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Full Length Research Paper

Testing the weak form efficiency of the Turkish stock market

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This paper examines the random walk hypothesis to determine the validity of weak-form efficiency for the Istanbul Stock Exchange (ISE) in Turkey. Data are obtained from daily observations of the ISE indices (ISE-100 index, services index, financial index, industrial index and technology index) for the period October 23, 1987 to July 15, 2011. The random walk hypothesis is tested using parametric and non-parametric tests. The parametric tests include Augmented Dickey-Fuller unit root test, serial autocorrelation test and variance ratio test. The nonparametric tests include Phillips-Peron unit root test and runs test. The empirical results of this study showed that Turkish stock market is weak-form inefficient. With the exception of the results from runs test for both services and technology indices, results from runs test, serial autocorrelation test and variance ratio test are similar and reject random walk hypothesis for Turkish stock market. However, Turkish stock market is inefficient at the weak level; as a result, this is likely to be an evidence that the prudent investor who deals with Turkish stock market will achieve abnormal returns using historical data of stock prices.

Key words: Efficient market hypothesis, weak-form efficiency, the Istanbul stock exchange, parametric and non-parametric tests.

INTRODUCTION

Capital market plays a crucial role in mobilization of domestic resources and channeling them efficiently to raise economic production and productivity. The level of capital market development is thus an important determinant of a country's level of savings, efficiency and investment and ultimately its rate of economic growth (Mahmood, 2007). The Istanbul Stock Exchange (ISE) was established on December 26, 1985 for the purpose of ensuring that securities are traded in a secure and stable environment and commenced to operate on January 3, 1986. The ISE has contributed to the development of Turkish capital markets and Turkish economy since the date of its establishment (http://www.ise.org).

During the past decades, the efficient market hypothesis (EMH) has been at the heart of the debate in the financial literature because of its important implications. Stock market efficiency is an important concept both in terms of an understanding of the working of stock markets and in their performance and contribution of the development of a country's economy. Efficiency in the context of capital market has been defined in many ways but the most common way has been defined it in terms of what sort of information is available to market participants and how they handle that information (Dimson and Mussavian, 1998). In other words, the EMH assumes that stock prices adjust rapidly to the arrival of new information and thus current prices fully reflect all available information (Moustafa, 2004; Aga and Kocaman, 2008). The EMH is a concept of informational efficiency and refers to market's ability to process information into prices. If this is true, it should not be possible for market participants to earn abnormal profits. The EMH is associated with the idea of a "random walk" which is a term loosely used in the finance literature to characterize a price series where all subsequent price changes represent random departures from previous prices (Malkiel, 2003; Gupta et al., 2007). Fama (1970) defined a market as being efficient if prices fully reflect all available information and suggested three models for

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testing market efficiency. According to Fama (1970), EMH can be categorized into three levels based on the definition of the available information set, namely weak form, semi-strong form and the strong form. The weak form of EMH implies that current market prices of stocks are independent on their past prices. In other words, a market is efficient in the weak form if stock prices follow a random walk process. The semi strong-form EMH asserts that prices fully reflect not only the historical information but also all public information including non-market information, such as earning and dividend announcements, economic and political news. Finally, the strong-form EMH contends that stock prices reflects all information from historical, public, and private sources, so that no one investor can realize abnormal rate of return.

Emerging stock markets have recently attracted increasing attention from both researchers and investors. The great interest is not surprising because during early nineties growth of emerging markets are remarkable (Chung, 2006). Today, Turkey is one of the fastest growing emerging economies in the world. This study aims at testing the weak-form of the EMH by applying parametric and nonparametric tests of Random Walk Model (RWM) that will provide clear evidence about the efficiency at the weak level. The study findings are expected to serve the investors for gaining profit, providing an evidence to be added for international evidences and will enable the ISE to improve the level of efficiency.

LITERATURE REVIEW

Over recent decades, there has been a large body of empirical research concerning the validity of the random walk hypothesis or weak-form efficient market hypothesis with respect to stock markets in both developed and developing countries. Empirical research on testing the random walk hypothesis has produced mixed results. This shows some prior studies that tested the weak form efficiency in both the developed and undeveloped markets.

Roberts' (1959) paper is one of the earliest papers on weak form market efficiency. He found that weekly changes of the Dow Jones Index behaved very much as if they had been generated by a simple chance model. He is an illustration of the random walk model for stock prices. Samuelson (1965) and Fama (1970) indicates that the EMH supposes that share price adjust rapidly to the appearance of new information, and thus, current prices fully reflect all available information and should follow a random walk process, which means successive stock price changes (returns) are independently and identically distributed. Laurence (1986) applies both the runs and autocorrelation test on the Kuala Lumpur Stock Exchange (KLSE) and the Stock Exchange of Singapore (SES). He uses price observations of the individual stock from the period 1973 to 1978 for both KLSE and the SES. The results of both tests suggest that both markets are not weak form efficient. Saw and Tan (1989) found that the Malaysian stock market is inefficient in the weak form when weakly data were used but pockets of market efficiency existed when monthly data were used.

