Share (FTSE 100) Index represents 70 percent of the equity capitalization of all United Kingdom equities. The Amsterdam European Options Exchange (EOE) Index consists of 25 shares, representing 88% of the total market while the Deutsche Aktien Index (DAX) in Frankfurt represents 60% of the equity capitalization of all German Equities, consisting of 30 shares. The Dow Jones Industrial Average (DJIA), however, is the average of 30 stocks in the NYSE, and represents only 22-25% of the total market.

4. Methodology

In this study, the methodology I use for common trends in international stock markets is based on the vector error correction model, VEC. The first step in examining trends in international stock markets is to test for stationarity of the time series.

4.1 Stationarity

A time series is stationary when its basic statistical properties remain constant over time. One method of detecting non-stationarity in a time series is to examine the correlogram. If one notices that the autocorrelations in the correlogram do not die down rapidly (say after the 5 or 6 lags), then the time series is not stationary. Another way is to test for the presence of a unit root in the country's stock price series.

Dickey-Fuller Test

The unit root test is proposed by David Dickey (1981) and Wayne-Fuller (1981) for testing for stationarity. The model used here is as follows. Let Y_t, which is growing over time, be described by the following equation:

$$Y_t = A + Bt + PY_{t-1} + e_t \qquad (1)$$

where

Y_t	:market index
A	:drift variable
B	:trend coefficient
t	:time for t=0, ...,1485
P	:coefficient
e_t	:error term

There are two possible explanations for the growing characteristic of Y_t, namely, Y_t has a positive trend (B>0) and would be stationary after detrending. In this case, Y_t could be used in a regression. Another possibility is that Y_t has been growing because it is a non-stationary series with a positive drift (i.e. A>0, B=0, P=1). In this case, one would like to work with delta Y_t.

Dickey and Fuller (1981) generated statistics in order to test for non-stationarity. The test procedure is as follows (Kendall, 1990). Let Y_t be described by the following unrestricted equations:

with-constant, no-trend

(i) $$Y_t - Y_{t-1} = A + (P-1)Y_{t-1} + \Sigma_j L_j dY_{t-j} + e_t \qquad (2)$$

with-constant, with-trend

(ii) $$Y_t - Y_{t-1} = A + Bt + (P-1)Y_{t-1} + \Sigma_j L_j dY_{t-j} + e_t \qquad (3)$$

The null hypothesis for each is

(i) H_0: Y_t is a random walk plus drift, P=1

(ii) H_0: Y_t is a random walk plus drift around a stochastic trend, P=1

and the restricted equation

$$Y_t - Y_{t-1} = A + \sum_j L_j dY_{t-j} + e_t \qquad \text{(B=0 and P=1)} \qquad (4)$$

t-ratio

For each case *i* and the chosen lag order j the following t-test statistic should be calculated:

$$t_i(P, j) = [(P - 1)/SE(P)]$$

where SE(P) refers to the standard error of parameter P.

F-test

The restricted and one of the unrestricted regressions should be runned and the F-ratio should be calculated as follows:

$$F = (N\text{-}k)(ESS_R - ESS_{UR})/\{q(ESS_{UR})\} \qquad (6)$$

where

N :number of observations
k :number of estimated parameters in unrestricted regression
q :number of parameter restrictions
ESS :sum of squared error residuals from restricted model (ESS_R) and unrestricted models (ESS_{UR})

Then, F- distributions calculated by Dickey and Fuller (1981) are used for testing the hypothesis of a non-stationarity (i.e. (A, B, P) = (A, 0, 1)).

4.2 Short- and Long term linkages

The methodology used to examine short- and long term linkages among equity markets, is the vector error correction model, VEC. The VEC model is based on the concept of causality in the Granger sense and on the notion of cointegration.

a) Granger Causality Tests

When analyzing a vector of time series it is useful to ask if one group of series is generated separately from another group. Two assumptions are made:

(i) The future cannot cause the past. Strict causality can only occur with the past causing the future.

(ii) A cause contains unique information about an effect that is not available elsewhere.

Granger causality tests are used to examine causality in time series models. A series X_t causes another series Y_t if it seen that the series X_t has information helping to characterize future Y's that is unique. More specific, X is said to cause Y if a coefficient a_i is not zero in the following equation:

$$Y_t = C_0 + \sum_{i=1}^{m} a_i X_{t-i} + \sum_{j=1}^{m} b_j Y_{t-j} + e_t \qquad (7)$$

Similarly, Y is said to cause X if some coefficient a_i is not zero in equation (8):

$$X_t = \Phi_0 + \sum_{i=1}^{m} \alpha_i Y_{t-i} + \sum_{j=1}^{m} \beta_j X_{t-j} + \mu_t \qquad (8)$$

If X causes Y and also Y causes X, then there is said to be feedback. The test for causality is based on an F-statistic that is computed by running the above regressions in both unconstrained (full model) and constrained (reduced model) forms:

$$F = [\tfrac{(SSE_r - SSE_f)}{m}] / [\tfrac{SSE_f}{T-2m-1}] \qquad (9)$$

where SSE_r and SSE_f are the sum of squares of the residuals of the reduced model and full model, respectively, and m the number of lags and T the number of observations.

b) Cointegration Tests

Although individual series that contain stochastic trends are non-stationary in their levels, if the stochastic trends are common across series there will be stationary linear combinations of the levels. This phenomenon is known as co-integration.

A process X_t is said to be an integrated process, if it is generated by an equation of the form

$$a_p(B)(1-B)^d X_t = b_q(B)\, e_t \qquad (10)$$

where e_t is zero-mean white noise, a(B), b(B) are polynomials in B of orders p, q respectively (a(B) being a stationary operator), and d is an integer. Such a process will be denoted X_t ~ARIMA(p, d, q) (autoregressive integrated moving average of order p, d, q) or $X_t \sim I(d)$. If X_t and Y_t are a pair of I(d) series, then it will be generally true that a linear combination, such as

$$Z_t = X_t - AY_t \qquad (11)$$

will also be I(d). However, it can happen that there exists a constant A such that $Z_t \sim I(d-b)$, $b>0$. When this happens, the pair of variables X_t and Y_t will be said to be co-integrated and denoted $(X_t, Y_t) \sim CI(d, b)$. When d=b=1 and there exists an A such that $Z_t = X_t - AY_t$ is stationary, i.e. $Z_t \sim I(0)$ then it means that both series individually have extremely important long-run components, but that in forming Z_t these long-run components cancel out and vanish. Z_t can now be interpreted as the equilibrium error, that is, the extent to which the economy is out of equilibrium. Engle and Granger suggest to estimate the value of A by running the regression:

$$X_t = \gamma + AY_t + \varepsilon_t \qquad (12)$$

We can then calculate the values of Z_t.

If two time series produce a stationary trend, then there exists an error correction representation, which suggest that one stock price index can be used to forecast the other. In other words, the existence of cointegration between two stock price indices implies that either one or both markets are inefficient.

c) Vector Error Correction Model, VEC

By combining the causality and cointegration test it is possible to develop a model that allows to test for both short-term and long-term relationships between the series X_t and Y_t: the vector error correction model (VEC):

$$Y_t - Y_{t-1} = a_0 + a_1 \hat{Z}_{t-1} + \sum_{i=1}^{m} c_i (X_{t-i} - X_{t-i-1}) + \sum_{j=1}^{m} d_j (Y_{t-j} - Y_{t-j-1}) + \varepsilon_t \qquad (13)$$

where $\hat{Z}_{t-1} = X_{t-1} - AY_{t-1}$ as defined in (4).

