The Extent and Stability of Long-Run Relationship Between Stock Prices: Evidence From the U.S., the U.K. and Australia

Daniel Buncic and Eduardo Roca

Abstract

We examine whether a significant long-run relationship between the US, UK and Australian stock market prices exists and whether this relationship is temporally stable, based on the use of cointegration methodology as applied to the period of 1984 to 2001. We find a stationary long-run relationship between the UK and US, but not between the Australian and US, and Australian and UK, markets. Our results further reveal that the UK-US relationship was impacted by two structural shocks – the October 1987 stock market crash and the 1993-1994 US bond market crash. This relationship was stable during the period before the October 1987 crash and remained to be so after this period until it was disrupted by the 1993-1994 US bond market crash. During the period starting after 1994 up to 2001, this relationship between the UK and US markets, however, ceased to exist. Thus, for investors with UK and US stocks in their portfolios, there was no need for re-balancing of their portfolio during the periods of 1984 to 1993 but this had to be done after 1994.

JEL Classification: G15; G11; C32

Key words : Equity Market Integration, Cointegration, Long-Term Linkage, Stock Price Linkage, Granger Causality.

1. Introduction

In this study, we examine whether a long-run relationship exists between stock market prices. If such a relationship exists, we also determine whether this is temporally stable. These two issues have important implications for long-term investors. The degree of relationship between prices of different stock markets determines the degree of international diversification benefits that investors can reap. The stability of the extent of this relationship over time determines the stability of these diversification benefits and also the necessity of re-balancing portfolios.

There is already a voluminous literature dealing with the first issue. However, the results from these studies are at best mixed depending on the markets or data, time period, methodology and theoretical framework used. Thus, no conclusive statement can be made yet as to whether stock market prices are significantly related or not in the long-run. There is also no clear conclusion yet from the literature with respect to the stability of equity market relationships. In most of the existing literature, structural breaks in the data set are not explicitly tested for, rather prior knowledge of major events such as the October 1987 stock market crash, the Asian financial crisis in 1997, Russian financial crisis 1998, etc., are used to partition the data into sub-samples. However, it is not clear whether such strategies aid in determining structural changes that may have occurred, as it is only possible to account for incidences that are already known, while a general deficiency in studies exists attempting to determine a structural change/break that is unknown *a priori*. This paper therefore provides a robust extension to the literature on these issues.

We focus our examination on the relationship between the US, UK and Australian markets. These are markets which are developed and perceived to be relatively stable and therefore are good candidates to be included in the portfolio of long-term investors. We examine the relationship between the prices of these stock markets with a more comprehensive application of the multi-equation Johansen (1988, 1991), Johansen and Juselius (1990) Maximum Likelihood (ML) procedure for testing long-run cointegrating relationships.

In contrast to previous studies, we do not confine our study to testing the existence of a cointegration vector; we thoroughly analyse the size, significance and temporal stability of the cointegrating parameters and therefore provide a more robust extension to the existing literature. Linear identifying restrictions on the cointegrating space are imposed to determine the statistical significance of all markets in the cointegrating relationship, as well as tests on the full market integration hypothesis and weak exogeneity are conducted. Furthermore, the stability of the cointegrating relationship is examined by estimating the conditional model recursively and obtaining time plots of the non-zero eigenvalues as well as the estimates of the speed of adjustment and cointegrating coefficients in order to identify possible instabilities and structural breaks in the relationship.

The remainder of the analysis is structured as follows. A background to the data set employed in the study is outlined in Section 2. Section 3 gives a brief overview of the methodology, while the empirical results of the research paper are presented in Section 4. Section 5 contains conclusions that are drawn.

2. Data Set

The time series data considered in the study consist of end-of-the-day closing prices in local currency units for the Dow Jones Industrial Average 30, the Financial Times Stock Exchange 100 Share Index and the All Ordinaries Index (XPI) obtained from the Bridge DFS database. The period observed spans from the 3rd of January 1984 to the 16th of February 2001, yielding 4469 observations. Throughout the study, the stock price of each series is defined as the natural logarithm of the stock prices. For notational simplicity, the "Dow Jones" will represent the Dow Jones Industrial Average 30, "the FTSE100" will represent the Financial Times Stock Exchange 100 Share Index and the "All Ordinaries" will represent the All Ordinaries Index (XPI). Missing observations in the sample due to the day(s) when the stock market is closed are filled using the previous day's closing prices, as suggested by Hirayama and Tsutsui (1998).

A few notes on the choice of data utilised in the research are called for, as it is palpable that the use of high frequency daily data attracts some potential problems in the modelling of stock price linkages. Firstly, the markets of the All Ordinaries, the Dow Jones and the FTSE100 operate in different time zones. While there exists no trading overlap between the All Ordinaries and the Dow Jones and the FTSE100 at any given trading day, a two-and-a-half hour overlap of trading exists between the FTSE100 and the Dow Jones on any given trading day (see Bracker *et al.*, 1999). Hypothetically, this would imply that information transfer between the FTSE100 and the Dow Jones occurs on the same trading day, also incorporating the information generated on the All Ordinaries on the same day, while information generated on the FTSE100 and Dow Jones would be reflected on the next day of trading on the All Ordinaries. In the empirical literature, however, this conceptual predicament does not seem to have been addressed when daily frequencies and markets in different time zones are examined in a cointegration analysis framework (see, for example, Rogers (1994), Hassan and Naka (1996), Masih and Masih (1999) and Gerrits and Yüce (1999)). Although Malliaris and Urrutia (1992) did adjust for the time zones when testing for Granger causality, others do not seem to have followed (see, for instance, Elyasiani *et al.* (1998), Masih and Masih (1999), and Gerrits and Yüce (1999)). It appears rather that the different time zones do not impact upon the results obtained from the long-run cointegrating analysis[1].

