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Random walks and market efficiency in European equity markets

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This paper tests for random walks and weak-form market efficiency in European equity markets. Daily returns for sixteen developed markets (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom) and four emerging markets (Czech Republic, Hungary, Poland and Russia) are examined for random walks using a combination of serial correlation coefficient and runs tests, Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski, Phillips, Schmidt and Shin (KPSS) unit root tests and multiple variance ratio (MVR) tests. The results, which are in broad agreement across the approaches employed, indicate that of the emerging markets only Hungary is characterized by a random walk and hence is weak-form efficient, while in the developed markets only Germany, Ireland, Portugal, Sweden and the United Kingdom comply with the most stringent random walk criteria.

Keywords: Developed and emerging markets, random walk hypothesis, market efficiency

JEL classifications: C12, C14, G14, G15.

I. INTRODUCTION

Study of the stock return generating process has long been dominated by interest in its random walk properties. Justification for such interest is not hard to find, given that the presence (or absence) of a random walk has important implications for investors and trading strategies, fund managers and asset pricing models, capital markets and weak-form market efficiency, and consequently financial and economic development as a whole. Trading strategies, for example, differ when returns are characterised by random walks or by positive autocorrelations (or persistence) over short horizons and negative autocorrelations (or mean reversion) over long horizons. In this instance, as the investment horizon lengthens, an investor would invest more (less) in stocks if the relative risk aversion is greater (less) than unity, than if the returns were serially independent.

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Similarly, random walks in stock returns are crucial to the formulation of rational expectations models and the testing of weak-form market efficiency. In an efficient market, the prices of stocks fully incorporate all relevant information and hence stock returns will display unpredictable (or random walk) behaviour. In stock prices not characterised by a random walk, the return generating process is dominated by a temporary component and therefore future returns can be predicted by the historical sequence of returns. Lastly, the ability of stock markets to play the role that is usually ascribed to them – attracting foreign investment, boosting domestic saving and improving the pricing and availability of capital – depends upon the presence of random walks. A market following a random walk is consistent with equity being appropriately priced at an equilibrium level, whereas the absence of a random walk infers distortions in the pricing of capital and risk. This has important implications for the allocation of capital within an economy and hence overall economic development.

To this end, an ever-increasing number of studies have examined random walks in the world's stock markets. Fama (1970) and later Fama (1991) comprehensively survey early departures from random walks, so in the interests of brevity the following focuses on the most recent evidence. Of these, some of have chosen to concentrate on individual markets. These include studies of random walks in Korea (Ayadi and Pyun 1994, Ryoo and Smith 2002), China (Lee et al. 2001), Hong Kong (Cheung and Coutts 2001), Slovenia (Dezlan 2000), Spain (Regúlez and Zarraga 2002), the Czech Republic (Hajek 2002), Portugal (Manuel et al. 2002), the United Kingdom (Poon 1996) and Turkey (Zychowicz et al. 1995, Buguk and Brorsen 2003). Others have elected instead to focus on emerging markets, particularly on a regional basis. Markets in Asia (Huang 1995, Groenewold and Ariff 1998), Latin America (Urrutia 1995, Ojah and Karemera 1999. Grieb and Reyes 1999, Karemera et al. 1999), Africa (Smith et al. 2002, Appiah-Kusi and Menyah 2003) and the Middle East (Abraham et al. 2002) have been addressed in this manner.

However, and rather glaringly, examination of the existing empirical literature concerning random walks (and hence weak-form market efficiency) reveals that European stock markets have received rather less attention. Quite apart from the more usual benefits conferred by an understanding of random walk behaviour and market efficiency, this is an important omission in the European context for two additional reasons. First, capital provision in Europe in general, and in the newly expanded European Union in particular, relies upon a relatively large number of smaller developed markets and an increasing proportion of emerging markets. Knowledge of random walks and market efficiency in this instance yields valuable insights into the ability of these markets to provide appropriately priced and efficiently allocated equity capital, especially for the purposes of national (regional) development in the smaller European (European Union) nation (Member) states. Second, there has been increasing pressure for the consolidation of European equity markets over the past decade. Given that market liquidity, breadth and depth are thought to be closely associated with market efficiency, the failure to attain some nominal level of efficiency in a given market provides a strong rationale for technological and regulatory reform, and the creation of institutional linkages in the form of collaborative partnerships, even mergers.

Accordingly, the purpose of this paper is to examine the random walk behaviour and market efficiency of European equity markets. The paper itself is divided into four main areas. Section II provides a description of the data employed in the analysis. Section III discusses the empirical methodology used. The results are dealt with in Section IV. The paper ends with some concluding remarks in Section V.

II. DESCRIPTION AND PROPERTIES OF THE DATA

The data employed in the study is composed of market value-weighted equity indices for twenty European equity markets, comprising sixteen developed markets – Austria (AUS), Belgium (BEL), Denmark (DEN), Finland (FIN), France (FRA), Germany (GER), Greece (GRE), Ireland (IRE), Italy (ITL), Netherlands (NTH), Norway (NRW), Portugal (POR), Spain (SPN), Sweden (SWE), Switzerland (SWI) and the United Kingdom (UNK) – and four emerging markets – Czech Republic (CZH), Hungary (HGY), Poland (POL) and Russia (RUS). All data is obtained from Morgan Stanley Capital International (MSCI) and specified in US dollar terms. The series encompass dissimilar sampling periods given the varying availability of each index. The end date for all series is 28-May-2003 with AUS, FIN, FRA, GER, GRE, IRE, ITL, NTH, NRW, SPN, SWE and UNK starting on 31-Dec-1987, BEL, DEN and SWI on 31-Dec-1986, POL on 31-Dec-1992, CZH, HGY and RUS on 2-Jan-1994 and POR on 4-Aug-1995. MSCI indices are widely employed in the financial literature on the basis of the degree of comparability and avoidance of dual listings, and are constructed to overcome problems associated with infrequent or non-synchronous trading in markets.