The potential long-run and short-run impact of the series X on the series Y are in the VEC model decomposed as follows:

- a long-run component, represented by the cointegration term $a_1\hat{Z}_{t-1}$, also known as the error-correction term. The correction adjustments of Y_t to a disequilibrium error from the previous period Z_{t-1} can spread over several periods of time, with the coefficient a_1 indicating the speed of the correction mechanism.
- a short-run component, given by the summation terms in the right hand side of equation (13). These two terms represent past changes in the variables X and Y and characterize the short-run dynamics. Specifically, the first summation term in equation (13) gives the short-run impact of X on Y.

Similarly, the potential long-run and short-run impact of the series Y on the series X can be expressed in the VEC model as follows:

$$X_t - X_{t-1} = \alpha_0 + \alpha_1 \hat{Z}_{t-1} + \sum_{i=1}^{m} \kappa_i (Y_{t-i} - Y_{t-i-1}) + \sum_{j=1}^{m} \lambda_j (X_{t-j} - X_{t-j-1}) + \mu_t \qquad (14)$$

From equations (6) and (7) follows that:

- the series X_t and Y_t are cointegrated when at least one of the coefficients of a_1 or a_1 is different from zero. In this case, X_t and Y_t exhibit long-run comovements. The significance and size of the error-correction terms a_1 and a_1 essentially captures the single-period response of the dependent variable to departures from equilibrium.

- there is a short-term relationship between the series X_t and Y_t when at least one of the coefficients of c_i or k_i is different from zero.

The error correction model has the standard interpretation: the change in X_t is due to the immediate, short-run effect from the change in Y_t and to last period's error, Z_{t-1}, which represents the long-run adjustment to past disequilibrium. Hence, estimation of the error-correction equations is also expected to provide evidence about the long-run relationship and the nature of the adjustment process among national stock markets. Furthermore, the error-correction analysis is fundamental for testing the cross-border market efficiency hypothesis since it describes the long-run dynamic adjustment process between two stock exchange markets.

5. Empirical Results

In this chapter, the characteristics and the stationarity of the data sets will be discussed, by means of data plots, correlograms and Dickey-Fuller test.

5.1. Stationarity Properties of the Time Series

a) Data plots and correlograms

When we look at the data, visualized in Figure 1-4, no errors or outliers can be detected.

First, the natural logarithmic transformation is executed on the data for the different stock exchanges. When we look at the correlogram of the DAX data, it can be seen that the autocorrelations hardly die out (Figure 5). This is true for all four stock exchanges.(Appendix 1-3).

```
                                 The SAS System
                                 ARIMA Procedure
                             Name of variable = LNX.

          Mean of working series =  7.4338
          Standard deviation     = 0.139927
          Number of observations =     1188

Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
  0   0.019579    1.00000  |                    |********************|
  1   0.019482    0.99501  |                   .|********************|
  2   0.019383    0.98996  |                  . |********************|
  3   0.019286    0.98500  |                  . |********************|
  4   0.019192    0.98021  |                 .  |********************|
  5   0.019089    0.97495  |                 .  |******************* |
  6   0.018993    0.97005  |                 .  |******************* |
  7   0.018897    0.96514  |                .   |******************* |
  8   0.018797    0.96002  |                .   |******************* |
  9   0.018704    0.95528  |                .   |******************* |
 10   0.018611    0.95053  |                .   |******************* |
 11   0.018512    0.94546  |               .    |******************* |
 12   0.018405    0.94000  |               .    |******************* |
                             "." marks two standard errors
```

Figure 5: SAS autocorrelations using the ln(X) DAX data

b) Unit root tests

After running Dickey-Fuller unit roots tests on the natural logarithmic transformed data, by estimating the unrestricted and restricted regression equation, the results obtained are summarized in the tables below (Table 1-4). The tests are conducted against two alternatives, one

