Efficiency tests in the Iberian stock markets

Testes de eficiência aos mercados de acções ibéricos

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Abstract
This paper investigates the efficiency of the two major stock indexes of the Iberian Peninsula, the Portuguese Stock Index (PSI-20) and the Spanish Stock Index (IBEX-35). We used daily data from January 1993 to September 2001 for the Portuguese stock index and daily data from October 1990 to September 2001 for the Spanish stock index.
Serial correlations, unit root tests and variance ratio tests are used to test the efficiency of these two stock indexes. Although the complementary of these tests, we used all of them to get a higher robustness of the conclusions. We examined serial correlation coefficients for successive stock index changes to test whether they are statistically equal to zero to establish the random walk nature of stock indexes. The augmented Dickey-Fuller (ADF) test are used to test the null hypothesis that the series has a unit root and the variance ratio tests are used to examine the random walk hypothesis for the series of these two stock indexes.
The results of the serial correlations, unit root tests and variance ratio tests provide ambiguous evidence for the random walk hypothesis. The empirical evidence from the unit root tests do not reject the efficient market hypothesis for the two stock indexes, while the results from the variance ratio tests and serial correlations do.
Keywords: stock indexes; market efficiency; unit roots

Resumo
Este trabalho investiga a eficiência de mercado dos dois principais índices de acções da Península Ibérica, o índice de acções português (Portuguese Stock Index, PSI-20) e o índice de acções espanhol (Spanish Stock Index, IBEX-35). Foram utilizados três tipos de testes para avaliar a eficiência dos dois índices de acções: testes de correlação em série, testes de raízes unitárias e testes do rácio de variância. A evidência empírica dos testes de raízes unitárias não rejeita a hipótese de mercado eficiente para os dois índices, enquanto que os resultados empíricos dos testes do rácio de variância e dos testes de correlação em série rejeitam a hipótese destes dois mercados serem eficientes.
Palavras-chave: índices de acções; eficiência de mercado; correlação em série; raízes unitárias; rácio de variância

1. Introduction

The concept of efficiency is extremely important to finance because the hypothesis that securities markets are efficient represents the basis for most research that is made in financial economics. This concept is used to describe a market in which the price of financial assets fully reflect all of the available information that is relevant, i.e., its prices exhibit an unpredictable behaviour, given all of disposal information. In other words, the theory define an efficient market as one in which the use of the available information do not permit that any investor can be able to consistently obtain an abnormal return. So, in an efficient market the price of a security is an unbiased estimate of its true value. This means that an efficient market does not require that the market price of the security must be equal to its true value at every point in time. Indeed, all it requires is that the errors in the market price be unbiased, i.e., each price can be greater than or less than its true value, as long as these errors are random.

The concept of market efficiency was originally anticipated by Bachelier (1900), but his contribution receives more highlights after it was published in English by Cootner (1964). There were subsequent works such as Working (1934), Cowles and Jones (1937), Kendall (1953) and Fama (1965) who examined serial correlation coefficients for successive price changes and had concluded that the behaviour of the stock prices follows a randomly process that was labelled as the random walk model. The subsequent research about the market efficiency have used a new methodology to test the random walk nature of stock prices that is known by unit root tests, developed by Dickey and Fuller (1979, 1981), among others. Due to the lack of power of the unit root tests and even its fail to detect some deviations from the random walk nature of time series, it was developed another type of tests for the market efficiency hypothesis labelled as the variance ratio tests originated from the pioneering works of Cochrane (1988), Lo and MacKinlay (1988, 1989) and Chow and Denning (1993).

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Most of the research on the random walk hypothesis is concentrated on the major stock markets of the world (Summers (1986), Fama and French (1988), Lo and MacKinlay (1988) and Poterba and Summers (1988)). With the recent developments of some other markets, however, it is interesting to study the dynamics of its equity markets. In this sense, the purpose of this paper is to investigate the efficiency of the two major stock indexes of the Iberian Peninsula, the Portuguese Stock Index (PSI-20) and the Spanish Stock Index (IBEX-35). Serial correlations, unit root tests and variance ratio tests are used to test the efficiency of these two stock indexes. Although the complementary of these tests, we used all of them to get a higher robustness of the conclusions.

The remainder of the paper is organised as follows. Section 2 reviews the literature of market efficiency tests. Section 3 describes the data and discusses the empirical methodology and test hypothesis used. Section 4 reports the empirical results. Section 5 summarises the findings of this paper.

2. Literature review

There are two competing schools of thought about market efficiency. On the one hand, one of them argues that markets are efficient and returns are unpredictable. Fama (1970) summarises the early works, which largely concludes that the stock market is efficient. On the other hand, the works of Summers (1986), Fama and French (1988), Lo and MacKinlay (1988) and Poterba and Summers (1988), among others, shows empirical evidence against the random walk hypothesis of stock returns. The existence or absence of a random walk nature in stock prices has important implications. Indeed, if the stock return dynamics do not follows a randomly process, than it is possible to design a profitable trading strategy based on historical stock prices.