Daily data is specified. The natural log of the relative price is computed for the daily intervals to produce a time series of continuously compounded returns, such that

$r_t = \log(p_t / p_{t-1}) \times 100$, where p_t and $p_{t\text{-}1}$ represent the stock index price at time t and t-1, respectively. Table 1 presents a summary of descriptive statistics of the daily returns for the twenty markets. Sample means, maximums, minimums, standard deviations, skewness, kurtosis and Jacque-Bera statistics and *p*-values are reported. The lowest mean returns are in Portugal (0.0001), Italy (0.0001) and Austria (0.0002) while the highest mean returns are for Poland (0.0005), Hungary (0.0005) and Russia (0.0006). The lowest minimum returns are in Greece (-0.9720), Finland (-0.6818) and Switzerland (-0.3471) and the highest maximum returns are in Hungary (0.3796), Finland (0.6758) and Greece (0.8521). The standard deviations of returns range from 0.0108 (United Kingdom) to 0.0925 (Greece). On this basis, of the seven markets the returns in the United Kingdom, Netherlands and Austria are the least volatile, with Denmark, Switzerland and Greece being the most volatile.

<TABLE 1 HERE>

By and large, the distributional properties of all twenty return series appear non-normal. Given that the sampling distribution of skewness is normal with mean 0 and standard deviation of $\sqrt{6/T}$ where T is the sample size, all of the return series are significantly skewed. All markets save Hungary are negatively skewed, indicating the greater probability of large deceases in returns than rises, while Hungary is positively skewed, signifying the greater likelihood of large increases in returns than falls. The kurtosis, or degree of excess, in all market returns is also large, ranging from 5.0435 for the Czech republic to 241.4213 for Finland, thereby indicating leptokurtic distributions. Given the sampling distribution of kurtosis is normal with mean 0 and standard deviation of $\sqrt{24/T}$ where T is the sample size, then all estimates are once again statistically significant at any conventional level. Finally, the calculated Jarque-Bera statistics and corresponding *p*-values in Table 1 are used to test the null hypotheses that the daily distribution of European market returns is normally distributed. All *p*-values are smaller than the .01 level of significance suggesting the null hypothesis can be rejected. None of these returns are then well approximated by the normal distribution.

III. EMPIRICAL METHODOLOGY

Random walk hypothesis

Consider the following random walk with drift process:

$$p_t = p_{t-1} + \beta + \varepsilon_t \tag{1}$$

or

$$r_t = \Delta p_t = \beta + \varepsilon_t \qquad (2)$$

where p_t is the price of the index observed at time t, β is an arbitrary drift parameter, r_t is the change in the index and ε_t is a random disturbance term satisfying $E(\varepsilon_t) = 0$, $\sigma^2_{\varepsilon_t}$ is constant and $E(\varepsilon_t\varepsilon_{t-g}) = 0$, $g \neq 0$, for all t. Under the random walk hypothesis, a market is (weak-form) efficient if the most recent price contains all available information and therefore the best predictor of future prices is the most current price.

Within the random walk hypothesis, three successively more restrictive sub-hypotheses with sequentially stronger tests for random walks exist (Campbell et al. 1997). The least restrictive of these is that in a market that complies with a random walk it is not possible to use information on past prices to predict future prices. That is, returns in a market conforming to this standard of random walk are serially uncorrelated, corresponding to a random walk hypothesis with dependent but uncorrelated increments. However, it may still be possible for information on the variance of past prices to predict the future volatility of the market. A market that conforms to these conditions implies that returns are serially uncorrelated, corresponding with a random walk hypothesis with increments that are independent but not identically distributed. Finally, if it is not possible to predict either future price movements or volatility on the basis of information from past prices then such a market complies with the most restrictive notion of a random walk. In this market, returns are serially uncorrelated and conform to a random walk hypothesis with independent and identically distributed increments.

This provides a number of complementary testing procedures for random walks or weak-form market efficiency. To start with, the parametric serial correlation test of independence and the non-parametric runs test can be used to test for serial independence in the series. Alternatively, unit root tests can be used to determine if the series is difference or trend non-stationary as a necessary condition for a random walk. Finally, multiple variance ratio procedures can focus attention on the uncorrelated residuals in the series, under assumptions of both homoskedastic and heteroskedastic random walks.

Tests of serial independence

Two approaches are employed to test for serial independence in the returns. These correspond to the test that $E(\varepsilon_t\varepsilon_{t-g}) = 0$ in Equations (1) and (2). First, the serial correlation coefficient test is a widely employed procedure that tests the relationship between returns in the current period and those in the previous period. If no significant autocorrelations are found then the series are assumed to follow a random walk. Second, the runs test determines whether successive price changes are independent and unlike the serial correlation test of independence, is non-parametric and does not require returns to be normally distributed. Observing the number of 'runs' - or the sequence of successive price changes with the same sign - in a sequence of price changes tests the null hypothesis of randomness. In the approach selected, each return is classified according to its position with respect to the mean return. That is, a positive change is when the return is greater than the mean, a negative change when the return is less than the mean, and zero change when the return equals the mean.