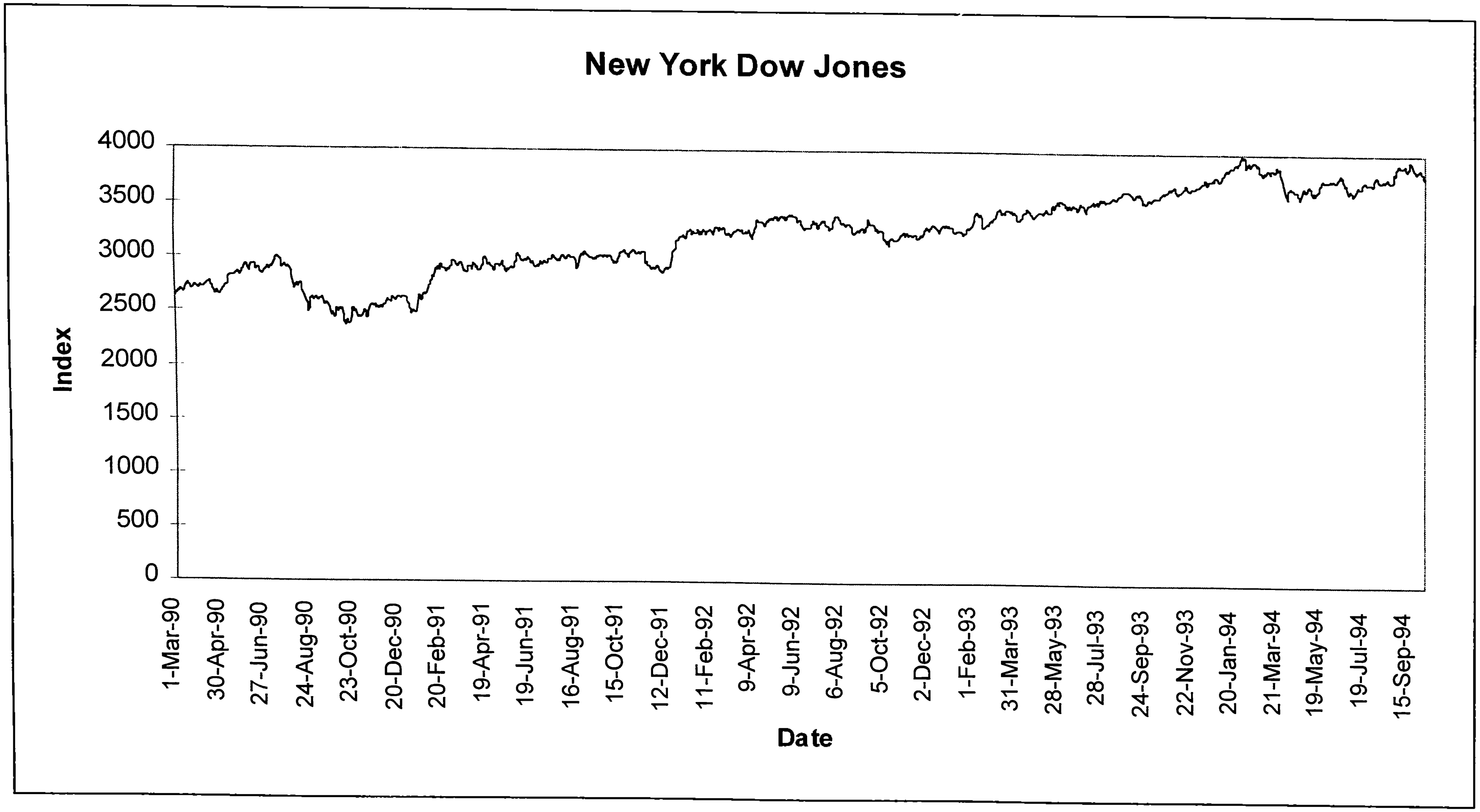

Figure 1: Daily closing prices of New York DJIA, 01/03/90-05/10/94

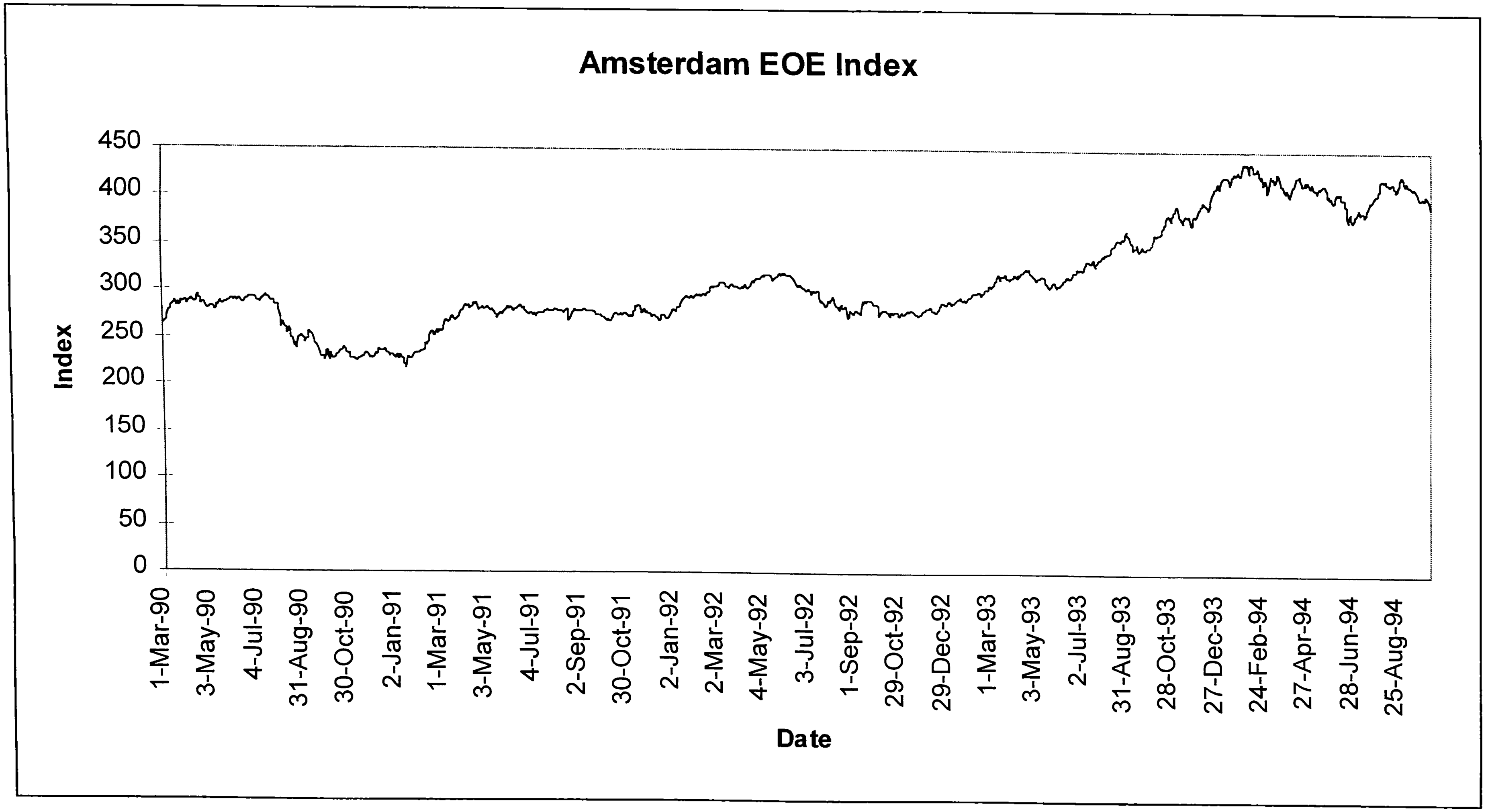

Figure 2: Daily closing prices of Amsterdam EOE, 01/03/90-05/10/94

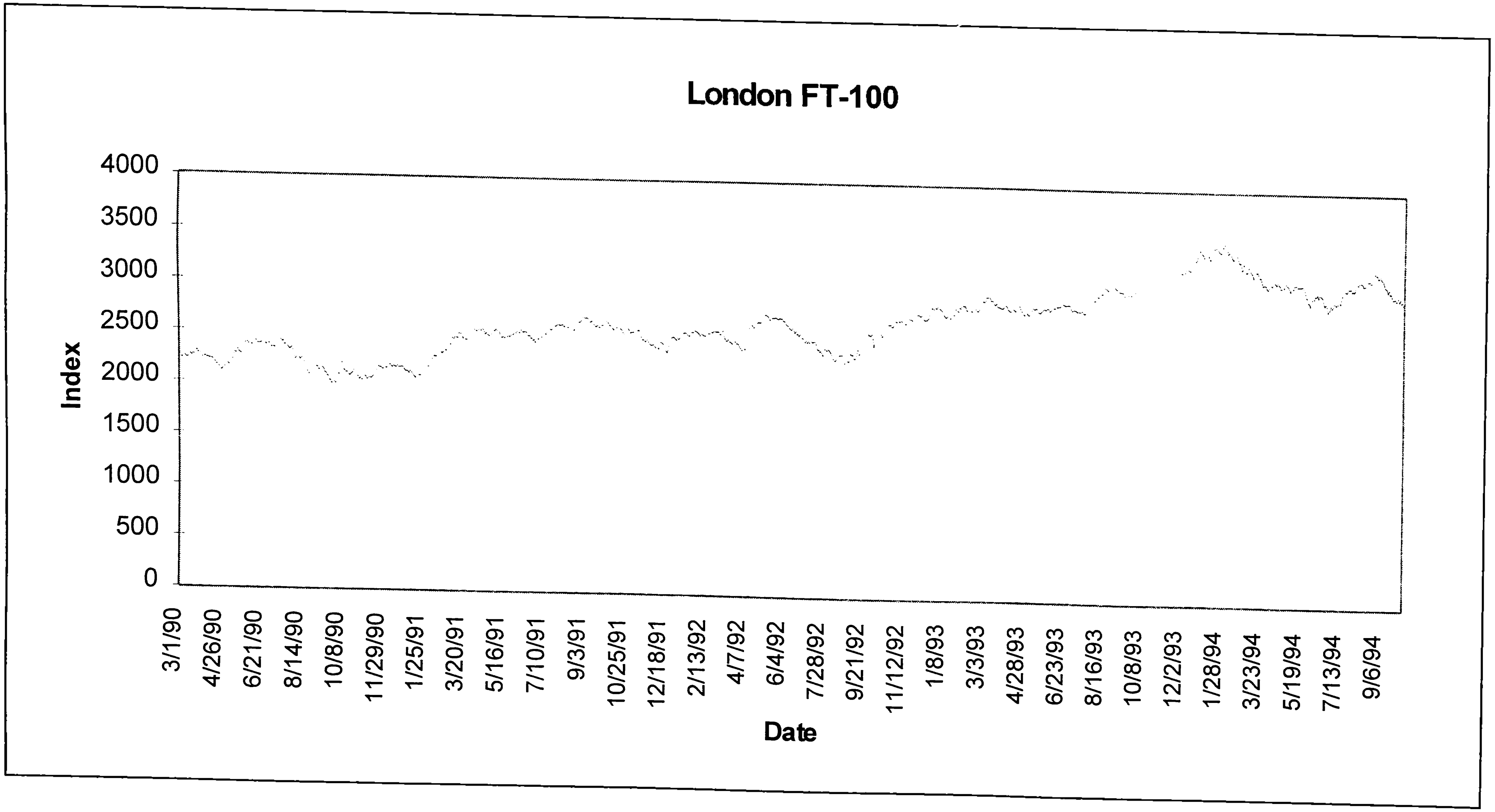

Figure 3: Daily closing prices of London FT, 01/03/90-05/10/94

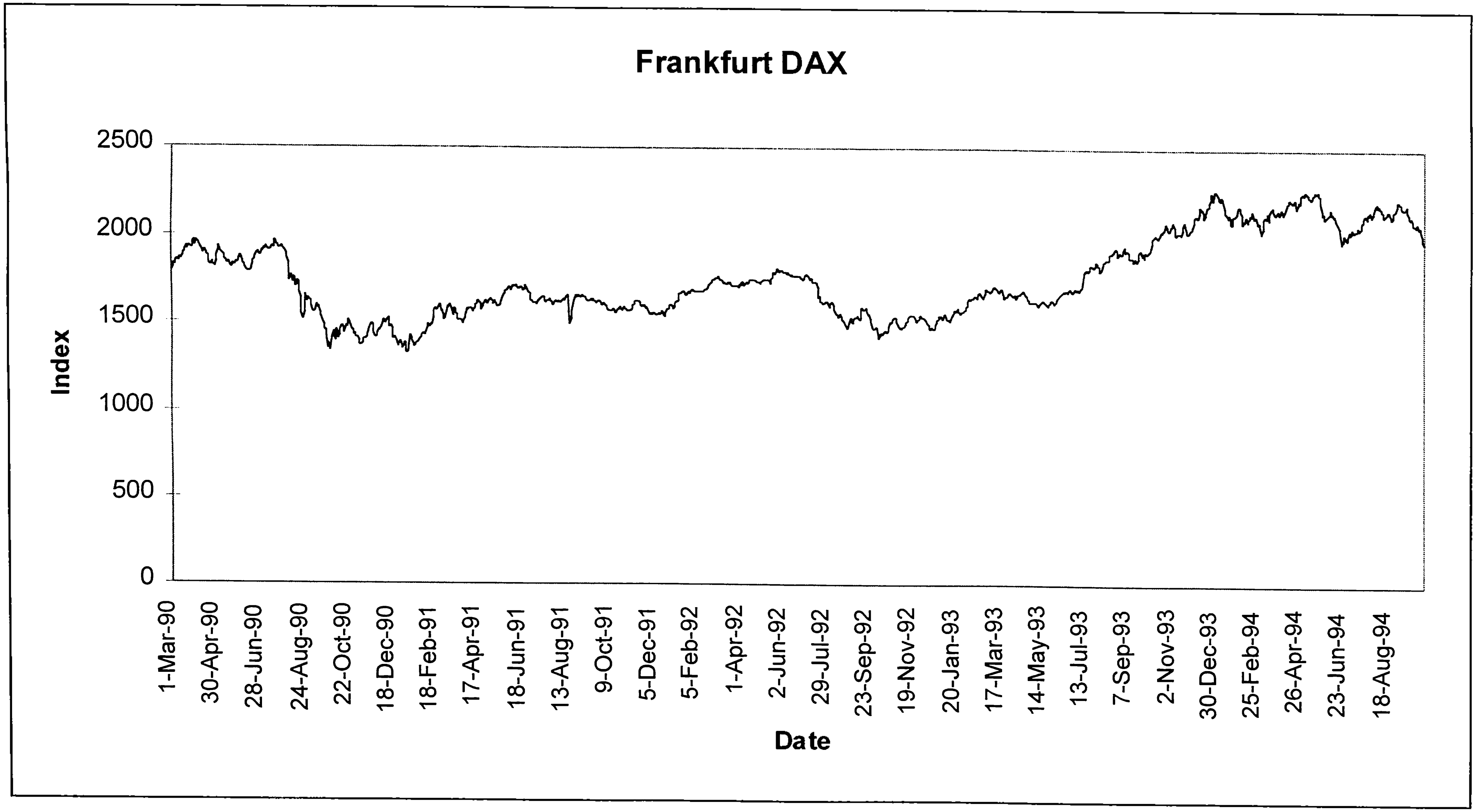

Figure 4: Daily closing prices of Frankfurt DAX, 01/03/90-05/10/94

consistent with fluctuations around a constant mean, the other with stationary fluctuations around a deterministic linear trend:

(i) H_0: Y_t is a random walk plus drift, P=1

(ii) H_0: Y_t is a random walk plus drift around a stochastic trend, P=1

Table 1: Summary of Dickey-Fuller and Phillips-Perron tests on Ln(AEX) data

Ln(AEX)	**Dickey-Fuller Test Statistic**	**Critical values at 10% level**	**Phillips-Perron Test Statistic**	**Critical values at 10% level**
constant, no trend				
t-statistic	-0.79907	-2.57	-0.52941	-2.57
F-test	0.52165	3.78	0.94452	3.78
constant, trend				
t-statistic	-3.0430	-3.13	-1.9164	-3.13
F-test	4.9537	5.34	1.9789	5.34

Table 2: Summary of Dickey-Fuller and Phillips-Perron tests on Ln(DJ) data

Ln(DJ)	**Dickey-Fuller Test Statistic**	**Critical values at 10% level**	**Phillips-Perron Test Statistic**	**Critical values at 10% level**
constant, no trend				
t-statistic	-0.92410	-2.57	-1.2696	-2.57
F-test	1.5215	3.78	1.6960	3.78
constant, trend				
t-statistic	-2.8425	-3.13	-3.1236	-3.13
F-test	4.0408	5.34	5.2195	5.34