The early tests about market efficiency examined serial correlations of daily and weekly stock returns, which largely concludes that the stock market is efficient[1], i. e., the stock prices follows a randomly process. The hypothesis of a pure random walk model is given by the following equation:

$$p_t = \alpha + p_{t-1} + \varepsilon_t \qquad (1)$$

where p_t is the natural logarithm of the securities price series under consideration at time t, α is a drift parameter and ε_t is the random error term. The usual stochastic assumptions of ε is that $E(\varepsilon) = 0$ and $E(\varepsilon^2) = \sigma^2$.

Summers (1986) challenges the way as the efficient market hypothesis is tested in the early tests. He argues that the commonly used tests to evaluate market efficiency have very low power. If a market is inefficient it means that prices have slowly decaying stationary components. He shows that serial correlations of short-horizon returns cannot give a clearer impression of the importance of these mean-reverting price components, because the slow mean reversion can be missed with the short return horizons commonly used in the efficiency tests. Based on these findings, Fama and French (1988) conduct efficiency tests which try to identify if the behaviour of long-horizon returns can shows the importance of mean-reverting price components. They use a model for stock prices that is the sum of a random walk and a stationary component. In their tests they find a pattern that is consistent with the hypothesis that stock prices have a slowly decaying stationary component. At the short return horizons the negative serial correlations generated by a slowly decaying component is weak, but it becomes stronger as the return horizon increases. So, it is clear that the random walk properties of securities returns are crucial for the efficient market hypothesis. Indeed, if a security price series follows a random walk process, it manifests significant permanent components and hence there is no mean-reversion tendency. But on the other hand, if a security price series do not follows a randomly process and presents significant temporary components, than it is possible to predict the future security prices based on historical prices. In this case, it is possible to design a profitable trading strategy based on historical data.

The subsequent research about the market efficiency has used a new methodology to test the random walk nature of stock prices that is known by unit root tests[2]. This methodology is used to examine the stationarity of the time series and was developed by Dickey and Fuller (1979, 1981), among others. The most commonly used test to examine the existence of a unit root is the augmented Dickey-Fuller

[1] A summarised description of these early works can be found in Fama (1970).
[2] A random walk is a special case of a unit root process.

(ADF) test[3]. For example, Käppi (1997) use this procedure to test the stationarity of yield series before examine the cointegration between yields on bonds and futures contracts on coupon bonds.

Due to the lack of power of the unit root tests and even its fail to detect some deviations from the random walk nature of time series, it was developed another type of tests for the market efficiency hypothesis labelled as the variance ratio tests. This kind of tests was originated from the pioneering works of Cochrane (1988), Lo and MacKinlay (1988, 1989) and Chow and Denning (1993). For example, Urrutia (1995) used the variance ratio methodology to test the hypothesis that Latin American emerging equity market prices (Argentina, Brazil, Chile and Mexico) follow a random walk. The empirical evidence found in this study reject the random walk hypothesis for the four Latin American markets, but the results from runs tests indicate that these markets are weak-form efficient. Thus, these results suggest that domestic investors might not be able to detect patterns in stock prices which permit the design of trading strategies to earn abnormal returns. However, this author did not use the Chow and Denning (1993) critical values that control the level of significance when there are multiple comparisons. Ojah and Karemera (1999) study the efficiency of the same Latin American markets, but they use additionally the multiple variance ratio test of Chow and Denning (1993)[4]. Their results suggest that the four Latin American markets follow a random walk which indicates market efficiency. So, the international investors of these markets cannot use historical data to establish systematically a profitable trading strategy because future long-term returns are not dependent on past returns. For the Portuguese securities market Gama (1998) use the variance ratio test of Lo and MacKinlay (1988) and conclude that this market do not follow a random walk process. However, this author did not use the multiple variance ratio test of Chow and Denning (1993).

The methodology of variance ratio test has been also used to analyse the efficiency of other financial assets. For example, Liu and He (1991) use the procedure of Lo and MacKinlay (1988) to provide empirical evidence of the random walk hypothesis in five pairs of foreign exchange rates (CAN/USD, FRF/USD, DEM/USD, JPY/USD and GBP/USD) and they reject the random walk hypothesis. Lee and Mathur (1999) use this methodology to test the efficiency of four futures contracts traded on the Spanish futures markets and have concluded that they are efficient.

As state above, serial correlations, unit root tests and variance ratio tests can be used to test the efficiency hypothesis. Although the complementary of these tests, they can be used all together to get a higher robustness of the conclusions. Lee, Gleason and Mathur (2000) used all of them to test the efficiency of four financial futures contracts and have obtained overwhelming evidence that the random walk hypothesis cannot be rejected for all of the contracts. As suggested by the empirical evidence cited above, it should be mentioned that we cannot conclude that any market is efficient or not without making an empirical test.