To perform this test, A is assigned to each return that equals or exceeds the mean value and B for the items that are below the mean. Let n_A and n_B be the sample sizes of items A and B respectively. The test statistic is U, the total number of runs. For large sample sizes, that is where both n_A and n_B are greater than twenty, the test statistic is approximately normally distributed (Berenson and Levine 2002):

$$Z = \frac{U - \mu_U}{\sigma_U} \tag{3}$$

where $\mu_{\mathrm{U}} = \frac{2n_A n_B}{n} + 1$, $\sigma_U = \sqrt{\frac{2n_A n_B(2n_A n_B - n)}{n^2(n-1)}}$ and $n = n_A + n_B$

Unit root tests

Three different unit root tests are used to test the null hypothesis of a unit root. These correspond to the test that $E(\varepsilon_t\varepsilon_{t-g}) = 0$ but $\sigma^2(\varepsilon_t\varepsilon_{t-g})$ is not constant in Equations (1) and (2). They are the Augmented Dickey-Fuller (ADF) test, the Phillips-Peron (PP) test, and the Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test. To start with, the well-known ADF unit root test of the null hypothesis of nonstationarity is conducted in the form of the following regression equation:

$$\Delta p_{it} = \alpha_0 + \alpha_1 t + \rho_0 p_{it-1} + \sum_{i=1}^{q} \rho_i \Delta p_{it-i} + \varepsilon_{it} \tag{4}$$

where p_{it} denotes the price for the i-th market at time t, $\Delta p_{it} = p_{it} - p_{it-1}$, ρ are coefficients to be estimated, q is the number of lagged terms, t is the trend term, α_1 is the estimated coefficient for the trend, α_0 is the constant, and ε is white noise. MacKinnon's critical values are used in order to determine the significance of the test statistic associated with ρ_0. The PP incorporates an alternative (nonparametric) method of controlling for serial correlation when testing for a unit root by estimating the non-augmented Dickey-Fuller test equation and modifying the test statistic so that its asymptotic distribution is unaffected by serial correlation. Finally, the KPSS test differs from these other unit root tests in that the series is assumed to be (trend) stationary under the null.

Multiple variance ratio tests

The multiple variance ratio (MVR) test as proposed by Chow and Denning (1993) is used to detect autocorrelation and heteroskedasticity in the returns. This corresponds to the test that $E(\varepsilon_t \varepsilon_{t-g}) = 0$ and $\sigma^2(\varepsilon_t \varepsilon_{t-g})$ is constant or $\varepsilon_t \sim$ iid in Equations (1) and (2). Based on Lo and MacKinlay's (1988) earlier single variance ratio (VR) test, Chow and Denning (1993) adjusts the focus of the tests from the individual variance ratio for a specific interval to one more consistent with the random walk hypothesis by covering all possible intervals. As shown by Lo and MacKinlay (1988), the variance ratio statistic is derived from the assumption of linear relations in observation interval regarding the variance of increments. If a return series follows a random walk process, the variance of a qth-differenced variable is q times as large as the first-differenced variable. For a series partitioned into equally spaced intervals and characterised by random walks, one qth of the variance of $(p_t - p_{t-q})$ is expected to be the same as the variance of $(p_t - p_{t-1})$:

$$Var(p_t - p_{t-q}) = qVar(p_t - p_{t-1}) \tag{5}$$

where q is any positive integer. The variance ratio is then denoted by:

$$VR(q) = \frac{\frac{1}{q}Var(p_t - p_{t-q})}{Var(p_t - p_{t-1})} = \frac{\sigma^2(q)}{\sigma^2(1)} \tag{6}$$

such that under the null hypothesis $VR(q) = 1$. For a sample size of $nq + 1$ observations ($p_0, p_1, \ldots, p_{nq}$), Lo and Mackinlay's (1988) unbiased estimates of $\sigma^2(1)$ and $\sigma^2(q)$ are computationally denoted by:

$$\hat{\sigma}^2(1) = \frac{\sum_{k=1}^{nq}(p_k - p_{k-1} - \hat{\mu})^2}{(nq-1)} \tag{7}$$

and

$$\hat{\sigma}^2(q) = \frac{\sum_{k=q}^{nq}(p_k - p_{k-q} - q\hat{\mu})^2}{h} \tag{8}$$

where $\hat{\mu} =$ sample mean of $(p_t - p_{t-1})$ and:

$$h \equiv q(nq+1-q)(1-\frac{q}{nq}) \tag{9}$$

Lo and Mackinlay (1988) produce two test statistics, *Z(q)* and *Z*(q)*, under the null hypothesis of homoskedastic increments random walk and heteroskedastic increments random walk respectively. If the null hypothesis is true, the associated test statistic has an asymptotic standard normal distribution. With a sample size of nq + 1 observations (p_0, p_1, …,p_{nq}) and under the null hypothesis of homoskedastic increments random walk, the standard normal test statistic *Z(q)* is:

$$Z(q) = \frac{V\hat{R}(q)-1}{\hat{\sigma}_0(q)} \tag{10}$$

where

$$\hat{\sigma}_0(q) = \left[\frac{2(2q-1)(q-1)}{3q(nq)}\right]^{1/2} \tag{11}$$

The test statistic for a heteroskedastic increments random walk, *Z*(q)* is:

$$Z^*(q) = \frac{V\hat{R}(q)-1}{\hat{\sigma}_e(q)} \tag{12}$$

where

$$\hat{\sigma}_e(q) = \left[4\sum_{k=1}^{q-1}\left(1-\frac{k}{q}\right)^2 \hat{\delta}_k\right]^{1/2} \tag{13}$$

and

$$\hat{\delta}_k = \frac{\sum_{j=(k+1)}^{nq}(p_j - p_{j-1} - \hat{\mu})^2 (p_{j-k} - p_{j-k-1} - \hat{\mu})^2}{\left[\sum_{j=1}^{nq}(p_j - p_{j-1} - \hat{\mu})^2\right]^2} \tag{14}$$