Lastly, three additional factors should be considered: (*i*) the different nature of the index calculation of the series, (*ii*) the exchange rate, and (*iii*) multi-country listings of company stocks. With respect to the index calculation, Roll (1992) noted that problems may be encountered as stock index behaviour could stem simply from the differing procedures of index construction, the number of stocks included, as well as the industrial concentration. For example, the Dow Jones consists of only 30 stocks and is calculated as a simple average, while the All Ordinaries and the FTSE100 comprise a much larger number of stocks and are computed as market capitalisation

[1] To avoid any uncertainties with regards to the cointegration results, an analysis based upon weekly data and one that adjusts for the time zone differences also performed. The results are highly consistent with the findings from daily data and are available upon request.

weighted indices. Even though these differences are apparent, the choice of these three indices was made, as they seem to represent the equity markets of Australia, the U.S. and the U.K. most adequately, and they are the most widely publicly available indices to which reference is most frequently made. The importance of the Dow Jones, in particular, with respect to the Australian financial media, is well captured in Valentine's words: "The Dow Jones has been chosen to represent the U.S. share prices, although it is an industrial index, because the Australian financial media concentrate on it as a summary of recent developments in the U.S. market. The Dow Jones index is the headline overseas share index in Australia" (2000, p. 185). It would thus seem undesirable to use a representative index for the U.S. stock market that does not comprise those characteristics of the Dow Jones pointed out by Valentine.

Pertaining to the exchange rate issue, Roll (1992) further pointed out that if local-currency denominated stock index series are used, part of the stock index's volatility may be induced by monetary phenomena such as changes in inflation rates. He further emphasised though, that the exchange rate's influence on the series still remains, even if stock indices are converted to a common currency. It appears that in either instance the influence of the exchange rate on the stock index series still persists, thus rendering the common practice of converting stock indices to a single, usually U.S. Dollar denominated, currency conceptually impotent. A number of empirical research papers have, in light of the previous argument, found that their results do not seem to be influenced by different specifications about the exchange rate (see Dwyer and Hafer (1988), Arshanapalli and Doukas (1993), Longin and Solnik (1995), Atteberry and Swanson (1997), Kanas (1998), and Chen *et al.* (2000), among others).

In relation to the third point, another major factor that may contribute to the co-movement of stock prices is the multiple listing of stocks of international corporations on different stock exchanges around the world, as was pointed out by Gjerde and Settem (1995) and Roca (2000)[1]. Although the stock market indices employed here are not explicitly adjusted for the cross listings of international corporations, only a small number of four stocks are cross-listed. These are British-American Tobacco, Rio Tinto and Cable & Wireless listed on both the All Ordinaries and the FTSE100, and Coca-Cola, which is cross-listed on the Dow Jones and the All Ordinaries. Since the number of cross listings is small, this issue is unlikely to raise any bias in the analysis.

3. Methodology

It is necessary to perform unit root tests, as the ML procedure requires that the individual series be integrated of an order less than two, (*I*(2)). As it is commonly accepted that stock prices follow a random walk and the primary objective of the unit root tests are to ensure that the series are not *I*(2), two very general tests, the Augmented Dickey-Fuller (ADF) test, proposed by Dickey and Fuller (1981) and Said and Dickey (1984) and the Phillips and Perron (1988) (PP) test, based on the work by Phillips (1987a, 1987b) are utilised.

The Johansen (1988, 1991) and Johansen and Juselius (1990) ML procedure entails estimating a Vector Error Correction Model (VECM) of a *k*-dimensional VAR process of lag order *p*, taking the form:

$$\Delta x_t = \Pi x_{t-1} + \sum_{i=1}^{p} \Gamma_i \Delta x_{t-i} + \Phi D + \varepsilon_t , \quad (1)$$

[1] At this stage it appears crucial to note that, while cross-listed stocks can be observed and acknowledged to some degree, it seems virtually impossible to adjust for, or even keep track of cross ownership between international corporations listed on different exchanges. Cross ownership between corporations implies that a firm's earnings will be (to some extent at least) subject to dividend payments (or some other form of return on investment) of those firms in which it holds share ownership. For the purpose of this analysis, it would imply that the earnings of one firm would impact the earnings potential of another firm on another stock exchange and thereby also be reflected in the price of its equity. A prime example is the 25% share holding of British Airways in Qantas. Although no cross listings exist between those two firms on either the FTSE100 or the All Ordinaries, the share price of British Airways would partially be influenced by earnings from Qantas' dividend payments, and therefore also reflect such an influence upon the FTSE100. As this issue does not seem to have been addressed in the existing literature, there is no indication of the size of any possible effects, and is thus not further considered in the analysis. It seems also conceptually appealing that the existence of cross ownership may be one of the determining factors leading to equity market integration in the first place.

where Dx_t is a differenced vector of variables, *D* is a vector of deterministic constants with *F* being its coefficient, G_i is a matrix of coefficients on Dx_{t-i} representing the short run dynamics, *P* is a matrix whose rank (*r*) denotes the number of independently linear combinations that render non-stationary vector x_t stationary and e_t is a vector of *niid* disturbance terms. *P* can be further decomposed into two matrices, *α* and *b*, each having dimensions of *k* × *r*, so that $P = \alpha b'$. The matrix of loadings *α* measures the average speed of convergence to the long-run equilibrium $b'x_t$ and *b* is a matrix of coefficients that renders $b'x_t$ stationary, thereby ensuring that x_t converges to its long-run steady state solution. The number of stationary long-run solutions that exist in *b* is equal to *r*, while $k - r$ represents those components of *b* that do not become stationary by $b'x_t$, thereby continue to contain a unit root and are referred to as the common stochastic trends.