3. Data and methodology

3.1. Data

We use daily data from January 1993 to September 2001 for the Portuguese Stock Index and daily data from October 1990 to September 2001 for the Spanish stock index. The PSI-20 is the most important index of the Euronext Lisbon. The PSI-20 is a cap weighted index that includes the twenty most liquid and representative shares from the universe of companies listed on the Portuguese main market. For ordinary reviews, the index composition is revised each six months, in January and July, but the Technical Committee may decide to do an extraordinary review. The PSI-20 was launched with two objectives: to act as a benchmark for the Portuguese equity market; and to act as the underlying variable for futures and options contracts. The IBEX-35 is the most important index of the Spanish stock market. The IBEX-35 is composed of the thirty five securities quoted on the Joint Stock Exchange System of the four Spanish Stock Exchanges, which were most liquid during the control period. This control period for the securities included in the index shall be, for ordinary reviews, the six-month interval beginning with the seventh month prior to the start of the calendar half-year period. For extraordinary reviews, the control period should be decided by the Technical Advisory Committee at that time. Figures 1 and 2 shows the PSI-20 and the IBEX-35 series of open-high-low-close prices, respectively.

[3] A detailed description of other tests used to examine the existence of a unit root can be found in Maddala and Kim (1998).
[4] In their study, they have also used the auto-regressive fractionally integrated moving average test of Geweke and Porter-Hudak (1983) to test the random walk hypothesis of these markets. Even with this methodology they found that the market prices of Argentina, Brazil, Chile and Mexico follow a random walk.

Fig. 1. PSI-20 series of open-high-low-close prices during
4 January 1993 to 10 September 2001

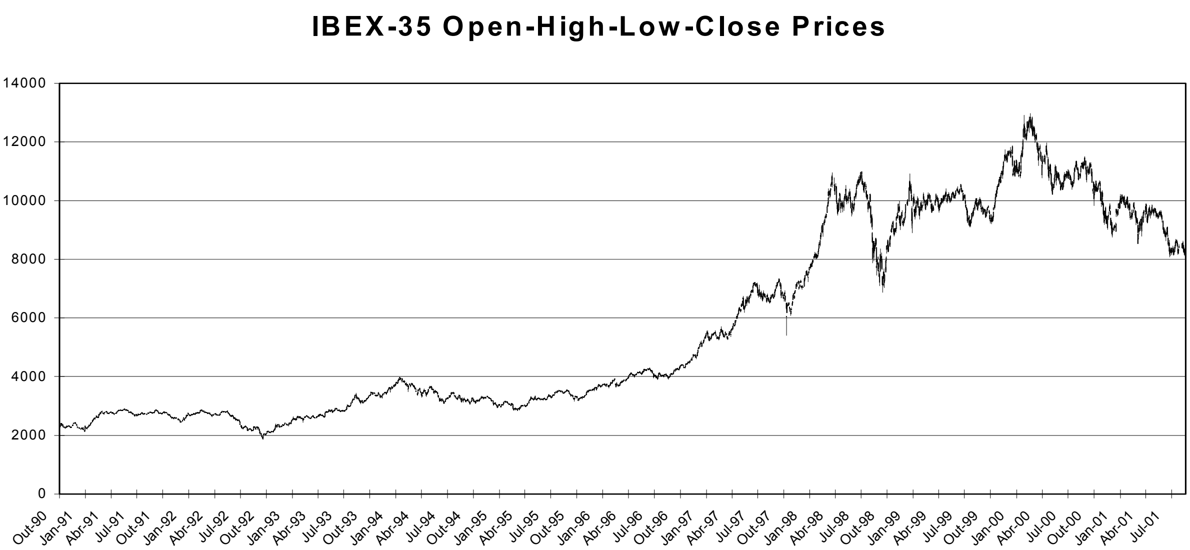

Fig. 2. IBEX-35 series of open-high-low-close prices during
18 October 1990 to 6 September 2001

3.2. Methodology

To investigate the difference in volatility during trading and non-trading periods we use both open-to-open $\Delta\rho_{O-O}$ and close-to-close $\Delta\rho_{C\text{-}C}$ returns, which are respectively based on opening prices and on closing prices. These returns are calculated as follows:

$$\Delta p_{O_t - O_{t-1}} = \ln\left(p_{O_t} / p_{O_{t-1}}\right)$$

and

$$\Delta p_{C_t - C_{t-1}} = \ln\left(p_{C_t} / p_{C_{t-1}}\right)$$

In order to incorporate the intraday volatility, we also use middle-to-middle $\Delta\rho_{M-M}$ returns, which is a value estimator based on opening prices, closing prices and daily high and daily low prices. This return is calculated as follows:

$$\Delta p_{M_t - M_{t-1}} = \ln\left(p_{M_t} / p_{M_{t-1}}\right)$$

where P_{M_t} is determined by:

$$P_{M_t} = \frac{open_t + high_t + low_t + close_t}{4}$$

Serial correlations, unit root tests and variance ratio tests are used to test the efficiency of these two stock indexes. Although the complementary of these tests, we used all of them to get a higher robustness of the conclusions. We examined serial correlation coefficients for successive stock index changes to test whether they are statistically equal to zero to establish the random walk nature of stock indexes. Indeed, these tests are tests of a linear relationship between today's returns and past returns. This issue is estimated by the following regression:

$$r_t = \alpha + \beta r_{t-1-L} + \varepsilon_t \qquad (2)$$

where the term α measures the expected return that is unrelated to previous return and the term β measures the relationship between the previous return and today's return. If L=0, then it represents the relationship between today's return and yesterday's return. If L=1, it represents the relationship between today's return and the return two periods previously and so on. The term ε_t incorporates the variability of the return that is not related with the previous returns.