Lo and MacKinlay's (1988) procedure is devised to test individual variance ratios for a specific aggregation interval, q, but the random walk hypothesis requires that $VR(q) = 1$ for all q. Chow and Denning's (1993) multiple variance ratio (MVR) test generates a procedure for the multiple comparison of the set of variance ratio estimates with unity. For a single variance ratio test, under the null hypothesis, $VR(q) = 1$, hence $M_r(q) = VR(q) - 1 = 0$. Consider a set of m variance ratio tests $\{M_r(q_i) \mid i = 1,2,\ldots,m\}$. Under the random walk null hypothesis, there are multiple sub-hypotheses:

$$H_{oi}: \quad M_r(q_i) = 0 \qquad \text{for } i = 1,2,\ldots,m$$
$$H_{1i}: \quad M_r(q_i) \neq 0 \qquad \text{for any } i = 1,2,\ldots,m \tag{15}$$

The rejection of any one or more H_{oi} rejects the random walk null hypothesis. For a set of test statistics, say $Z(q)$, $\{Z(q_i) \mid i = 1,2,\ldots,m\}$, the random walk null hypothesis is rejected if any one of the estimated variance ratio is significantly different from one. Hence only the maximum absolute value in the set of test statistics is considered. The core of the Chow and Denning's (1993) MVR test is based on the result:

$$PR\{\max\left(\left|Z(q_1)\right|,\ldots,\left|Z(q_m)\right|\right) \leq SMM(\alpha;m;T)\} \geq 1-\alpha \tag{16}$$

where $SMM(\alpha;m;T)$ is the upper α point of the Standardized Maximum Modulus (*SMM*) distribution with parameters m (number of variance ratios) and T (sample size) degrees of freedom. Asymptotically when T approaches infinity:

$$\lim_{T\to\infty} SMM(\alpha;m;\infty) = Z_{\alpha^*/2} \tag{17}$$

where $Z_{\alpha^*/2}$ = standard normal distribution and $\alpha^* = 1-(1-\alpha)^{1/m}$. Chow and Denning (1993) control the size of the *MVR* test by comparing the calculated values of the standardized test statistics, either $Z(q)$ or $Z^*(q)$ with the *SMM* critical values. If the maximum absolute value of, say $Z(q)$ is greater than the *SMM* critical value than the random walk hypothesis is rejected.

Importantly, the rejection of the random walk under homoskedasticity could result from either heteroskedasticity and/or autocorrelation in the equity price series. If the heteroskedastic random walk is rejected than there is evidence of autocorrelation in the equity series. With the presence of autocorrelation in the price series, the first order autocorrelation coefficient can be estimated using the result that $\hat{M}_r(q)$ is asymptotically equal to a weighted sum of autocorrelation coefficient estimates with weights declining arithmetically:

$$\hat{M}_r(q) = 2\sum_{k=1}^{q-1}\left(1-\frac{k}{q}\right)\hat{\rho}(k) \tag{18}$$

where $q = 2$:

$$\hat{M}_r(2) \equiv V\hat{R}(2) - 1 = \hat{\rho}(1) \tag{19}$$

In tests of the random walk hypothesis, the serial correlation and runs tests are used to determine if the return series are uncorrelated; the unit root tests are used to detect if the return series are identically distributed; and the multiple variance ratio tests are employed to determine if the return series are both independent and identically distributed. Since the multiple variance ratio tests encompass both conditions they are regarded as being more powerful and more useful in testing the random walk hypothesis (Smith et al. 2002).

IV. EMPIRICAL RESULTS

Table 2 provides two sets of test statistics. The first set includes the statistics and *p*-values for the tests of serial independence, namely, the parametric serial correlation coefficient and the nonparametric one sample runs test. The null hypothesis in the former is for no serial correlation while in the latter it is the random distribution of returns. The second set of tests is unit root tests and comprises the ADF and PP *t*-statistics and *p*-values and the KPSS LM-statistic and asymptotic significance. In the case of the former, the null hypothesis of a unit root is tested against the alternative of no unit root (stationary). For the latter, the null hypothesis of no unit root is tested against the alternative of a unit root (non-stationary).

<TABLE 2 HERE>

Turning first to the tests of independence, the null hypotheses of no serial correlation for all of the four emerging markets and twelve of the developed markets are rejected at the .05 level or better. The null hypothesis of no serial correlation fails to be rejected for Germany, Ireland, the Netherlands and Portugal. The significance of the autocorrelation coefficient indicates that the null hypothesis of weak-form market efficiency may be rejected and we may infer that sixteen of the European markets are weak-form inefficient over the various sample periods.

In terms of serial correlation, the coefficients for SWI, DEN, FIN, GRE, SPN, BEL, NRW, GER and IRE are negative indicating mean reversion in returns, with mean reversion being higher in Switzerland (-0.2890), Denmark (-0.2580) and Finland (-0.2340) and lower in Norway (-0.0340), Germany (-0.0100) and Ireland (-0.0090). The average mean reversion is -0.1344. For the remaining markets (AUS, POR, NTH, SWE, UNK, FRA, ITL, HGY, RUS, CZH and POL) the positive serial correlation coefficients are indicative of return persistence (or predictability), with persistence being higher in Austria (0.1480) and Poland (0.1430) and lower in Portugal (0.0090) and the Netherlands (0.0200). However, it should be noted that over shorter horizons the markets exhibiting persistence (mean-reversion) could also exhibit mean-reversion (persistence).

For the runs tests, all of the estimated *z*-values are significant at the .10 level for all markets except the United Kingdom, Netherlands and Germany. The negative *z*-values for all other markets, both emerging and developed, save Denmark, Germany and Switzerland indicates that the actual number of runs falls short of the expected number of runs under the null hypothesis of return independence. These indicate positive serial correlation. The positive *z*-

values for Denmark, Germany and Switzerland are indicative of negative serial correlation. Germany and Netherlands are then weak form efficient under both tests, while Ireland, Portugal and the United Kingdom are efficient under one test or the other. All remaining markets do not follow random walks and are then weak form inefficient.