The VECM in Equation (1) can be analysed by using reduced rank regression and the solutions can be found by solving the eigenvalue problem, as shown by Anderson (1951). The relative size of the eigenvalues, also interpreted as the squared canonical correlations, gives an indication about how strongly the linear combination $b'x_t$ is correlated with the stationary part of the process, Dx_t. While the relative size of the eigenvalues gives an indication of how strong the cointegrating relationship is, the number of the non-zero eigenvalues represents the number of cointegrating vectors, rank of *P*, and thus the number of stationary long-run relationships that exist in the system of individually non-stationary series. The number of non-zero eigenvalues is estimated within a Trace test framework[1].

Johansen and Juselius (1990, 1992) and Johansen (1991) provided a coherent framework for testing hypothesis of linear restrictions on the space spanned by the matrices *α* and *b*. Should any of the speed of adjustment coefficients *α* not be significantly different from zero, a series is said to be weakly exogenous, and is therefore not determined within the system of equations. It is further possible to conduct inferences conditional on weakly exogenous series without any loss of relevant sample information (see Engle *et al.* (1983) for a further discussion). Similarly, should any of the *b* coefficients not be significantly different from zero, then that particular series does not enter the long-run relationship significantly and thus, does not impact the system of equations. These restrictions are tested by using a general Likelihood Ratio (LR) test statistic.

The causal relationship between the three equity markets will be investigated using the notion of Granger (1969) causality. A variable *x* is said to Granger cause *y* if past values of *x* can be used to predict *y* more accurately, but past values of *y* cannot be used to predict *x* (Granger, 1969). Additionally, Granger (1986, 1988) showed that, when series are cointegrated, Granger non-causality can be ruled out and causality in the Granger sense must run in either a uni- or bi-directional manner. Causality through the Error Correcting Term (ECT) in a cointegrated system will thus also be accounted for, as it captures the size of the forces that push any disequilibria back into line with the long-run steady state solution of the system (see Masih and Masih, 1999).

4. Empirical Findings

The results of the formal ADF and PP unit root tests are presented in Table 1. Both unit root tests' results indicate that the null hypothesis of all three series containing a unit root in level

[1] In general, Johansen and Juselius (1990) propose two test statistics to determine the (*r*)*P*, i.e. number of non-zero eigenvalues, (i) the Trace test, and (ii) the Maximum Eigenvalue test. Cheung and Lai (1993), however, found that the Trace test appears to be more robust an estimator with regards to data suffering from excess kurtosis, such as financial data. Consequently, the analysis will focus on the results obtained from the Trace statistic only, which is derived as: $\lambda_{trace}(r) = -N\sum_{i=r+1}^{k}\ln(1-\hat{\lambda}_i)$ with test hypotheses of □□: number of distinct cointegrating vectors $\leq r$ and □□: number of distinct cointegrating vectors $\geq r$ where $\hat{\lambda}_i$ are the largest squared canonical correlations, *N* is the sample size and *k* is the number of variables.

form cannot be rejected, while tests on the first differenced series reject the null of a unit root. This confirms the preliminary findings that all three series become stationary after being differenced once and are thus *I*(1). It is therefore possible to implement the ML procedure to test for a long-run cointegrating relationship between the FTSE100, the Dow Jones and the All Ordinaries.

Table 1

Unit root test results

(1)	(2)		(3)	
Market	ADF Test		PP Test	
	Level	Difference	Level	Difference
FTSE100	-3.3056	-8.7274*	-3.4539	-62.192*
Dow Jones	-2.4485	-8.8733*	-2.9591	-65.794*
All Ordinaries	-3.1464	-8.1007*	-2.4342	-60.991*

* Significant at the 5% level [critical value = -3.43 obtained from Fuller (1976, p. 373) and Dickey and Fuller (1981, p. 1063)]. The null hypothesis of a unit root in the most unrestricted model is rejected. Note that the lag length in the unit root tests was set equal to the highest significant lag order from either the Auto-correlation Function or the Partial Auto-correlation Function. The Newey and West (1987) method was used to correct for the effects of possible serial correlation in the PP test.

As Johansen (1991) pointed out that the asymptotic distribution of the rank test statistics depends on the choice of deterministic components included in the VECM, the choice of the deterministic components and the rank of the *P* are estimated consistently following the Pantula (1989) principle, as advocated by Johansen (1992b, 1994). Johansen (1995) noted further that the procedure to estimate the appropriate lag length should commence at a fairly large number of lags, which then ought to be reduced to subsequent shorter ones until it is not possible to reduce the number of lags further without loss of relevant sample information[1].