Table 3: Summary of Dickey-Fuller and Phillips-Perron tests on Ln(FT) data

Ln(FT)	**Dickey-Fuller Test Statistic**	**Critical values at 10% level**	**Phillips-Perron Test Statistic**	**Critical values at 10% level**
constant, no trend				
t-statistic	-1.2915	-2.57	-1.2899	-2.57
F-test	1.2591	3.78	1.2048	3.78
constant, trend				
t-statistic	-2.4673	-3.13	-2.5977	-3.13
F-test	3.0921	5.34	3.4031	5.34

Table 4: Summary of Dickey-Fuller and Phillips-Perron tests on Ln(DAX) data

Ln(DAX)	**Dickey-Fuller Test Statistic**	**Critical values at 10% level**	**Phillips-Perron Test Statistic**	**Critical values at 10% level**
constant, no trend				
t-statistic	-1.3453	-2.57	-1.3858	-2.57
F-test	0.92810	3.78	0.98240	3.78
constant, trend				
t-statistic	-2.2050	-3.13	-2.2431	-3.13
F-test	2.6885	5.34	2.7607	5.34

We cannot reject the presence of a unit root in the level series, which indicates non-stationarity in all the time series. Now we will proceed to check if the time series are integrated of order one by searching a unit root in the difference series.

Differencing the Logarithmic Transformed Data

The correlogram of $dln(X) = ln(X_t)-ln(X_{t-1})$ for the DAX data is given in Figure 6.

```
                              ARIMA Procedure
                           Name of variable = DLNX.

                   Mean of working series = 0.000268
                   Standard deviation     = 0.011859
                   Number of observations =     1188

                              Autocorrelations

Lag Covariance  Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
  0 0.00014064     1.00000  |                    |********************|
  1 2.89408E-6     0.02058  |                   .|.                   |
  2 -2.2749E-6    -0.01618  |                   .|.                   |
  3 -4.2489E-6    -0.03021  |                   *|.                   |
  4 6.67231E-6     0.04744  |                   .|*                   |
  5 -6.0131E-6    -0.04275  |                   *|.                   |
  6 -2.7093E-6    -0.01926  |                   .|.                   |
  7 3.72859E-6     0.02651  |                   .|*                   |
  8 -5.9435E-6    -0.04226  |                   *|.                   |
  9 -1.0241E-6    -0.00728  |                   .|.                   |
 10 5.26501E-6     0.03744  |                   .|*                   |
 11 3.25242E-6     0.02313  |                   .|.                   |
 12 2.21241E-6     0.01573  |                   .|.                   |
                               "." marks two standard errors
```

Figure 6: SAS autocorrelations using the $dlnX= ln(X_t)- ln(X_{t-1})$ DAX data

In this correlogram can be seen that the autocorrelation dies out quickly and we can consider this data set as stationary.

After running Dickey-Fuller unit roots tests on the differenced natural logarithmic transformed data, by estimating the unrestricted and restricted regression equation, the results obtained are summarized in the table below (Table 5-8).

Table 5: Summary of Dickey-Fuller and Phillips-Perron tests on dLn(AEX) data

dLn(AEX)	Dickey-Fuller Test Statistic	Critical values at 10% level	Phillips-Perron Test Statistic	Critical values at 10% level
constant, no trend				
t-statistic	-4.9316*	-2.57	-33.780*	-2.57
F-test	12.195*	3.78	570.54*	3.78
constant, trend				
t-statistic	-4.9818*	-3.13	-33.773*	-3.13
F-test	12.423*	5.34	570.33*	5.34

Table 6: Summary of Dickey-Fuller and Phillips-Perron tests on dLn(DJ) data

dLn(DJ)	Dickey-Fuller Test Statistic	Critical values at 10% level	Phillips-Perron Test Statistic	Critical values at 10% level
constant, no trend				
t-statistic	-5.4649*	-2.57	-32.693*	-2.57
F-test	14.938*	3.78	534.41*	3.78
constant, trend				
t-statistic	-5.4618*	-3.13	-32.680*	-3.13
F-test	14.919*	5.34	533.99*	5.34

Table 7: Summary of Dickey-Fuller and Phillips-Perron tests on dLn(FT) data

dLn(FT)	Dickey-Fuller Test Statistic	Critical values at 10% level	Phillips-Perron Test Statistic	Critical values at 10% level
constant, no trend				
t-statistic	-6.3043*	-2.57	-33.203*	-2.57
F-test	19.885*	3.78	551.27*	3.78
constant, trend				
t-statistic	-6.3028*	-3.13	-33.191*	-3.13
F-test	19.893*	5.34	550.89*	5.34

Table 8: Summary of Dickey-Fuller and Phillips-Perron tests on dLn(DAX) data

dLn(DAX)	Dickey-Fuller Test Statistic	Critical values at 10% level	Phillips-Perron Test Statistic	Critical values at 10% level
constant, no trend				
t-statistic	-5.1655*	-2.57	-33.395*	-2.57
F-test	13.367*	3.78	557.61*	3.78
constant, trend				
t-statistic	-5.2322*	-3.13	-33.394*	-3.13
F-test	13.728*	5.34	557.58*	5.34

The null hypothesis of a unit root in first differences of the stock price indices is rejected for all four stock price index series. Comparing these values with the critical values, it is apparent that we can reject the hypothesis of a non-stationarity for the differenced ln(X) data (dln(X) data) at the 5 and 10 percent level. Therefore, we can conclude that the differenced natural logarithmic transformations of all market indices are stationary, as seen in the correlogram, indicating that all the national stock index series are individually integrated of order one.

c) Statistical properties

The basic statistical properties for all four stationary time series, the differenced natural logarithmic transformations, are given in table 9. In appendix 4-7, the statistical properties of the different time series are more extensively given.

Table 9: Statistical properties of dln(X) data

	DAX	AEX	FT	DJ
N	1187	1187	1187	1187
Sum Wgts	1187	1187	1187	1187
Mean	0.000268	0.000269	0.000347	0.000391
Sum	0.388445	0.932806	0.505753	0.568692
Std Dev	0.011863	0.008962	0.008515	0.008111
Variance	0.000141	0.00008	0.000073	0.000066
Skewness	-1.0798	-0.60812	0.188037	-0.48118
Kurtosis	16.72381	4.997861	2.289167	6.291457

5.2. Cointegration Tests

Next we examine whether the national stock market index series are cointegrated. The results of the pairwise cointegration tests of stock market indices are presented in table 10-11.