For econometric purposes, the financial literature highlights the notorious papers of Dickey and Fuller (1979, 1981). The augmented Dickey-Fuller test (ADF test) is appropriate to test the presence of a unit root, i. e., an *I(1)* process. This procedure tests the presence of a unit root as the null hypothesis by estimating the regression on the natural logarithm of the stock index prices. This issue is addressed by the following formulation:

$$p_t = \mu + \beta t + \gamma p_{t-1} + \varepsilon_t \qquad (3)$$

A convenient reformulation of the *I(1)* model is:

$$\Delta p_t = \mu + \gamma^* p_{t-1} + \varepsilon_t \qquad (4)$$

where

$$\gamma^* = \gamma - 1$$

With this reformulation the ADF test is carried out by the following model:

$$\Delta p_t = \mu + \beta t + \gamma^* p_{t-1} + \sum_{j=1}^{L} \phi_j \Delta p_{t-j} + \varepsilon_t \qquad (5)$$

where L is the lag parameter. This model has a time trend where t is the number of observations. The presence of an unit root is tested by using the joint hypothesis that $\beta = \gamma = 0$. If the null hypothesis is not rejected the random walk hypothesis is supported which implies market efficiency. In this case, the efficiency market hypothesis is tested using unit root as null. Indeed, it is assumed that the null hypothesis is correct but it is not given any relevant alternative hypothesis. As suggested by Summers (1986) the usefulness of any test of a hypothesis depends on its ability to discriminate between it and other plausible alternative hypothesis. This issue can be addressed by conducting alternative tests of stationarity, i.e., we test the null hypothesis of stationarity and a unit as the alternative hypothesis[5]. So, these tests can be used to confirm our conclusions about unit roots.

One of these tests was developed by Kwiatkowski et al. (1992) (KPSS test) which start with the following model:

$$y_t = \delta t + \zeta_t + \varepsilon_t \quad (6)$$

where ε_t is a stationary process and ζ_t is a random walk given by

$$\zeta_t = \zeta_{t-1} + \mu_t \quad (7)$$

where $\mu_t \sim iid\left(0, \sigma^2_\mu\right)$. The null hypothesis of stationarity is formulated as $\sigma^2_\mu = 0$ or ζ_t is a constant. This is a special case of a test for parameter constancy against the alternative that the parameters follow a random walk process. For testing the null of level stationarity instead of trend stationarity the test statistic is calculated as follows:

$$\eta_\tau = T^{-2} \sum_{t=1}^{T} \frac{S_t^2}{S^2(L)} \quad (8)$$

where L is the lag parameter, S_t is the cumulative sum of the residuals (e_t) from a regression of the series on a constant and a linear trend (i.e., $S_t = \sum e_t, t = 1, 2, ..., T$) and where $S^2(L)$ is calculated by the following formulation:

$$S^2(L) = T^{-1} \sum_{t=1}^{T} e_t^2 + T^{-1} \sum_{S=1}^{L} \left(1 - S/(L+1)\right) \sum_{t=S+1}^{T} e_t \, e_{t-S} \quad (9)$$

The null hypothesis of stationarity is rejected in favour of the unit root alternative hypothesis if the calculated test statistic exceeds the critical values estimated in Kwiatkowski et al. (1992).

Due to the lack of power of the unit root tests and even its fail to detect some deviations from the random walk nature of time series, it was developed another type of tests for the market efficiency hypothesis labelled as the variance ratio tests. Indeed, although the presence of a unit root supports market efficiency, Liu and He (1991) have shown that unit root tests may not detect departures from a random walk. The variance ratio tests were originated from the pioneering works of Cochrane (1988), Lo and MacKinlay (1988, 1989) and Chow and Denning (1993).

The single variance ratio test of the random walk hypothesis tests the null that the variance ratio equals one at all horizons of $q>1$. If the null hypothesis is not rejected there is evidence of a random walk process and hence efficiency market. The presence of variance ratios greater than one at horizons of less than one year reveals positive serial correlation, i.e., is consistent with investor overreaction in the short run. The presence of variance ratios less than one at horizons greater than one year indicates negative serial correlation, i.e., is consistent with a mean-reversion process in the long run. Our analysis does not allow us to conclude about this last issue.