The test results of the ML procedure summarised in Table 2 indicate that the null hypothesis of no cointegrating relationship is rejected as the computed l_{Trace} test statistic of 47.83 exceeds its critical value of 35.65 at the 10% level of significance. Thus, at least one cointegrating vector exists. The ensuing test on the alternative hypothesis of a second cointegrating relationship cannot, however, be maintained. It can be concluded, therefore, that one stationary equilibrium relationship exists.

Table 2

Test Results of the Johansen-Juselius ML procedure

(1)	(2)	(3)	(4)	(5)
Eigenvalue	l_{Trace} Test Statistic	H_0: *r*	$k-r$	90% Critical Value†
0.0079	47.83	*r* = 0	3	26.70
0.0028	12.63*	*r* < 0	2	13.31
0.0000	0.00	*r* < 2	1	2.71

* The null hypothesis cannot be rejected at the 10% level of significance.

† Obtained from Johansen and Juselius (1990). Note also that the number of significant lags used in the estimation is 27 daily lags, and the only deterministic component is an intercept term in the level variables. The stochastic properties of the model are as follows:

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[1] The appropriate lag length is determined within a VAR framework employing a LR test, specified in the follow manner: $LR = (N-c)(ln|W_R|) - (ln|W_{UR}|)$, where p is the number of lags, u – the lag restrictions imposed, N – the number of observations and c is the number of parameters estimated in each equation of the unrestricted system, $\ln|W_R|$ and $\ln|W_{UR}|$ are the natural logarithms of the determinants of the variance/covariance matrix of the residuals in the restricted (pu lags) and unrestricted (p lags) model (Sims, 1980). The LR test is asymptotically X^2 distributed, with degrees of freedom equal to the number of restrictions imposed.

p-values for Serial Correlation tests, with the null hypothesis of no correlation;

Ljung and Box (1978) (LB)-test: *p*-value = 1.00, Lagrange-Multiplier (LM)-test (Godfrey 1988) for first and fourth order serial correlation: *p*-value for LM(1) = 0.66; LM(4) = 0.84.

The Multivariate Normality Shenton and Bowman (1977) test: *p*-values = 0.00. rejects the null of normality, which seems to be largely due to excess kurtosis (8.11, 32.03, 88.17) rather then skewness (-0.47, -1.55, -3.67) respectively for the FTSE100, the All Ordinaries and the Dow Jones. Nonetheless, Johansen (1995, p. 29) pointed out that the "asymptotic properties of the methods only depend on the *iid* assumption of the errors. Thus the normality assumption is not so serious for the conclusion" so that the stochastic properties of the model seem acceptable.

The estimates of the α and b coefficients of the P matrix are displayed in Table 3. It is noticeable from this table that the estimate of the b coefficient on the All Ordinaries is quite low, which may be an indication that the long-run relationship spanned by cointegrating vector b is only significant for the FTSE100 and the Dow Jones series. It is further noticeable, that only the α coefficient of the FTSE100 is significant, while the All Ordinaries and the Dow Jones appear to be weakly exogenous. However, to ascertain the preliminary findings about the size of the coefficient estimates, formal restrictions on the cointegrating space will be imposed, as outlined by Johansen and Juselius (1990). Restrictions of particular interest are: (*i*) do all markets enter the cointegrating relationship significantly?, (*ii*) are the markets perfectly integrated?, and (*iii*) which markets are weakly exogenous[1] to the system? Table 4 displays the restrictions imposed upon the b and α coefficients.

Table 3

Estimates of the α and b coefficients[†]

(1)	(2)	(3)	(4)
Market	b	α	*t*-value
FTSE100	1.000	-0.016	-5.041*
Dow Jones	-0.133	0.004	1.397
All Ordinaries	-0.690	0.000	0.036

* Significant at the 10% level.

[†] The coefficients are normalised on the FTSE100. The rational behind normalising on the FTSE100 is that, since the *t*-statistics for both the Dow Jones and the All Ordinaries are below conventional significance levels so that their coefficients are effectively equal to zero, and thus exogenous, the FTSE100 is the only endogenous series (i.e. left hand variable) that remains in the VECM.

Table 4

Restrictions imposed on the cointegrating space

(1)	(2)	(3)
H_O (Null Hypothesis)	*p*-value	Conclusion
$b_{FTSE100} = 0$	0.00*	Reject H_O
$b_{All\ Ordinaries} = 0$	0.12	Do not Reject H_O
$b_{Dow\ Jones} = 0$	0.00*	Reject H_O
$b_{FTSE100} = b_{Dow\ Jones}$	0.00*	Reject H_O
$\alpha_{All\ Ordinaries} = \alpha_{Dow\ Jones} = 0$	0.50	Do not Reject H_O

* The null hypothesis is rejected at the 10% level of significance.

Initially, zero restrictions on the b coefficients of the FTSE100, the All Ordinaries and the Dow Jones are imposed. These restrictions, however, are rejected for the FTSE100 and the Dow

[1] Weak exogeneity implies that a series is not determined within the equilibrium relationship of the VECM. Engle *et al.* (1983) demonstrated that it is possible to conduct statistical inference conditional on weakly exogenous series, without any loss of relevant sample information. Additionally Johansen (1992a) noted that conditioning on weakly exogenous variables can be very advantageous as a means of improving the stochastic properties of the estimated model. By conditioning on weakly exogenous variables, the remainder of the estimated model is more likely to be better behaved statistically.