The unit root tests in Table 2 are also generally supportive of the hypothesis that most European equity markets are weak form inefficient. The ADF and PP *t*-statistics reject the null hypotheses of a unit root at the .01 level or lower, thereby indicating that all of the return series examined are stationary. For the KPSS tests of the null hypothesis of no unit root, the *LM*-statistic exceeds the asymptotic critical value at the .01 level or higher only for the Netherlands (0.3771), Portugal (0.4792) and Poland (0.4166). As a necessary condition for a random walk, the ADF and PP unit root tests reject the requisite null hypothesis in the case of all twenty emerging and developed markets, while the KPSS unit root tests fail to reject the required null with the exception of the Netherlands, Portugal and Poland.

Table 3 presents the results of the multiple variance ratio tests of returns in the sixteen developed and four emerging European equity markets. The sampling intervals for all markets are 2, 5, 10 and 20 days, corresponding to one-day, one week, one fortnight and one month calendar periods. For each interval, Table 3 presents the estimates of the variance ratio *VR(q)* and the test statistics for the null hypotheses of homoskedastic, *Z(q)* and heteroskedastic, *Z*(q)* increments random walk. Under the multiple variance ratio procedure, only the maximum absolute values of the test statistics are examined. For sample sizes exceeding at least 1,113 observations (Russia) and where the number of sampling intervals $m = 4$, the critical value for these test statistics is 2.49 at the .05 level of significance. For each set of multiple variance ratio tests, an asterisk denotes the maximum absolute value of the test statistic that exceeds this critical value and thereby indicates whether the null hypothesis of a random walk is rejected.

<TABLE 3 HERE>

Consider the results for Italy. The null hypothesis that daily equity returns follow a homoskedastic random walk is rejected at Z(2) = 5.2277. Rejection of the null hypothesis of a random walk under homoskedasticity for a 2-day period is also a test of the null hypothesis of a homoskedastic random walk under the alternative sampling periods and we may therefore conclude that Italian equity returns do not follow a random walk. However, rejection of the null hypothesis under homoskedasticity could result from heteroskedasticity and/or autocorrelation in the return series. After a heteroskedastic-consistent statistic is calculated, the null hypothesis is also rejected at Z*(2) = 4.0982. The heteroskedastic random walk hypothesis is thus rejected because of autocorrelation in the daily increments of the returns on Italian equity. We may conclude that the Italian equity market is unambiguously weak form inefficient, along with the other developed markets of AUS, BEL, DEN, GRE and SWI and the emerging markets of CZH, POL and RUS.

Further, Lo and MacKinlay (1988) show that for q=2, estimates of the variance ratio minus one and the first-order autocorrelation coefficient estimator of daily price changes are asymptotically equal [Italy's serial correlation coefficient in Table 2 is 0.0820]. On this basis, the estimated first order autocorrelation coefficient is 0.0825 corresponding to the estimated variance ratio $V\hat{R}(2)$ of 1.0825 (i.e. 1.0825 - 1.0000). Further, where $V\hat{R}(2) < 1$ a mean reverting process is indicated, whereas when $V\hat{R}(2) > 1$ persistence is suggested. This indicates there is positive autocorrelation (or persistence) in Italian equity returns over the long horizon.

By way of comparison, observe the results for the United Kingdom. At none of the sampling intervals are the test statistics for the null hypotheses of homoskedastic, *Z(q)* and heteroskedastic, *Z*(q)* random walks greater than the critical value of 2.49. This suggests that the UK equity market is weak form efficient. On the same criteria, neither are GER, IRE, HGY, POR and SWE. Alternatively, in the case of France the null hypotheses of a homoskedastic random walk is rejected [*Z(q)*=3.3225], but the null hypothesis of heteroskedastic random walk is not [*Z*(q)*=2.4076]. This indicates that rejection of the null hypothesis of a homoskedastic random walk could be the result, at least in part, of heteroskedasticity in the returns, and cannot be assigned exclusively to the autocorrelation in returns. The rejection of the null hypothesis of the homoskedastic but not the heteroskedastic random walk is also found for FIN, NTH, NRW and SPN.

As noted, just a few European studies exist for which a direct comparison of results can be made. In terms of emerging markets, Rockinger and Urga (2000: 471) used daily data and GARCH analysis to also conclude that of the markets considered (Czech Republic, Hungary, Poland and Russia) only "…the Hungarian market is nonpredictable over the entire sample and, therefore, satisfies our criteria for weak efficiency. This result is in line with the fact that this market has existed for 10 years longer than the other markets and is strongly regulated". Hajek (2002: 377) likewise found in a study of the Czech market that "results from serial correlation, Box-Pierce and Variance Ratio tests provide evidence that a random walk hypothesis cannot be validated with respect to the daily returns. The weak form of efficiency on the Czech equity markets was thus not proved". For developed markets, Regúlez and Zarraga (2002) decided that Spanish equity returns were serially correlated, while Poon (1996: 177) concluded, largely on the basis of multiple variance ratio tests in the UK market, "the null hypothesis of a random walk can clearly be rejected and persistence at short lags accepted".

V. CONCLUDING REMARKS

This paper examines the weak form market efficiency of twenty European equity markets, of which sixteen are regarded as developed and the remainder as emerging. Three different procedures are employed to test for random walks in daily returns: (i) the parametric serial correlation coefficient and the nonparametric runs test are used to test for serial correlation; (ii) Augmented Dickey-Fuller, Phillips-Perron and Kwiatkowski, Phillips, Schmidt and Shin unit root tests are used to test for non-stationarity as a necessary condition for a random walk; and (iii) multiple variance test statistics are used to test for random walks under the varying distributional assumptions of homoskedasticity and heteroskedasticity.