By recognising that the procedure of Lo and MacKinlay (1988) for the variance test ratio involves multiple comparisons, i.e., at each horizon we conduct a hypothesis test, Chow and Denning (1993) obtain a bound for the overall dimension of the test. Thus, the multiple variance ratio procedure provides both a multiple comparison of variance ratios and a control of the joint test size. By using one-day as the base observation interval, we calculate variance ratio estimates ($VR(q)$), asymptotic variances of the variance ratio ($\phi(q)$ and $\phi^*(q)$) and variance ratio test statistics ($Z(q)$ and $Z^*(q)$) for each of the cases q = 2, 4, 8, 16, 32, 64, 128 and 256 (see Appendix A for additional

[5] There have been several tests for stationarity as null. For a description of these tests see Maddala and Kim (1998).

details). We also compute the multiple variance ratio estimates $\left(Max \left\{ \left| Z^*(q) \right| \right\} \right)$ which give the largest of the absolute values of the test statistics (see Appendix B for additional details).

4. Empirical results

4.1. Basic statistics

Table 1 presents the basic statistics of daily returns. The returns are not normally distributed. Rather, they are characterised by significantly high skewness and kurtosis. For the index PSI-20, the open-to-open returns have higher standard deviation than the close-to-close returns, suggesting that the agents in the market have different behaviours. In the IBEX-35 index we found a different result. The volatility is almost the same, suggesting that the open and the close prices are not influenced by different behaviours of market participants. The skewness and kurtosis of the PSI-20 are higher than the IBEX-35 and they are all very significantly different from zero.

Table 1: Basic statistics for returns

	PSI-20			IBEX-35		
	O-O	C-C	M-M	O-O	C-C	M-M
Observations	2145	2145	2145	2707	2707	2707
Sample mean	0.000417	0.000419	0.000417	0.000483	0.000461	0.000472
Std. dev.	0.013617	0.010939	0.010834	0.012696	0.012740	0.011122
SE mean	0.000294	0.000236	0.000234	0.000244	0.000244	0.000214
t-Statistic	1.419	1.773	1.782	1.981	1.883	2.209
Sign. Level (Mean=0)	0.156	0.076	0.075	0.048	0.060	0.027
Skewness	-0.301	-0.661	-0.702	-0.266	-0.247	-0.473
Sign. Level (Sk=0)	0.000	0.000	0.000	0.000	0.000	0.000
Kurtosis	73.886	8.029	32.643	6.250	2.978	5.273
Sign. Level (Ku=0)	0.000	0.000	0.000	0.000	0.000	0.000

4.2. Serial correlation results

Table 2 reports the Q statistics of the Ljung-Box test. With the exception of Q(10), Q(15) and Q(20) statistics for the PSI-20 open-to-open returns and Q(5) statistic for the IBEX-35 open-to-open returns, these statistics show that the white noise hypothesis can be rejected for any series. In the 48 Q statistics reported, those 4 are not significant, 1 is significant at the 10% level, 7 at the 5% level and 36 at the 1% level.

Table 2: Serial correlations of returns, Ljung-Box test

	PSI-20			IBEX-35		
	O-O	C-C	M-M	O-O	C-C	M-M
Q(5)	11.0534 (0.0503)	84.1500 (0.0000)	84.4923 (0.0000)	7.8445 (0.1650)	24.6559 (0.0002)	190.7496 (0.0000)
Q(10)	12.0816 (0.2796)	89.7480 (0.0000)	90.0179 (0.0000)	21.6454 (0.0170)	31.1394 (0.0006)	198.1402 (0.0000)

Q(15)	18.1492 (0.2549)	109.9127 (0.0000)	102.0924 (0.0000)	41.3893 (0.0003)	60.8482 (0.0000)	231.1534 (0.0000)
Q(20)	18.7227 (0.5399)	117.5195 (0.0000)	104.9524 (0.0000)	43.8838 (0.0016)	70.5716 (0.0000)	235.6747 (0.0000)
Q(25)	42.4148 (0.0162)	142.7494 (0.0000)	126.2496 (0.0000)	46.1185 (0.0062)	73.0487 (0.0000)	238.9884 (0.0000)
Q(30)	48.0039 (0.0198)	149.7132 (0.0000)	134.6981 (0.0000)	49.3258 (0.0146)	73.8590 (0.0000)	240.1162 (0.000)
Q(35)	52.9964 (0.0261)	157.4878 (0.0000)	140.0452 (0.0000)	56.6915 (0.0116)	80.7443 (0.0000)	248.1297 (0.0000)
Q(40)	62.4010 (0.0132)	162.5243 (0.0000)	149.1959 (0.0000)	64.4772 (0.0084)	85.1578 (0.0000)	256.7746 (0.0000)

4.3. Unit root test results (ADF)

Table 3 reports the results of the unit root tests. The ADF results show that the null hypothesis of one unit root cannot be rejected for any of the two indexes. An interesting result comes from the sign of the test statistics in the ADF test without constant and trend (notice that the coefficients of the constant and of the constant and trend in the two other regressions are not significant), suggesting that the strongest alternative to the unit root hypothesis is not the stationarity of the series but that the series are explosive. The analysis of the graphics of the series suggestions are in the same direction.

4.4. Stationarity test results (KPSS)

Also in Table 3 are the results of stationarity tests performed by the KPSS test. The null hypothesis of stationarity is rejected for the two indexes, confirming the ADF results and supporting the efficiency of these markets.