Jones series, indicating that a valid cointegrating relationship between the FTSE100 and the Dow Jones exists, while the All Ordinaries does not seem to enter this relationship. Nevertheless, the restriction of the Dow Jones and the FTSE100 being of equal size is rejected, so that it can be concluded that the FTSE100 and the Dow Jones are not perfectly integrated markets. The joint zero restrictions on α for the All Ordinaries and the Dow Jones cannot be rejected. This confirms the earlier finding that the Dow Jones and the All Ordinaries are weakly exogenous.

In summary, the findings of the restrictions on the b coefficients suggest that firstly, the All Ordinaries does not enter the cointegrating relationship; and secondly, the magnitudes of the b coefficients of the FTSE100 and the Dow Jones are not equal. The conclusion that can be drawn is that, although the FTSE100 and Dow Jones are cointegrated, the hypothesis of perfect market integration is clearly rejected. A one-unit change in the Dow Jones variable does not induce a respective one-unit change in the FTSE100 over the long-run cointegrating relationship. Moreover, the Dow Jones is found to be weakly exogenous to the stationary long-run relationship that it forms with the FTSE100, and is therefore not determined within the relationship[1]. The coefficient estimates of the restricted model are presented below in Table 5. As the α coefficients on the long-run relationship have been shown to be equal to zero in the ECM for both the Dow Jones and the All Ordinaries, the identifying restrictions reduce the three equations VECM to a single equation, explaining only the behaviour of the FTSE100. Additionally, it was shown that the b coefficient of the All Ordinaries is effectively zero, so that only the FTSE100 and the Dow Jones comprise the stationary steady-state solution in the system.

Table 5

Coefficient estimates of the Restricted Model

(1)	(2)	(3)	(4)
Market	b	α	t-value
FTSE100	1.000	-0.015	-5.207*
Dow Jones	0.000	0.000	0.000
All Ordinaries	-0.763	0.000	0.000

* Significant at the 10% level.

The structural stability of the estimated cointegrating relationship can be analysed by focusing particularly on the time paths of the eigenvalues, and the α and b coefficients. Figures 1-3 show the time paths of the non-zero eigenvalues, the α coefficient of the FTSE100 and the b coefficient of the Dow Jones of the recursively estimated partial model, with 95% upper and lower confidence bounds.

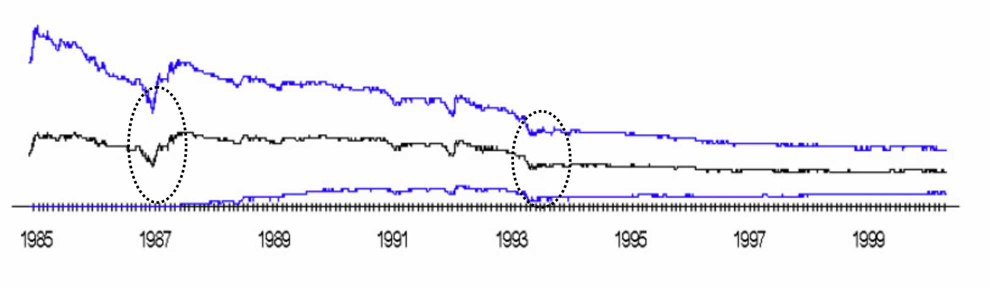

Fig. 1. Time Plot of the Non-zero Eigenvalues

[1] Hansen and Juselius (1995) pointed out that the roots of the companion matrix under the restricted model should be calculated to ascertain that the restricted model has not become explosive due to the restrictions imposed, that is, none of the roots are outside the unit root circle, which would imply an $I(2)$ process. The companion matrix of the restricted system suggests that the model converges to the long-run, as two unit roots exist, with the remaining roots well inside the unit circle.