Table 10: Cointegration test, Dickey-Fuller: Constant, no trend (10% critical value = -3.04)

	lnaex	lndj	lnft	lndax
lnaex		-2.2893	-1.7536	-2.7463
lndj	-2.5833		-2.5973	-2.4034
lnft	-2.1856	-2.8910		-2.3049
lndax	-3.1790*	-2.6983	-2.1962	

Table 11: Cointegration test, Phillips-Perron: Constant, no trend (10% critical value = -3.04)

	lnaex	lndj	lnft	lndax
lnaex		-2.4751	-1.8388	-2.8534
lndj	-2.7767		-3.2214*	-2.4313
lnft	-2.1950	-3.2290*		-2.1718
lndax	-3.1473*	-2.4033	-2.1765	

Table 12: Cointegration test, Dickey-Fuller: Constant, trend (10% critical value = -3.50)

	lnaex	lndj	lnft	lndax
lnaex		-2.2841	-1.8085	-4.3802*
lndj	-2.5615		-2.7627	-3.0213
lnft	-2.2826	-3.0279		-2.9154
lndax	-4.4694*	-2.4461	-2.1063	

Table 13: Cointegration test, Phillips-Perron: Constant, trend (10% critical value = -3.50)

	lnaex	lndj	lnft	lndax
lnaex		-2.4835	-1.7976	-4.6999*
lndj	-3.6281		-3.6024*	-3.4560
lnft	-2.5431	-3.0287		-2.5094
lndax	-4.8486*	-2.5409	-2.0887	

Several interesting observations emerge when we look at the results in table 10 and 11. First, the results from the entire sample show that the stock markets of the Netherlands and Germany, and the US and the UK appear to be cointegrated. However, the null hypothesis of no cointegration between the other pairs of stock markets cannot be rejected. At the 5 percent level, the critical value of the DF statistic is 3.37. These results suggest that the link among stock prices in those pairs of stock exchanges has been very weak over the period. The US stock market, however, seems to influence somewhat the other stock markets just as the German market.

5.3. Vector Error Correction

Having established that the stock markets in the Netherlands and Germany are cointegrated, I next examine the interactions among these markets be estimating the error correction equations (13 and 14). The term Z_{t-1} , used in the error correction regressions was obtained from the OLS estimation of the cointegration equations (4). The result of the error correction equations are reported table 14.

Table 14: Error correction results

Dependent	Independent	a1	c1	c2	c3	c4	c5	F-statistics
Amsterdam	New York	0.0098820 (2.137) *	0.34502 (10.44)	-0.02914 (-0.8438)	-0.0090465 (-0.2627)	-0.016242 (-0.4713)	0.027779 (0.8064)	22.56*
Amsterdam	London	0.011936 (2.623) *	0.061702 (1.594)	-0.049239 (-1.273)	-0.053930 (-1.392)	0.055249 (1.422)	0.023224 (0.6007)	1.60
Amsterdam	Frankfurt	-0.0061874 (-1.376)	-0.012375 (-0.4021)	-0.047940 (-1.557)	-0.039921 (-1.293)	0.0059092 (0.1915)	0.070494 (2.3)	1.88
New York	Amsterdam	0.0019028 (0.6048)	-0.029687 (-1.021)	0.021912 (0.7536)	-0.031171 (-1.073)	0.043805 (1.509)	-0.013466 (-0.4845)	1.19
New York	London	0.0070113 (1.438)	-0.023246 (-0.7979)	0.015819 (0.5437)	-0.026887 (-0.9244)	0.025744 (0.8837)	-0.015573 (-0.5480)	0.62
New York	Frankfurt	-0.0009045 (-0.3829)	-0.02804 (-1.301)	-0.013071 (-0.6062)	-0.041089 (-1.908)	0.042424 (1.971) *	0.0048392 (0.2325)	2.00
London	Amsterdam	-0.0025920 (-0.7455)	-0.13412 (-3.630) *	0.014007 (0.377)	0.038064 (1.028)	0.099497 (2.687) *	-0.04077 (-1.098)	4.51*
London	New York	0.0099255 (1.774)	0.26916 (8.153) *	-0.02673 (-0.7878)	-0.0047266 (-0.1398)	0.046485 (1.373)	0.31116 (0.9187)	13.84*
London	Frankfurt	-0.0044224 (-1.655)	-0.17546 (-0.7173)	-0.015492 (-0.6343)	-0.0007177 (-0.029)	0.069911 (2.866)*	0.035315 (1.46)	2.22*
Frankfurt	Amsterdam	0.011687 (2.616) *	0.16706 (3.156) *	0.13692 (0.2576)	0.045934 (0.8639)	0.028769 (0.5426)	-0.062235 (-1.176)	2.47*
Frankfurt	New York	0.0072836 (2.085) *	0.40184 (9.318) *	-0.095089 (-2.132) *	0.0574475 (1.289)	0.031750 (0.7113)	0.052671 (1.180)	19.44*
Frankfurt	London	0.0087218 (2.544) *	0.22609 (5.271) *	-0.070569 (-1.633)	-0.076671 (-1.770)	0.053094 (1.223)	-0.19565 (-0.4506)	7.09*

The t-ratios are given in parenthesis. The asterix indicates significance at the 5 percent level. The joint significance of the indices is determined by the standard F-test.

The t-ratio for the coefficient of the error-correction term, Z_{t-1}, indicates a long-run relationship when the t-value is significant. This result implies that the equilibrium error can be used to predict next period's stock market price changes in either stock exchange. Another interesting aspect of the error correction analysis is that it yields information about the 'short-run' influence from the change in one market on the performance of another market.

The results (table 14) of the application of the VEC model on the different time series indicate a substantial short-term and long-term relationship between the German and British market, as well as between the British and Dutch market. Although the short-run influences from changes in one market on the other market are not as substantial as in the case of the US on the three European markets, they are significant. In the case of these two pairs of national markets, the earlier reported test have not indicated significant cointegration.

In contrast, table 10-13 show that the stock markets of the Netherlands and Germany appear to be cointegrated. However, table 14 reports that Amsterdam has a significant impact on the German stock market in the long-run, but not vice versa. Furthermore, short-run changes in the Dutch stock market seem to have a significant influence on the German market.

The results in table 14 report a significant impact of the US on the three European markets in the short- and long-run for the period examined. In all regressions reported in table 14, the results show that the US market exerts especially a substantial amount of influence in the short-run with F-values of 22.56, 13.84 and 19.44 on Amsterdam, London, and Frankfurt, respectively. However, other tests have reported no significant cointegration between the US and the European markets. In contrast, European 'short- and long-run' stock market changes do not appear to have any significant impact on the US stock market. This result is inconsistent with the view that foreign stock market innovations have exerted substantial influence on the US market in the post-October 1987 period.

6. Conclusion

The theory of causality and the notion of cointegration is used to examine linkages and dynamic interactions among stock price indices in four stock exchanges (Amsterdam, London, New York and Frankfurt) by means of the error-correction model. The data used in this study are daily closing prices of the stock exchanges. The sample consists of 1188 observations and covers the period of March 1990 through October 1994.

Tests of stationarity allow us to conclude that the level series are nonstationary, but the difference series are stationary. Thus, prices are integrated of order one, I(1), and the use of the vector error correction model is appropriate to test for long- and short-run interdependencies between the four stock exchanges. The error-correction analysis produced some interesting results with respect to the stock market interactions among the four stock exchanges.

The US market exerts a significant long-term impact on the European markets, but not vice versa. Moreover, the US stock price index variable has a substantial amount of short-term influence on all other markets. This result is inconsistent with the view that foreign stock market innovations have exerted substantial influence on the US market in the post-October 1987 period.