Table 3: Unit root and stationarity tests

	PSI-20			IBEX-35		
	O-O	C-C	M-M	O-O	C-C	M-M
ADF test ^{nc}						
Test statistics	1.4019	1.1196	1.3727	1.8003	1.6652	1.7626
Lags in ADF	3	13	3	7	13	7
ADF test ^{c}						
Test statistics	-1.7405	-1.6391	-1.7532	-0.9254	-1.0790	-0.9583
Lags in ADF	3	13	3	7	13	7
Coef. constant	0.00985	0.00736	0.00777	0.00383	0.00437	0.00332
T-stat. coef. const.	1.8195	1.7024	1.8306	1.0486	1.1936	1.0789
ADF test ^{ct}						
Test statistics	0.1512	-0.1510	0.1810	-1.2304	-1.2102	-1.1758
Lags in ADF	3	13	3	7	13	7
Coef. constant	-0.00018	0.00236	-0.00040	0.01254	0.01247	0.01014
T-stat. coef. const.	-0.0168	0.2653	-0.0459	1.3002	1.2843	1.2472
Coef. linear trend	-0.00000	-0.00000	-0.00000	0.00000	0.00000	0.00000
T-stat. trend	-1.0434	-0.6453	-1.0837	0.9759	0.9005	0.9060
KPSS test						

H_0: series is stationary around a level[a]						
Test statistic: L=0	187.497	187.416	187.489	255.110	255.102	255.111
Test statistic: L=5	31.313	31.297	31.308	42.581	42.578	42.578
Test statistic: L=10	17.111	17.102	17.108	23.255	23.253	23.253
KPSS test						
H_0: series is trend stationary[b]						
Test statistic: L=0	19.138	19.242	19.186	26.865	26.813	26.836
Test statistic: L=5	3.214	3.229	3.220	4.506	4.498	4.500
Test statistic: L=10	1.764	1.773	1.768	2.471	2.467	2.468

[nc] Regression with no constant and no trend. Critical values are –1.95 and –2.58 at the 5% and 1% levels, respectively. The null hypothesis that the series is I(1), i.e., non-stationary, is rejected if the test statistic exceeds the critical value.

[c] Regression with constant and no trend. Critical values are –2.86 and –3.43 at the 5% and 1% levels, respectively.

[ct] Regression with constant and trend. Critical values are –3.41 and –3.96 at the 5% and 1% levels, respectively.

[a] Critical values are 0.347, 0.463, 0.574 and 0.739 at the 10%, 5%, 2.5% and 1% levels, respectively. The null hypothesis that the serie is stationary is rejected if the test statistic exceeds the critical value, i.e., the series has a unit root.

[b] Critical values are 0.119, 0.146, 0.176 and 0.216 at the 10%, 5%, 2.5% and 1% levels, respectively. The null hypothesis that the serie is stationary is rejected if the test statistic exceeds the critical value, i.e., the series has a unit root.

4.5. Variance ratio tests

Table 4 provides some evidence that the random walk hypothesis can be rejected for the price series. Before adjusting for heteroscedasticity in the return series, the hypothesis that the variance ratio is one can be rejected (37 in 48 tests reject the hypothesis, 21 in 24 for the PSI-20 index and 16 in 24 for the IBEX-35 index). After adjusting for heteroscedasticity, the hypothesis that the variance ratio is one can still be rejected with higher evidence for the PSI-20 (22 in 48 tests reject the hypothesis, 15 in 24 for the PSI-20 index and 7 in 24 for the IBEX-35 index). We also perform the multivariate variance ratio test on tests adjusted for heteroscedasticity (Chow and Denning (1993)), which is a more robustness test. At the 5% level, the hypothesis of random walk is rejected for the close-to-close returns of the PSI-20 index and for the mean-to-mean returns of the IBEX-35 index. The hypothesis can also be rejected for the mean-to-mean returns of the PSI-20 index at the 10% level.

Table 4: Estimate of variance-ratio VR(q), variance-ratio test statistics Z(q) and Z*(q) and multivariate variance-ratio test statistic Max{Z*(q)}

	PSI-20			IBEX-35		
	O-O	C-C	M-M	O-O	C-C	M-M
Q	2	2	2	2	2	2
VR(q)	0.94433	1.18834	1.18448	1.03503	1.08456	1.25847
Z(q)	-2.57813	8.72283	8.54402	1.82276	4.39981	13.44782
Signif. Level of Z(q)	0.00497	1.36e-18	6.48e-18	0.03417	5.42e-06	1.59e-41
Z*(q)	-0.20831	2.37836	1.05487	0.46197	1.56791	3.78657
Signif. Level of Z*(q)	0.41749	0.00869	0.14574	0.32205	0.05845	7.64e-05
Q	4	4	4	4	4	4
VR(q)	0.92996	1.29572	1.32283	1.05542	1.07812	1.33619
Z(q)	-1.73395	7.32074	7.99201	1.54136	2.17251	9.34957
Signif. Level of Z(q)	0.04146	1.23e-13	6.64e-16	0.06161	0.01491	4.40e-21
Z*(q)	-0.24699	2.42604	1.58904	0.46752	084045	3.13421
Signif. Level of Z*(q)	0.40246	0.00763	0.05603	0.32006	0.20033	8.62e-04
Q	8	8	8	8	8	8
VR(q)	0.97929	1.43078	1.47006	1.04796	1.04888	1.34438