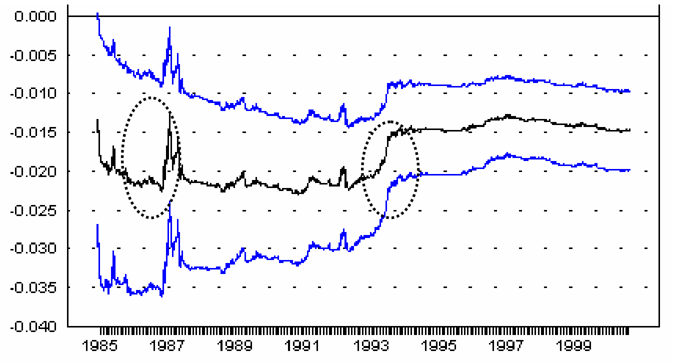

Fig. 2. Time Plot of the *α* coefficient of the FTSE100

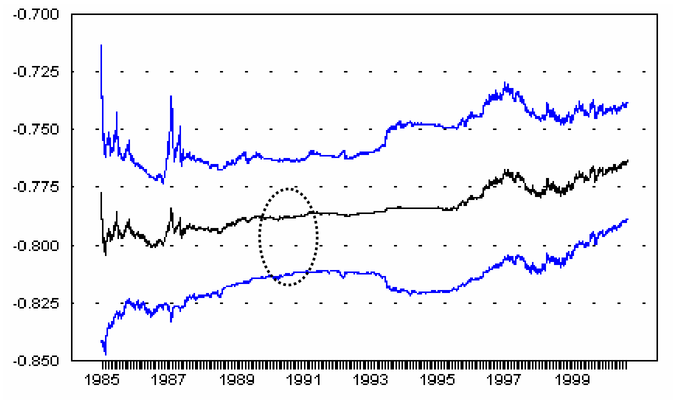

Fig. 3. Time Plot of the *b* coefficient of the Dow Jones

A few interesting observations can be made from the time plots. Firstly, all three of the plots seem to mark the significance of the October 1987 stock market crash on the equilibrium relationship between the FTSE100 and the Dow Jones, indicated by the "spikes" in the plots. Nevertheless, the influence of the stock market crash appears to have been only of a temporary nature, that is, the shock that occurred only influenced the relationship for a short momentum, as the relative size of the non-zero eigenvalues and the *α* and *b* coefficients moved back into line with the coefficient values maintained prior to the October 1987 crash. It is also evident that a second, more permanent structural change between the end of 1993 and the beginning of 1994, visible from the sharp shifts in the eigenvalues and the *α* coefficient in Figures 2 and 3 respectively, took place. This period corresponds to the US bond market crash (see, Thorbecke, 1997)

Recall that the size of the eigenvalues measures the "strength" of the cointegrating relationship, so that a downward shift in the eigenvalues can be associated with a weakening of the stationary relationship formed between the FTSE100 and the Dow Jones. Furthermore, recall that the *α* coefficients represent the speed of adjustment to the long-run relation and, due to $P = ab'$, form part of the rank of *P*, denoting the linearly independent stationary combinations, i.e., the number of cointegrating relations, in the system. Thus, if *α* becomes zero, the single rank of the *P* matrix will effectively become zero as well and the significance of the long-run relationship in the ECM for the FTSE100 will decrease to zero, so that no stationary solution to the system exists and thereby the cointegrating relationship ceases.

Although the plots of the eigenvalues as well as the *α* and *b* coefficients suggest that changes have occurred, some of a seemingly temporary and some of an apparently more permanent nature, the plots do not allow for testing these changes explicitly. It would be beneficial, therefore, to partition the data into sub-samples according to the structural changes anticipated and to re-estimate the cointegrating relationship. The anticipated sub-periods are as follows: period one spans from the 3rd of January 1984 to the 1st of October 1987, period two is from the 1st of December 1987 to 16th of August 1993 and period three spans from the 16th of March 1994 to the 16th of February 2001[1]. The exact testing sequence as conducted in the full sample period was maintained; however, in order to save space, only the results of the ML procedure, the coefficient estimates, restrictions imposed and the coefficients of the restricted model are reported. Table 6 summarises the cointegration test results of the sub-samples.

Table 6

Test Results of the Johansen-Juselius ML procedure for the sub-periods

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Eigenvalue			H_O: *r*	$k-r$	l_{Trace} Test Statistic			90% Critical Value†	
Period 1	Period 2	Period 3			Period 1††	Period 2^	Period 3^	Period 1	Periods 2&3
0.0154	0.0146	0.0055	$r=0$	3	27.96	33.22	19.94*	26.70	31.88
0.0096	0.0067	0.0044	$r\leq 1$	2	12.86*	11.46*	10.23	13.31	17.79
0.0036	0.0011	0.0014	$r\leq 2$	1	3.47	1.56	2.52	2.71	7.50

†† Includes an intercept in the level series as deterministic component.
^ Includes an intercept in the cointegrating relation as deterministic component.
* The null hypothesis cannot be rejected at the 10% level of significance.
† Obtained from Johansen and Juselius (1990). Note also that the number of significant lags used in the estimations are 5, 11 and 58 daily lags, respectively, for periods 1, 2, and 3.

The null hypothesis of one cointegrating vector for the first and second period cannot be rejected at the 10% level of significance, while for the third period the null hypothesis of zero cointegrating vectors cannot be rejected. One stationary equilibrium relationship was formed in the first and second periods only, while no such relationship was maintained in the third period. These findings are consistent with the expectations developed from observing the time plots of the recursive estimation. Furthermore, it will be beneficial to analyse the magnitudes of the α and b coefficients of the first two sub-periods to investigate whether the primary structure of the relationship between the three series has changed. Table 7 reports the α and b coefficient estimates of the unrestricted model for the first two periods.

Table 7

Estimates of the α and b coefficients of the unrestricted model†

(1)	(2)			(3)		
Stock Index	Period 1			Period 2		
	b	*α*	*t*-value	*b*	*α*	*t*-value
FTSE100	1.000	-0.013	-3.465*	1.000	-0.018	-3.341*
All Ordinaries	-0.106	0.004	0.830	-0.023	0.008	1.135
Dow Jones	-0.721	0.006	1.036	-0.798	0.002	0.144
Intercept	-	-	-	-1.252	-	-

* Significant at the 10% level.
† The coefficients are normalised on the FTSE100.

Over both periods, the estimates of the b coefficients seem to remain fairly stable. It is noticeable that the b coefficient of the All Ordinaries is close to zero again over both periods,

[1] Two months are allowed for between the first and the second period to account for any abnormalities shortly before and after the October 1987 stock market crash. The gap between the second and third period of seven months is chosen rather large, in order to allow for the structural adjustment that occurred at the end of 1993 and beginning of 1994.

while the inclusion of the intercept term in the cointegrating space in the second period reduces the size of the b coefficient of the All Ordinaries. The estimates of the α coefficients of the All Ordinaries and the Dow Jones are also quite low again over both periods. Identifying restrictions similar to those of the full sample period are then imposed on the coefficients to determine their significance. A summary of the imposed restrictions on the α and b coefficients, including joint restrictions, are reported in Table 8.