The three European markets also influence each other in the short- and long-run, with the exception of Amsterdam that not seems to be influenced significantly by the German market. This result implies that these markets are not independent from each other but move together. This can be explained by the fact that the three countries are members of the European Union. The implementation of some institutional agreements of the European Union concerning equity markets, the exchange rate mechanism that is partly coordinated among the countries, and intensive trade and other cooperation between the national governments have removed many barriers and resulted in a high degree of integration. As a result, the markets have been globalized. Previous studies have made a strong case for international portfolio diversification to reduce the risk of a portfolio while enhancing the performance opportunities. However, the condition that national stock markets lack interdependence is rejected for the examined stock exchanges because of significant reported short- and long-term linkages. Therefore, diversification among those national stock markets will not greatly reduce the portfolio risk without sacrificing expected return.

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Appendix I: Correlograms for Amsterdam EOE Index

```
                              The SAS System
                             ARIMA Procedure
                          Name of variable = LNX.

                  Mean of working series =  5.71753
                  Standard deviation     = 0.159459
                  Number of observations =    11880

                             Autocorrelations

Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
  0   0.025427     1.00000 |                    |********************|
  1   0.025359     0.99731 |                   .|********************|
  2   0.025285     0.99441 |                  . |********************|
  3   0.025213     0.99157 |                . . |********************|
  4   0.025142     0.98877 |                 .  |********************|
  5   0.025065     0.98577 |                 .  |********************|
  6   0.024987     0.98269 |                 .  |********************|
  7   0.024910     0.97968 |                .   |********************|
  8   0.024833     0.97664 |                .   |********************|
  9   0.024755     0.97355 |                .   |******************* |
 10   0.024674     0.97038 |               .    |******************* |
 11   0.024591     0.96710 |               .    |******************* |
 12   0.024505     0.96372 |               .    |******************* |
                     "." marks two standard errors

                              The SAS System
                             ARIMA Procedure
                          Name of variable = DLNX.

                  Mean of working series = 0.000269
                  Standard deviation     = 0.008959
                  Number of observations =     1187

                             Autocorrelations

Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
  0 0.00008026     1.00000 |                    |********************|
  1 6.57985E-7     0.00820 |                   .|.                   |
  2 -1.1143E-6    -0.01388 |                   .|.                   |
  3 -2.2183E-6    -0.02764 |                   *|.                   |
  4 4.35817E-6     0.05430 |                   .|*                   |
  5 7.41296E-7     0.00924 |                   .|.                   |
  6 -2.9868E-7    -0.00372 |                   .|.                   |
  7 4.52945E-7     0.00564 |                   .|.                   |
  8 9.29215E-7     0.01158 |                   .|.                   |
  9 4.38984E-6     0.05470 |                   .|*                   |
 10 2.36198E-6     0.02943 |                   .|*                   |
 11 8.80638E-7     0.01097 |                   .|.                   |
 12 9.50978E-7     0.01185 |                   .|.                   |
                     "." marks two standard errors
```

Appendix II: Correlograms for New York Dow Jones

```
                                 The SAS System
                                ARIMA Procedure
                            Name of variable = LNX.

                     Mean of working series = 8.025258
                     Standard deviation     = 0.151372
                     Number of observations =     1188

                                Autocorrelations

Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
  0   0.022914     1.00000 |                    |********************|
  1   0.022822     0.99599 |                   .|********************|
  2   0.022732     0.99206 |                  . |********************|
  3   0.022640     0.98807 |                . . |********************|
  4   0.022551     0.98416 |                 .  |********************|
  5   0.022463     0.98033 |                 .  |********************|
  6   0.022373     0.97641 |                 .  |********************|
  7   0.022288     0.97271 |                .   |*******************  |
  8   0.022210     0.96927 |                .   |*******************  |
  9   0.022134     0.96596 |                .   |*******************  |
 10   0.022055     0.96253 |                .   |*******************  |
 11   0.021975     0.95904 |               .    |*******************  |
 12   0.021894     0.95552 |               .    |*******************  |
                                   "." marks two standard errors


                                 The SAS System
                                ARIMA Procedure
                            Name of variable = DLNX.

                     Mean of working series = 0.000391
                     Standard deviation     = 0.008109
                     Number of observations =     1187

                                Autocorrelations

Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
  0 0.00006575     1.00000 |                    |********************|
  1 1.26179E-6     0.01919 |                   .|.                   |
  2 8.53557E-7     0.01298 |                   .|.                   |
  3 -1.2777E-6    -0.01943 |                   .|.                   |
  4 -1.9704E-6    -0.02997 |                   *|.                   |
  5 2.55598E-7     0.00389 |                   .|.                   |
  6 -3.0276E-6    -0.04605 |                   *|.                   |
  7 -3.9793E-6    -0.06052 |                   *|.                   |
  8 -1.9442E-6    -0.02957 |                   *|.                   |
  9 2.13894E-6     0.03253 |                   .|*                   |
 10  -2.909E-7    -0.00442 |                   .|.                   |
 11 2.59835E-6     0.03952 |                   .|*                   |
 12 2.93585E-6     0.04465 |                   .|*                   |
                                   "." marks two standard errors
```

Appendix III: Correlograms for London FT-100 Index

```
                              The SAS System
                             ARIMA Procedure
                          Name of variable = LNX.

                 Mean of working series = 7.840381
                 Standard deviation     = 0.145049
                 Number of observations =     1188

                             Autocorrelations

Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
  0   0.021039    1.00000  |                    |********************|
  1   0.020952    0.99585  |                   .|********************|
  2   0.020860    0.99149  |                   .|********************|
  3   0.020769    0.98717  |                 . .|********************|
  4   0.020677    0.98279  |                  . |********************|
  5   0.020585    0.97841  |                  . |********************|
  6   0.020490    0.97392  |                  . |*******************  |
  7   0.020398    0.96954  |                 .  |*******************  |
  8   0.020312    0.96543  |                 .  |*******************  |
  9   0.020221    0.96112  |                 .  |*******************  |
 10   0.020132    0.95687  |                 .  |*******************  |
 11   0.020040    0.95251  |                .   |*******************  |
 12   0.019951    0.94826  |                .   |*******************  |
                        "." marks two standard errors

                              The SAS System
                             ARIMA Procedure
                          Name of variable = DLNX.

                 Mean of working series = 0.000347
                 Standard deviation     = 0.008512
                 Number of observations =     1187

                             Autocorrelations

Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
  0 0.00007245    1.00000  |                    |********************|
  1 4.19475E-6    0.05790  |                   .|*                   |
  2 6.48622E-7    0.00895  |                   .|.                   |
  3 1.02556E-6    0.01416  |                   .|.                   |
  4 3.85911E-6    0.05327  |                   .|*                   |
  5 1.25761E-6    0.01736  |                   .|.                   |
  6 -1.6423E-6   -0.02267  |                   .|.                   |
  7 -3.2803E-6   -0.04528  |                   *|.                   |
  8 4.48745E-6    0.06194  |                   .|*                   |
  9 6.03618E-8    0.00083  |                   .|.                   |
 10 2.03821E-6    0.02813  |                   .|*                   |
 11 -2.7813E-8   -0.00038  |                   .|.                   |
 12 1.39094E-6    0.01920  |                   .|.                   |
                        "." marks two standard errors
```