Lee (1992) employs variance ratio test to examine whether weekly stock returns of the United States and 10 industrialized countries. He finds that the random walk model is still appropriate characterization of weekly return series of for majority of these countries. Choudhry (1994) investigates the stochastic structure of individual stock indices in seven OECD countries. He concludes that stock markets in seven OECD countries are efficient during the sample period (from the period 1953 to 1989). Dickinson and Muragu (1994) examined Nairobi Stock Exchange (NSE) using the autocorrelation and runs tests. The period of their data is from 1979 to 1989. Their data include weekly prices of the 30 most actively traded stocks. They find that the results support the weak-form of efficient market hypothesis in NSE. Huang (1995) examined the efficiency of nine Asian stock markets: Hong Kong, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore, Thailand and Taiwan by using the variance ratio statistic with both assumptions homoscedastic and heteroskedastic. His data consist of weekly stock returns of nine stock market indices from the period 1988 to 1992. Excluding the market in Indonesia, Japan and Taiwan, the random walk hypothesis for the remaining markets is rejected. Poshakwale (1996) examines weak form efficiency and daily of the week effect on the Bombay Stock Exchange (BSE) in India using daily BSE national data for the period January 1987 to October 1994. He concludes that the Indian stock market is not weak-form efficient. Al-Jefri and Basheikh (1997) confirmed that the Saudi stock market is efficient in the weak form applying the runs test to the weekly prices of 48 stocks for the period of May 1985 to December 1991. Khababa (1998) has examined the behavior of stock price in the Saudi financial market seeking evidence that for weak-form efficiency and find that the market is not weak-form efficient. He explained that the inefficiency might be due to delay in operations and high transaction cost, thinness of trading and illiquidity in the market. Al-Loughani and Chappel (1997) examine the validity of the weak-form of efficient market hypothesis for the United Kingdom stock market. Their data include daily observations of Financial Times Stock Exchange (FTSE) 30-share index from the period June 30, 1983 to November 16, 1989, a period that they describe as free of changing government economic policy toward financial markets. According to their results the series of FTSE 30-share index does not follow a random walk during the sample period. Groenewold (1997) examines both weak and semi-strong forms of the EMH for Australia and New Zealand using daily observations on the Statex Actuaries' Price Index for Australia and the NZSE-40 Index for New Zealand covering the full 1975-1992 sample period. He concludes that past returns in both countries might help to explain the current return in each, but the proportion of variation explained is still small. Karemera et al. (1999) find that the Latin American equity returns follow a random walk and are generally weak-form efficient.

Pant and Bishnoi (2001) have analyzed the behavior of daily and weekly returns of five Indian stock market indices for random walk during April-1996 to June-2001. The results support that Indian stock market indices do not follow random walk. Abraham et al. (2002) test the RWH for three Gulf equity markets; Saudi Arabia, Kuwait, and Bahrain. They find that the RWH and weak form efficiency are rejected for the Gulf markets. Mobarek and Keasey (2002) used the runs and autocorrelation tests to examine the validity of weak-form efficiency for the Dhaka stock market in Bangladesh. Their sample covers 2638 daily observations of daily price indices from the period 1988 to1997. The results of both non-parametric (Kolmogrov –Smirnov normality test and run test) test and parametric test (Auto-correlation test, Auto-regression, ARIMA model) provide evidence that the share return series do not follow random walk model and the significant autocorrelation co-efficient at different lags. Abrosimova at al. (2002) tested for weak-form efficiency using daily, weekly and monthly Russian Trading System Index (RTS) index time series. It was found that the null hypothesis of the random walk could not be rejected for the monthly data while it was rejected for the daily and weekly data. The fact that they have not succeeded in identifying any notable weak-form inefficiencies using daily, weekly or monthly data could be viewed as somewhat surprising, especially given the relative infancy of the Russian market and its associated regulatory institutions. Worthington and Higgs (2004) tested for random walks in sixteen developed markets. They used daily returns of market value weighted equity indices in US dollars from period for sixteen developed markets from December 31, 1987 to May 28, 2003, and for four emerging stock markets from December 30, 1994 to May 28, 2003. They show that the random walk hypothesis is not rejected in major European developed markets. Moustafa (2004) examines the behavior of stock prices in the United Arab Emirates (UAE) stock market using daily prices of 43 stocks included in the UAE market index for the period October 2, 2001 to September 1, 2003. He finds that the returns of the 43 stocks do not follow normal distribution. According to his results, the UAE is found to be weak-form efficient.