Table 8

Restrictions of the Sub-Periods

(1)	(2)		(3)	
H_O (Null Hypothesis)	Period 1		Period 2	
	p-value	Conclusion	*p*-value	Conclusion
$b_{FTSE100} = 0$	0.02	Reject H_O	0.00	Reject H_O
$b_{All\ Ordinaries} = 0$	0.75*	Do not Reject H_O	0.89*	Do not Reject H_O
$b_{Dow\ Jones} = 0$	0.02	Reject H_O	0.00	Reject H_O
$b_{FTSE100} = b_{Dow\ Jones}$	0.00	Reject H_O	0.00	Reject H_O
$\alpha_{Dow\ Jones} = \alpha_{All\ Ordinaries} = 0$	0.13*	Do not Reject H_O	0.14*	Do not Reject H_O

* Significant at the 10% level.

The results of the restrictions on the first period indicate that the b coefficient of the All Ordinaries is not significantly different from zero, while equal size restrictions of the b coefficients of the FTSE100 and the Dow Jones is rejected. The α coefficients of the Dow Jones and the All Ordinaries are also not significantly different from zero indicating once again that these two series are weakly exogenous. Tests for the second period produced similar outcomes. These results imply that the 1987 stock market crash only had a temporary impact on the equilibrium relationship between the FTSE100 and the Dow Jones, as anticipated from observation of the recursively estimated time plots. The stability of the relationship actually remains as can be seen from the relative size of the b coefficients over the two periods[1].

The coefficient estimates displayed in Table 9 show that the size of the b coefficient of the Dow Jones after the October 1987 stock market crash change marginally from -0.914 to -0.813. The size of the α coefficients, i.e., the speed of adjustment to the long-run equilibrium, stayed rather stable as well, with a slightly faster adjustment in the second period. This suggests that the structural break of the October 1987 stock market did not change the principle composition of the relationship between the Dow Jones and the FTSE100 until the beginning of 1994.

Table 9

Coefficients of the Restricted Models in Period 1 and 2

(1)	(2)			(3)		
Stock Index	Period 1†			Period 2†		
	b	*α*	*t*-values	*b*	*α*	*t*-values
FTSE100	1.000	-0.015	-2.942*	1.000	-0.021	-3.793*
All Ordinaries	0.000	0.000	0.000	0.000	0.000	0.000
Dow Jones	-0.914	0.000	0.000	-0.813	0.000	0.000
Intercept	-	-	-	-1.305	-	-

* Significant at the 10% level.
† The coefficients are normalised on the FTSE100.

[1] The models are re-estimated conditioned on the weakly exogenous variables. The stochastic properties of the models as well as the stability of the moduli of the companion matrix were re-examined to ensure that no mis-specification errors were made. The analysis of the residuals as well as the moduli of the largest roots are available on request.

It is clear now that firstly, the All Ordinaries does not enter the equilibrium relationship that is formed between the Dow Jones and the FTSE100 over either of the first two periods. Secondly, the October 1987 stock market crash influenced the cointegrating space only temporarily, which, after some adjustment, reverted back to its stationary long-run equilibrium relationship. Thirdly, after the beginning of 1994 a more permanent structural change occurred leading to the ceasing of the cointegrating relationship that existed between the FTSE100 and the Dow Jones. Lastly, the Dow Jones, exogenous to the cointegrating relationship and thus generated individually as well as systematically as a stochastic variable, accounted for around 91% and 81%, respectively, of the movement of the FTSE100[1] during the periods before and after the 1987 stock market crash. Put in another way, although the FTSE100 is non-stationary as a univariate process, it forms a stationary long-run cointegrating relationship with the Dow Jones series during the first and second sample periods, and thus shares the same stochastic trend with the Dow Jones. The All Ordinaries, on the other hand, by not entering this relationship, is determined by its own cumulative random disturbances.

In order to determine the interdependence between these three financial markets even further, it would be of interest to investigate possible causal relationships that may have existed. For this purpose, the notion of Granger-causality is utilised, which entails testing the causal impact of the cointegrating influence of the ECT, as well as the lagged effects of the differenced series based on the F statistic. The test results are displayed in Table 10 and summarised in a Granger causality flow diagram in Figure 4.

Table 10

Granger-Causality Test Results

(1)	(2)			(3)
Dependent Variables	Regressors			
	ΔFTSE100	ΔAll Ordinaries	ΔDow Jones	ECT†
F - statistic Period 1				*t* - statistic
ΔFTSE100	-	1.798	14.114*	-2.942*
ΔAll Ordinaries	5.026*	-	6.914*	-
ΔDow Jones	0.847	2.204*	-	-
F - statistic Period 2				
ΔFTSE100	-	2.989*	8.195*	-3.793*
ΔAll Ordinaries	2.669*	-	37.653*	-
ΔDow Jones	1.570	0.979	-	-
F - statistic Period 3				
ΔFTSE100	-	1.078	4.402*	-
ΔAll Ordinaries	1.791*	-	8.967*	-
ΔDow Jones	0.943	1.086	-	-

* Significant at the 10% level.