Appendix IV: Correlograms for Frankfurt DAX Index

```
                                                The SAS System
                                               ARIMA Procedure
                                            Name of variable = LNX.

          Mean of working series =  7.4338
          Standard deviation     = 0.139927
          Number of observations =    1188

               Autocorrelations

Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
 0   0.019579    1.00000 |                    |********************|
 1   0.019482    0.99501 |                   .|********************|
 2   0.019383    0.98996 |                  . |********************|
 3   0.019286    0.98500 |                  . |********************|
 4   0.019192    0.98021 |                 .  |********************|
 5   0.019089    0.97495 |                 .  |*******************  |
 6   0.018993    0.97005 |                 .  |*******************  |
 7   0.018897    0.96514 |                .   |*******************  |
 8   0.018797    0.96002 |                .   |*******************  |
 9   0.018704    0.95528 |                .   |*******************  |
10   0.018611    0.95053 |                .   |*******************  |
11   0.018512    0.94546 |                .   |*******************  |
12   0.018405    0.94000 |                .   |*******************  |
                                            "." marks two standard errors
```

```
                                                The SAS System
                                               ARIMA Procedure
                                            Name of variable = DLNX.

          Mean of working series = 0.000268
          Standard deviation     = 0.011859
          Number of observations =    1188

               Autocorrelations

Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
 0 0.00014064    1.00000 |                    |********************|
 1 2.89408E-6    0.02058 |                   .|.                   |
 2 -2.2749E-6   -0.01618 |                   .|.                   |
 3 -4.2489E-6   -0.03021 |                   *|.                   |
 4 6.67231E-6    0.04744 |                   .|*                   |
 5 -6.0131E-6   -0.04275 |                   *|.                   |
 6 -2.7093E-6   -0.01926 |                   .|.                   |
 7 3.72859E-6    0.02651 |                   .|*                   |
 8 -5.9435E-6   -0.04226 |                   *|.                   |
 9 -1.0241E-6   -0.00728 |                   .|.                   |
10 5.26501E-6    0.03744 |                   .|*                   |
11 3.25242E-6    0.02313 |                   .|.                   |
12 2.21241E-6    0.01573 |                   .|.                   |
                                            "." marks two standard errors
```

Appendix V: Statistical Properties of dLn(DAX) data

Variable=DLNX

Moments

N	1187	Sum Wgts	1187
Mean	0.000268	Sum	0.388445
Std Dev	0.011863	Variance	0.000141
Skewness	-1.0798	Kurtosis	16.72381
USS	0.203615	CSS	0.20351
CV	4419.249	Std Mean	0.000312
T:Mean=0	0.860767	Prob>|T|	0.3895
Num ^= 0	1438	Num > 0	742
M(Sign)	23	Prob>|M|	0.2353
Sgn Rank	22311.5	Prob>|S|	0.1567

Quantiles(Def=5)

100% Max	0.072875	99%	0.02791
75% Q3	0.00655	95%	0.016496
50% Med	0.000369	90%	0.013061
25% Q1	-0.00578	10%	-0.01207
0% Min	-0.13204	5%	-0.0169
		1%	-0.02753
Range	0.204912		
Q3-Q1	0.012329		
Mode	0		

Extremes

Lowest	Obs	Highest	Obs
-0.13204(	200)	0.051648(	445)
-0.09871(	659)	0.057712(	201)
-0.05586(	402)	0.05961(	416)
-0.05384(	413)	0.062322(	441)
-0.04525(	437)	0.072875(	513)

Appendix VI: Statistical Properties of dLn(AEX) data

Variable=DLNX

Moments

N	1187	Sum Wgts	1187
Mean	0.000269	Sum	0.392806
Std Dev	0.008962	Variance	0.00008
Skewness	-0.60812	Kurtosis	4.997861
USS	0.117201	CSS	0.117096
CV	3328.654	Std Mean	0.000235
T:Mean=0	1.147516	Prob>|T|	0.2514
Num ^= 0	1455	Num > 0	774
M(Sign)	46.5	Prob>|M|	0.0158
Sgn Rank	40421.5	Prob>|S|	0.0116

Quantiles(Def=5)

100% Max	0.051059	99%	0.021694
75% Q3	0.005391	95%	0.013341
50% Med	0.000583	90%	0.01011
25% Q1	-0.00446	10%	-0.00967
0% Min	-0.06794	5%	-0.01376
		1%	-0.02636
Range	0.118997		
Q3-Q1	0.009853		
Mode	0		

Extremes

Lowest	Obs	Highest	Obs
-0.06794(	202)	0.028566(	429)
-0.05033(	665)	0.030616(	449)
-0.04109(	404)	0.035642(	936)
-0.03627(	951)	0.040124(	419)
-0.03597(	84)	0.051059(	518)

Appendix VII: Statistical Properties of dLn(FT) data

Variable=DLNX

Moments

N	1187	Sum Wgts	1187
Mean	0.000347	Sum	0.505753
Std Dev	0.008515	Variance	0.000073
Skewness	0.188037	Kurtosis	2.289167
USS	0.105663	CSS	0.105488
CV	2451.275	Std Mean	0.000223
T:Mean=0	1.556642	Prob>|T|	0.1198
Num ^= 0	1451	Num > 0	739
M(Sign)	13.5	Prob>|M|	0.4949
Sgn Rank	23523.5	Prob>|S|	0.1407

Quantiles(Def=5)

100% Max	0.054396	99%	0.021365
75% Q3	0.005858	95%	0.012893
50% Med	0.000328	90%	0.010626
25% Q1	-0.00513	10%	-0.00978
0% Min	-0.0414	5%	-0.01284
		1%	-0.02056
Range	0.095795		
Q3-Q1	0.010987		
Mode	0		

Extremes

Lowest	Obs	Highest	Obs
-0.0414(	952)	0.029759(	759)
-0.03207(	201)	0.032908(	941)
-0.0312(	666)	0.034885(	447)
-0.03114(	449)	0.043444(	940)
-0.02859(	404)	0.054396(	831)

Appendix VIII: Statistical Properties of dLn(DJ) data

Variable=DLNX

Moments

N	1187	Sum Wgts	1187
Mean	0.000391	Sum	0.568692
Std Dev	0.008111	Variance	0.000066
Skewness	-0.48118	Kurtosis	6.291457
USS	0.095885	CSS	0.095663
CV	2075.275	Std Mean	0.000213
T:Mean=0	1.838044	Prob>|T|	0.0663
Num ^= 0	1447	Num > 0	768
M(Sign)	44.5	Prob>|M|	0.0207
Sgn Rank	40759.5	Prob>|S|	0.0103

Quantiles(Def=5)

100% Max	0.044665	99%	0.020888
75% Q3	0.004587	95%	0.013338
50% Med	0.000515	90%	0.009396
25% Q1	-0.00394	10%	-0.00863
0% Min	-0.07155	5%	-0.01221
		1%	-0.02016
Range	0.11622		
Q3-Q1	0.008527		
Mode	0		

Extremes

Lowest	Obs	Highest	Obs
-0.07155(	199)	0.029574(	752)
-0.04006(	727)	0.029788(	666)
-0.03377(	403)	0.030602(	418)
-0.03148(	448)	0.033723(	200)
-0.03043(	416)	0.044665(	517)