Z(q)	-0.32432	6.74468	7.35981	0.84362	0.85974	6.05727
Signif. Level of Z(q)	0.37285	7.67e-12	9.21e-14	0.19944	0.19497	6.92e-10
Z*(q)	-0.06885	2.49216	1.98232	0.29069	0.34467	2.20507
Signif. Level of Z*(q)	0.47255	0.00635	0.02372	0.38565	0.36517	0.01372
Q	16	16	16	16	16	16
VR(q)	1.07480	1.62636	1.66350	1.12275	1.11839	1.45396
Z(q)	0.78706	6.59052	6.98124	1.45092	1.39935	5.36586
Signif. Level of Z(q)	0.21562	2.19e-11	1.46e-12	0.07340	0.08085	4.03e-08
Z*(q)	0.22495	2.57005	2.29824	0.52749	0.58068	2.05580
Signif. Level of Z*(q)	0.41101	0.00508	0.01077	0.29893	0.28073	0.01990
Q	32	32	32	32	32	32
VR(q)	1.26584	1.93983	1.98323	1.26506	1.25711	1.64360
Z(q)	1.93020	6.82386	7.13901	2.16197	2.09713	5.24963
Signif. Level of Z(q)	0.02679	4.43e-12	4.70e-13	0.01531	0.01799	7.62e-08
Z*(q)	0.66930	2.84215	2.68880	0.83761	0.92720	2.18426
Signif. Level of Z*(q)	0.25165	0.00224	0.00359	0.20113	0.17691	0.01447
Q	64	64	64	64	64	64
VR(q)	1.45196	2.22707	2.27943	1.23239	1.22265	1.60272
Z(q)	2.29287	6.22508	6.49073	1.32443	1.26890	3.43495
Signif. Level of Z(q)	0.01093	2.41e-10	4.27e-11	0.09268	0.10224	2.96e-04
Z*(q)	0.90625	2.76275	2.67773	0.57636	0.60670	1.59057
Signif. Level of Z*(q)	0.18240	0.00287	0.00371	0.28219	0.27203	0.05585
Q	128	128	128	128	128	128
VR(q)	1.49210	2.29176	2.34548	1.19786	1.18841	1.56019
Z(q)	1.75488	4.60652	4.79812	0.79265	0.75480	2.24420
Signif. Level of Z(q)	0.03964	2.05e-06	8.01e-07	0.21399	0.22519	0.01241
Z*(q)	0.77705	2.12853	2.10474	0.36322	0.37831	1.09816
Signif. Level of Z*(q)	0.21857	0.01665	0.01766	0.35822	0.35260	0.13607
Q	256	256	256	256	256	256
VR(q)	1.49543	2.30585	2.35484	1.13123	1.12403	1.47493
Z(q)	1.24560	3.28315	3.40633	0.37064	0.35032	1.34141
Signif. Level of Z(q)	0.10646	5.13e-04	3.29e-04	0.35545	0.36305	0.08989
Z*(q)	0.56535	1.62902	1.56507	0.18631	0.18850	0.70800
Signif. Level of Z*(q)	0.28592	0.05165	0.05878	0.42610	0.42524	0.23947
Max{Z*(q)}	0.90625	2.84215	2.68880	0.83761	1.56791	3.78657
Critical value at 5% level	2.72739	2.72739	2.72739	2.72739	2.72739	2.72739
Crit. Value at 10% level	2.48148	2.48148	2.48148	2.48148	2.48148	2.48148

Table 5: Summary of the efficiency tests

	PSI-20			IBEX-35		
	O-O	C-C	M-M	O-O	C-C	M-M
Serial correlations	No**	No***	No***	No***	No***	No***
ADF	Yes	Yes	Yes	Yes	Yes	Yes
KPSS	Yes	Yes	Yes	Yes	Yes	Yes
Variance ratio	Yes	No**	No*	Yes	Yes	No**

[Yes] The efficient market hypothesis is supported.

[No] The efficient market hypothesis is not supported.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

5. Conclusion

The results of the serial correlations, unit root tests and variance ratio tests provide ambiguous evidence for the random walk hypothesis. The empirical evidence from the unit root tests do not reject the efficient market hypothesis for the two stock indexes, while the results from the variance ratio tests and serial correlations do (see Table 5.). So, the efficient market hypothesis is under question with higher evidence in the PSI-20 index and it is also in question for the IBEX-35 index.

Further investigation must be done to investigate if the series are predictable and if an eventual model could produce excess returns and compensate the risk of the investment. An hypothesis to investigate is the non-linearity of the series and another one is the cointegration between the two markets.