The results for the tests of serial correlation are in broad agreement and conclusively reject the presence of random walks in daily returns for all markets save Germany, Ireland, the Netherlands, Portugal and the United Kingdom. Similarly, the unit root tests conclude that unit roots, as a necessary but not sufficient condition for a random walk, are absent from all or nearly all of the return series. Finally, the multiple variance ratio procedure also rejects the presence of random walks in most European markets. Among the developed markets, only Germany, Ireland, Portugal, Sweden and the United Kingdom satisfy the most stringent random walk criteria with France, Finland, the Netherlands, Norway and Spain meeting at least some of the requirements of a strict random walk. Among the emerging markets, only Hungary satisfies the strictest requirements for a random walk in daily stock returns.

The results of this analysis are consistent with the generalisation that emerging markets are unlikely to be associated with the random walks required for the assumption of weak-form market efficiency. However, Hungary, as the most institutionally mature of these markets, does satisfy this criterion. The evidence regarding developed markets is rather less conclusive with some markets following random walks while others do not. It is not difficult to rationalize why the relatively large equity markets in Germany and the United Kingdom are weak form efficient; it is rather less easy to do so for the smaller markets of Ireland, Portugal and Sweden. This presents an interesting avenue for future research, as does the attempt to examine whether market efficiency has improved over time in any or all of these markets. Nonetheless, the results pleasingly indicate that the various tests for random walks, often encompassing more and less stringent criteria and assumptions, provide generally consistent evidence on the absence of random walks. This should provide some reassurance to future empirical researchers in this area.

A number of practical implications are highlighted by the results. To start with, a market following a random walk is consistent with equity being appropriately priced at an equilibrium level, whereas the absence of a random walk infers distortions in the pricing of capital and risk. Only in fully deregulated and liberalized markets characterized by appropriate incentives and institutional frameworks can we expect the necessary prerequisites - including market liquidity, breadth, depth and transactional and informational efficiency - to be satisfied. Policymakers and regulators can use the results of this study to guide policy development as a step towards ongoing financial and economic development. Investors can also gain practical advantage from the results. In markets not characterized by a random walk, the return generating process is dominated by a temporary component and therefore future returns can be predicted by the historical sequence of returns. The results then also provide guidance for investors interested in forecasting returns in these markets.

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TABLE 1. *Descriptive statistics for European developed and emerging markets*

	Market	Start	End	Observations	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	JB *p*-value
Developed markets	AUS	31-Dec-1987	28-May-2003	4019	1.51E-04	0.0927	-0.1349	0.0122	-0.3163	10.3789	9.18E+03	0.0000
	BEL	31-Dec-1986	28-May-2003	4280	2.09E-04	0.3200	-0.3210	0.0226	-2.0220	81.2378	1.09E+06	0.0000
	DEN	31-Dec-1986	28-May-2003	4280	3.69E-04	0.3351	-0.3447	0.0408	-0.4232	23.4911	7.50E+04	0.0000
	FIN	31-Dec-1987	28-May-2003	4019	3.44E-04	0.6758	-0.6818	0.0294	-0.5701	241.4213	9.52E+06	0.0000
	FRA	31-Dec-1987	28-May-2003	4019	2.89E-04	0.0737	-0.1018	0.0127	-0.2153	6.0282	1.57E+03	0.0000
	GER	31-Dec-1987	28-May-2003	4019	1.96E-04	0.0703	-0.1381	0.0143	-0.4487	8.6176	5.42E+03	0.0000
	GRE	31-Dec-1987	28-May-2003	4019	2.30E-04	0.8521	-0.9720	0.0925	-0.8579	36.2182	1.85E+05	0.0000
	IRE	31-Dec-1987	28-May-2003	4019	2.38E-04	0.1840	-0.1875	0.0133	-0.1342	30.2219	1.24E+05	0.0000
	ITL	31-Dec-1987	28-May-2003	4019	1.26E-04	0.0671	-0.1114	0.0143	-0.2096	5.9878	1.52E+03	0.0000
	NTH	31-Dec-1987	28-May-2003	4019	2.61E-04	0.0657	-0.0847	0.0119	-0.2420	7.4173	3.31E+03	0.0000
	NRW	31-Dec-1987	28-May-2003	4019	1.90E-04	0.2469	-0.2769	0.0156	-0.8743	67.3102	6.93E+05	0.0000
	POR	4-Aug-1995	28-May-2003	2038	1.04E-04	0.1784	-0.1791	0.0133	-0.2396	36.5900	9.58E+04	0.0000
	SPN	31-Dec-1987	28-May-2003	4019	1.97E-04	0.3232	-0.3163	0.0159	-0.1408	99.9690	1.57E+06	0.0000
	SWE	31-Dec-1987	28-May-2003	4019	3.35E-04	0.1298	-0.1768	0.0165	-0.2105	11.5403	1.22E+04	0.0000
	SWI	31-Dec-1986	28-May-2003	4280	3.09E-04	0.3014	-0.3471	0.0439	-0.9345	20.7355	5.67E+04	0.0000
	UNK	31-Dec-1987	28-May-2003	4019	1.78E-04	0.0727	-0.0538	0.0108	-0.1026	5.5093	1.06E+03	0.0000
Emerging markets	CZH	30-Dec-1994	28-May-2003	2193	1.60E-04	0.0676	-0.0739	0.0155	-0.1012	5.0435	3.85E+02	0.0000
	HGY	30-Dec-1994	28-May-2003	2193	5.28E-04	0.3796	-0.2580	0.0218	2.6035	71.5944	4.32E+05	0.0000
	POL	31-Dec-1992	28-May-2003	2714	4.82E-04	0.1253	-0.1159	0.0242	-0.1407	6.7288	1.58E+03	0.0000
	RUS	2-Jan-1995	28-May-2003	2193	5.80E-04	0.2422	-0.3101	0.0360	-0.3899	11.3524	6.43E+03	0.0000