† The *t*-statistics on the *α* coefficients of the ECT are obtained from the restricted models of the cointegrating relationships of the Johansen-Juselius ML procedure.

[1] Johansen (1995) noted that the notion of common stochastic trend and weak exogeneity are mathematically the same. He wrote to this: "another interpretation of the hypothesis of weak exogeneity is the following: if $\alpha_2 = 0$, then the space $(0, I)'$ is contained in space ($\alpha_{\perp}$) which means that $\sum_{i=1}^{t} e_{2i}$ is a common stochastic trend in the sense that the errors in the equations for x_{2t} cumulate in the system and give rise to the non-stationarity." (Johansen 1995, p. 123).

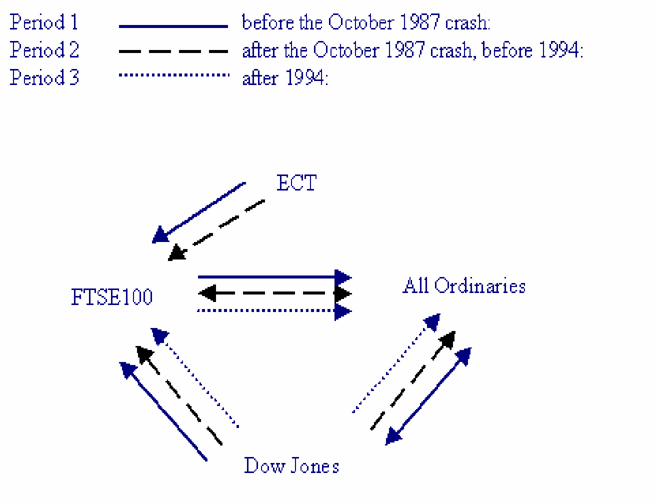

Fig. 4. Granger Causality Flow Diagram[1]

In the first period, bi-directional Granger causality exists between the All Ordinaries and the Dow Jones, while the Dow Jones Granger-causes the FTSE100. The FTSE100, on the other hand, Granger causes the All Ordinaries. In the second period, the Dow Jones Granger-causes the FTSE100 and the All Ordinaries, while bi-directional causality exists between the FTSE100 and the All Ordinaries. In the third period short-run Granger causality runs from the FTSE100 and the Dow Jones to the All Ordinaries and also from the Dow Jones to the FTSE100.

From the analyses of the causal relationship over the three sub-periods, it is clear that the Dow Jones is exogenous. It is independent of the occurrences in the other two markets while it exerts significant influence over them, particularly after the October 1987 stock market crash.

5. Conclusion

The extent of equity market linkages between the Dow Jones, the FTSE100 and the All Ordinaries was investigated. One long-run stationary equilibrium relationship was found, where the All Ordinaries does not enter this relationship significantly and the Dow Jones appears to be weakly exogenous. The recursively estimated time plots of the non-zero eigenvalues and a and b coefficients of the conditioned model suggest that two structural changes/breaks occur in the equilibrium relationship formed by the FTSE100 and the Dow Jones. The first, a seemingly temporary shock anticipated *a priori* was the October 1987 stock market crash, while a second, apparently more permanent structural shift took place between the end of 1993 and the beginning of 1994. The sample was therefore partitioned into three sub-samples to explicitly test for possible structural changes arising from these two major events.

The test results of the sub-samples suggest that, firstly, the relationship between the series remains rather stable over the periods before and after the October 1987 stock market crash. During both of these periods, the FTSE100 and the Dow Jones form a cointegrating relationship, while the All Ordinaries does not form part of this relation. The Dow Jones is weakly exogenous over both periods. The FTSE100 thus reacts to the same stochastic disturbance that is driving the Dow Jones over the two periods. However, the hypothesis of perfect market integration is refuted. For the period after the beginning of 1994, no such long-run equilibrium relationship existed between the two series. Hitherto, the literature has failed to document the existence of a more permanent structural change in the early 1990s. This could be because they took into account structural breaks that are anticipated *a priori*, rather then allowing the dynamic relationship between these series to determine where changes may have occurred.

[1] Where $\rightarrow$ denotes unidirectional causality, and $\leftrightarrow$ denotes bi-directional causality

Thus, in relation to portfolio diversification among these three markets, it appears that benefits can be realised in the long-run. The All Ordinaries is not cointegrated with the Dow Jones and the FTSE100, and while the Dow Jones and FTSE100 are cointegrated, no one to one relationship between them could be confirmed.

An important puzzle that still remains unresolved is what happened between the FTSE100 and the Dow Jones after 1994. The 1993-1994 structural break identified in this study corresponds to the US bond market crash. Further research directed towards analysing the structural shift during the end of 1993 and beginning of 1994 seems to be desirable. Some of the questions one could raise are: "Have other macroeconomic or financial sectors experienced a similar change? Have other European stock markets experienced a similar structural change *vis-à-vis* the U.S. and the U.K. markets?" It seems also beneficial to introduce a somewhat different methodology. The Johansen (1988, 1991) and Johansen and Juselius (1990) ML procedure conducts rank tests on linear relations only, while it is possible that the relationship between the FTSE100 and the Dow Jones may have become non-linear in quite a general way. Research work by Breitung (2001) and Park and Phillips (2001) introduce some of the concepts of testing for non-linear cointegration, which could be applied to testing for stock price linkages.

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