Appendix A

This appendix presents the formulation for calculating the variance ratio, the variance for the variance ratio and the variance ratio test. The basic idea behind the variance ratio test is that if a time series is a pure random walk like the model given in equation (1), the variance of its *q*-differences grows proportionally with the difference *q*. The variance ratio, *VR(q)*, is defined as:

$$VR(q) = \frac{\sigma_c^2(q)}{\sigma_a^2(q)} \tag{A1}$$

where $\sigma_c^2(q)$ is an unbiased estimator of *1/q* of the variance of the *q*-differences and $\sigma_a^2(q)$ is an unbiased estimator of the variance of the first differences. The formulas for calculating $\sigma_c^2(q)$ and $\sigma_a^2(q)$ are given below in equations (A2) e (A3):

$$\sigma_c^2(q) = \frac{1}{m} \sum_{t=q+1}^{nq+1} \left(p_t - p_{t-1} - q\mu\right)^2 \tag{A2}$$

and

$$\sigma_a^2(q) = \frac{1}{nq-1} \sum_{t=2}^{nq+1} \left(p_t - p_{t-1} - \mu\right)^2 \tag{A3}$$

where

$$m = q(nq - q + 1)(1 - 1/n) \text{ and } \mu = \frac{1}{nq}\left(p_{nq+1} - p_1\right)$$

The standard normal test statistic under the hypothesis of homoscedasticity, *Z(q)*, is:

$$Z(q) = \frac{VR(q) - 1}{\left[\phi(q)\right]^{1/2}} \sim N(0,1) \tag{A4}$$

where $\phi(q) = \left[2(2q-1)(q-1)\right] / \left[3q(nq)\right]$, which is the asymptotic variance of the variance ratio under homoscedasticity.

Lo and MacKinlay (1989) proposed a refined statistic, $Z^*(q)$, which adjusts for heteroscedasticity. The formula for calculating this statistic is given below:

$$Z^*(q) = \frac{VR(q) - 1}{\left[\phi^*(q)\right]^{1/2}} \sim N(0,1) \tag{A5}$$

where $\phi^*(q)$ is the heteroscedasticity-consistent asymptotic variance of the variance ratio, and is given by:

$$\phi^*(q) = \sum_{j=1}^{q-1} \left[\frac{2(q-j)}{q} \right]^2 \delta(j)$$

where

$$\delta(j) = \frac{\sum_{t=j+2}^{nq+1} \left(p_t - p_{t-1} - \mu\right)^2 \left(p_{t-j} - p_{t-j-1} - \mu\right)^2}{\left[\sum_{t=2}^{nq+1} \left(p_t - p_{t-1} - \mu\right)^2 \right]^2}$$

Appendix B

This appendix presents the formulation for calculating the multiple variance ratio of Chow and Denning (1993). By recognising that the procedure of Lo and MacKinlay (1988) for the variance ratio test involves multiple comparisons, i.e., at each horizon we conduct a hypothesis test, Chow and Denning (1993) obtain a bound for the overall size of the test. As we know, the random walk hypothesis requires that the variance ratios of all observation intervals, q`s, be equal to 1.0 simultaneously. So, the procedure of Chow and Denning (1993) provides both a multiple comparison of variance ratios and a control of the joint test size, which is necessary for multiple statistical comparisons.

For a sequence of m horizons we can obtain the test statistic for the variance ratios:

$$Z(q_1), \ldots, = Z(q_m) \qquad \text{(B1)}$$

where the q_i are the horizons that satisfy the following condition:

$$q_1(=2) < q_2 < \ldots < q_m \leq N/2$$

We define $Max\left\{Z^*(q)\right\}$ as the largest of the absolute values of the test statistics, i.e.:

$$Max\left\{Z^*(q)\right\} = Max\left\{\left|Z\left(q_1\right)\right|, \ldots, \left|Z\left(q_m\right)\right|\right\} \qquad \text{(B2)}$$

This variance ratio test is based on the Studentized Maximum Modulus (SMM) distribution. So, its $(1-\alpha)\times 100\%$ confidence interval is defined as:

$$Max\left\{Z^*(q)\right\} \pm SMM(\alpha; m; \infty) \qquad \text{(B3)}$$

where $SMM(\alpha; m; \infty)$ is the asymptotic critical value of the α point of the SMM distribution with parameter m and degrees of freedom ∞. The critical value is obtained from the normal distribution by the equality $SMM(\alpha; m; \infty) = Z_{\alpha^+/2}$, where $\alpha^+ = 1 - (1-\alpha)^{1/m}$. The asymptotic confidence interval for each variance ratio under homoscedasticity is given by:

$$\sqrt{nq}\left(VR\left(q_i\right) - 1\right) \pm \left(2\left(2q_i - 1\right)\left(q_i - 1\right)/3q_i\right)^{1/2} SMM(\alpha; m; \infty) \qquad i = 1, \ldots, m \qquad \text{(B4)}$$

The asymptotic confidence interval for each variance ratio under heteroscedasticity is given by:

$$\sqrt{nq}\left(VR\left(q_i\right) - 1\right) \pm \left(\phi^*(q)\right)^{1/2} SMM(\alpha; m; \infty) \qquad i = 1, \ldots, m \qquad \text{(B5)}$$

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