Notes: Developed markets: AUS – Austria, BEL – Belgium, DEN – Denmark, FIN – Finland, FRA – France, GER – Germany, GRE – Greece, IRE – Ireland, ITL – Italy, NTH – Netherlands, NRW – Norway, POR – Portugal, SPN – Spain, SWE – Sweden, SWI – Switzerland, UNK – United Kingdom. Emerging markets: CZH – Czech Republic, HGY – Hungary, POL – Poland, RUS – Russia. JB – Jarque-Bera. Critical values for significance of skewness and kurtosis at the .05 level are 0.0757 and 0.1514 for AUS, FIN, FRA, GER, GRE, IRE, ITL, NTH, NRW, SPN, SWE and UNK, 0.0733 and 0.1467 for BEL, DEN and SWI, 0.1063 and 0.2127 for POR, 0.1025 and 0.2050 for CZH, HGY and RUS and 0.0921 and 0.1843 for POL, respectively.

TABLE 2. *Serial correlation, runs and unit root tests for European developed and emerging markets*

		Serial correlation			Runs tests						Unit root tests					
	Market	Coefficient	*p*-value	Mean	Cases < mean	Cases ≥ mean	Total cases	Number of runs	Runs Z-value	*p*-value	ADF *t*-statistic	ADF *p*-value	PP *t*-statistic	PP *p*-value	KPSS *LM*-statistic	KPSS significance
Developed markets	AUS	0.1480	0.0000	1.51E-04	2029	1990	4019	1893	-3.7017	0.0002	-54.5871	0.0001	-54.6464	0.0001	0.1556	–
	BEL	-0.0670	0.0000	2.09E-04	2150	2130	4280	2015	-3.8510	0.0001	-13.2997	0.0000	-85.2791	0.0001	0.2255	–
	DEN	-0.2580	0.0000	3.69E-04	2172	2108	4280	2197	1.7272	0.0841	-15.2657	0.0000	-158.2299	0.0001	0.2167	–
	FIN	-0.2340	0.0000	3.44E-04	2026	1993	4019	1887	-3.8926	0.0001	-12.5470	0.0000	-82.0383	0.0001	0.2015	–
	FRA	0.0510	0.0006	2.89E-04	1959	2060	4019	1905	-3.2908	0.0010	-45.7688	0.0001	-60.1240	0.0001	0.2246	–
	GER	-0.0100	0.2631	1.96E-04	1971	2048	4019	2031	0.6703	0.5026	-63.9746	0.0001	-64.0523	0.0001	0.2953	–
	GRE	-0.2100	0.0000	2.30E-04	2107	1912	4019	1951	-1.7322	0.0832	-16.1915	0.0000	-145.5366	0.0001	0.1627	–
	IRE	-0.0090	0.2842	2.38E-04	1989	2030	4019	1887	-3.8905	0.0001	-63.9344	0.0001	-63.9547	0.0001	0.1727	–
	ITL	0.0820	0.0000	1.26E-04	2011	2008	4019	1947	-2.0035	0.0451	-58.3765	0.0001	-58.2193	0.0001	0.0620	–
	NTH	0.0200	0.1024	2.61E-04	1974	2045	4019	1973	-1.1638	0.2445	-39.4916	0.0000	-62.1057	0.0001	0.3771	0.1000
	NRW	-0.0340	0.0155	1.90E-04	2036	1983	4019	1859	-4.7699	0.0000	-65.5656	0.0001	-65.6608	0.0001	0.1927	–
	POR	0.0090	0.3423	1.04E-04	1027	1011	2038	919	-4.4731	0.0000	-44.6645	0.0001	-44.6732	0.0001	0.4792	0.0500
	SPN	-0.0990	0.0000	1.97E-04	2008	2011	4019	1901	-3.4549	0.0006	-70.0043	0.0001	-70.0142	0.0001	0.0926	–
	SWE	0.0290	0.0330	3.35E-04	2245	1774	4019	1719	-8.4425	0.0000	-61.5202	0.0001	-61.4992	0.0001	0.2260	–
	SWI	-0.2890	0.0000	3.09E-04	2159	2121	4280	2205	1.9621	0.0498	-15.4346	0.0000	-187.5331	0.0001	0.2165	–
	UNK	0.0350	0.0132	1.78E-04	2006	2013	4019	1985	-0.8044	0.4212	-39.6895	0.0000	-61.1453	0.0001	0.1860	–
Emerging markets	CZH	0.1200	0.0000	1.60E-04	1092	1101	2193	987	-4.7196	0.0000	-41.4357	0.0000	-41.3778	0.0000	0.2569	–
	HGY	0.0420	0.0246	5.28E-04	1453	740	2193	731	-11.9708	0.0000	-44.8837	0.0001	-44.8471	0.0001	0.1326	–
	POL	0.1430	0.0000	4.82E-04	1411	1303	2714	1255	-3.8786	0.0001	-45.0239	0.0001	-45.2754	0.0001	0.4166	0.1000
	RUS	0.0930	0.0000	5.80E-04	1113	1079	2192	957	-5.9720	0.0000	-42.6259	0.0000	-42.8094	0.0000	0.0732	–

Notes: Developed markets: AUS – Austria, BEL – Belgium, DEN – Denmark, FIN – Finland, FRA – France, GER – Germany, GRE – Greece, IRE – Ireland, ITL – Italy, NTH – Netherlands, NRW – Norway, POR – Portugal, SPN – Spain, SWE – Sweden, SWI – Switzerland, UNK – United Kingdom. Emerging markets: CZH – Czech Republic, HGY – Hungary, POL – Poland, RUS – Russia. For Augmented Dickey-Fuller (ADF) tests hypotheses are H_0: unit root, H_1: no unit root (stationary). The lag orders in the ADF equations are determined by the significance of the coefficient for the lagged terms. Intercepts only in the series. The Phillips-Peron (PP) unit root test hypotheses are H_0: unit root, H_1: no unit root (stationary). Intercepts only in the series. The Kwiatkowski, Phillips, Schmidt and Shin (KPSS) unit root test hypotheses are H_0: no unit root (stationary), H_1: unit root. The asymptotic critical values for the KPSS LM test statistic at the .10, .05 and .01 levels are 0.3470, 0.4630 and 0.7390 respectively.

TABLE 3. *Multiple variance ratio tests for European developed and emerging markets*

	Statistics	Market	q = 2	q = 5	q = 10	q = 20	Market	q = 2	q = 5	q = 10	q = 20
Developed markets	VRq	AUS	1.1487	1.2637	1.3282	1.4212	ITL	1.0825	1.0963	1.0606	1.1220
	Zq		*9.4268	7.6292	6.1624	5.3729		*5.2277	2.7879	1.1374	1.5560
	Z*q		*6.1334	4.8845	4.0860	3.8612		*4.0982	2.1631	0.9080	1.2891
	VRq	BEL	0.9334	0.6369	0.4341	0.3321	NTH	1.0207	0.9373	0.8476	0.8272
	Zq		-4.3567	-10.8418	*-10.9656	-8.7923		1.3122	-1.8156	*-2.8622	-2.2037
	Z*q		-1.1228	-3.0300	*-3.3583	-3.0006		0.7930	-1.0995	-1.7459	-1.3654
	VRq	DEN	0.7422	0.4700	0.2801	0.1403	NRW	0.9665	0.9072	0.8776	0.9048
	Zq		*-16.8674	-15.8271	-13.9488	-11.3171		-2.1260	*-2.6866	-2.2975	-1.2141
	Z*q		-6.7929	-7.0915	*-7.3321	-7.2844		-0.3741	-0.6342	-0.7205	-0.5045
	VRq	FIN	0.7660	0.6143	0.5648	0.5749	POR	1.0109	1.0448	1.0715	1.1051
	Zq		*-14.8357	-11.1618	-8.1714	-5.4224		0.4938	0.9225	0.9556	0.9547
	Z*q		-1.3548	-1.3903	-1.3869	-1.2705		0.1174	0.2930	0.3964	0.5052
	VRq	FRA	1.0524	1.0011	0.9300	0.9118	SPN	0.9012	0.8041	0.7629	0.7802
	Zq		*3.3225	0.0308	-1.3145	-1.1256		*-6.2610	-5.6672	-4.4523	-2.8036
	Z*q		2.4076	0.0220	-0.9577	-0.8420		-0.8939	-1.0975	-1.1601	-0.9833
	VRq	GER	0.9910	0.9505	0.9042	0.9027	SWE	1.0302	1.0060	0.9563	0.9878
	Zq		-0.5688	-1.4327	-1.7987	-1.2414		1.9119	0.1724	-0.8213	-0.1562
	Z*q		-0.3761	-0.9642	-1.2478	-0.8940		0.9532	0.0989	-0.5276	-0.1099
	VRq	GRE	0.7904	0.5584	0.3027	0.1141	SWI	0.7112	0.4348	0.2532	0.1253
	Zq		*-13.2889	-12.7790	-13.0920	-11.3000		*-18.8945	-16.8769	-14.4710	-11.5138
	Z*q		-4.1853	-4.3961	-5.2418	*-5.6087		*-7.4575	-7.2291	-7.2578	-7.1568
	VRq	IRE	0.9917	0.9823	0.9511	0.9868	UNK	1.0363	0.9560	0.8809	0.8706
	Zq		-0.5289	-0.5121	-0.9184	-0.1683		2.3011	-1.2738	-2.2359	-1.6504
	Z*q		-0.1406	-0.1784	-0.4091	-0.0944		1.6915	-0.9352	-1.6692	-1.2635
Emerging markets	VRq	CZH	1.1221	1.1910	1.1723	1.3414	POL	1.1452	1.3358	1.4047	1.6208
	Zq		*5.7185	4.0822	2.3902	3.2165		7.5629	*7.9845	6.2440	6.5076
	Z*q		*4.6378	3.2832	1.9160	2.6147		5.2307	*5.3495	4.2133	4.5407
	VRq	HGY	1.0427	1.0437	1.0233	1.1223	RUS	1.0939	1.2094	1.2882	1.4989
	Zq		1.9987	0.9331	0.3228	1.1520		4.3948	*4.4755	3.9960	4.6997
	Z*q		1.9141	0.9187	0.3273	1.1975		1.9353	2.3035	2.3310	*2.9737

Notes: Developed markets: AUS – Austria, BEL – Belgium, DEN – Denmark, FIN – Finland, FRA – France, GER – Germany, GRE – Greece, IRE – Ireland, ITL – Italy, NTH – Netherlands, NRW – Norway, POR – Portugal, SPN – Spain, SWE – Sweden, SWI – Switzerland, UNK – United Kingdom. Emerging markets: CZH – Czech Republic, HGY – Hungary, POL – Poland, RUS – Russia. VR(q) – variance ratio estimate, Z(q) - test statistic for null hypothesis of homoskedastic increments random walk, Z* (q) - test statistic for null hypothesis of heteroskedastic increments random walk; the critical value for Z(q) and Z*(q) at the 5 percent level of significance is 2.49, asterisk indicates significance at this level; Sampling intervals (q) are in days.