Chung (2006) examines the random walk hypothesis and tests the weak-form efficiency of two major stock markets in China using daily data of three Shanghai index series and three Shenzhen index series from the period 1992 to 2005. The empirical results of this study indicate that stock returns in both Chinese stock markets do not behave in a manner consistent with the weak-form of efficient market hypothesis. The results from three of these tests indicate the presence of positive autocorrelation in daily return series in all index series.

Rahman and Hossain (2006) examined the evidence whether Dhaka Stock Exchange (DSE) is efficient in the weak form or not by hypothesizing normality of the distribution series and random walk assumption. Results from the empirical analysis suggest that the DSE of Bangladesh is not efficient in weak-form. Ntim et al. (2007) empirically re-examines the weak form efficient markets hypothesis of the Ghana stock market using a new robust non-parametric variance-ratios test in addition to its parametric alternative. The main finding is that stock returns are conclusively not efficient in the weak form, neither from the perspective of the strict random walk nor in the relaxed martingale difference sequence sense. Mahmood (2007) has been used historical stock prices on a monthly and daily basis from a sample period of July 1996 to June 2006 of Karachi Stock Exchange-100 (KSE) Index Companies. The results conclude that the random walk hypothesis can be accepted for both monthly and daily returns. There is no “day of the week effect” or the “month effect”. Thus, the random walk theory is valid for the KSE which can be termed as an efficient market. Gupta and Basu (2007) test the weak form efficiency in the framework of random walk hypothesis for the two major equity markets in India for the period 1991 to 2006. The evidence suggests that the series do not follow random walk model and there is an evidence of autocorrelation in both markets rejecting the weak form efficiency hypothesis. Kalu (2008) tests the weak-form efficient market hypothesis of the Nigerian Stock Exchange (NSE) by hypothesizing normal distribution and random walk of the return series. Results from the tests suggest that the NSE is not weak form efficient.

Surveys covering about Turkey are the following. Antoniou et al. (1997) used daily stock prices of the ISE Composite Index for the period 1988 to 1993 to examine the weak form efficiency for the Istanbul Stock Exchange (ISE). According to their results the ISE is weakly inefficient. Smith and Ryoo (2003) investigated the random walk behavior in five European emerging markets using variance ratio tests. They employ weekly data of index prices in local currency for the period April 1991 to August 1998. According to their results, in four of the markets, Greece, Hungary, Poland and Portugal, the random walk hypothesis is rejected because returns have auto correlated errors. The positive autocorrelation is found be in four of the markets, while in Turkey, the ISE is found to follow a random walk. They claim that this might be deriving from the fact that the ISE being larger and liquid compared with the other four markets. Müslümov et al. (2003) examined weak-form market efficiency hypothesis in ISE using the broadest sample and time series coverage that have been ever used. They use stock prices data of all companies that constitute ISE-100 index with time series covering 1990-2002 years. Their findings show that the stock returns of the individual stocks that constitute 65% of the sample space do not show random walk behavior. However, remaining part of the individual stocks exhibit significant random walk behavior. The findings for the ISE-100 national index provide support to the evolving market efficiency hypothesis. While ISE-100 index do not follow random walk for the initial period of the analysis, it gains random-walk behavior in the second period. The discrimination analysis between stocks whose returns do not follow random walk behavior and those whose returns follow random walk behavior do not significantly discriminate them. Tas and Dursonoglu (2005) have confirmed the inefficiency result for Turkey using daily stock returns of the ISE 30 index from the period 1995 to 2004. Dickey-Fuller unit root and runs tests were used in their studies and the results of both tests reject random walk hypothesis in ISE-30 index. Omran and Farrar (2006) test the validity of the RWH in five Middle Eastern emerging markets, Jordan, Morocco, Egypt, Israel and Turkey. Their results reject the RWH for all markets. Hassan et al. (2006) conducted a test of efficiency in seven European emerging stock markets. They use International Finance Corporation’s weekly stock index data for the period December 1988 through August 2002. According to their results, except Greece, Slovakia and Turkey markets, in Czech Republic, Hungary, Poland and Russia are found to be unpredictable. Çelik and Taş (2007) tested weak-form market efficiency in selected emerging markets. Therefore, twelve emerging stock market indices were tested with runs test, unit root tests and variance ratio test by using weekly data for the period of April 1998-April 2007. One of the interesting findings of this study is that none of the tests can reject weak form market efficiency in the Turkish and Korean markets. Aga and Kocaman (2008) used index called “Return Index-20” which is monthly index composed by them and used a time series model to test weak form efficiency fort his index in ISE. The result obtained from time series analysis shows that the returns can be explained only by the constant term, which is the mean and there is a weak form of efficiency in ISE which means that the market is weakly efficient if the current time can not be explained with the past values. Duman et al. (2009) aimed to provide the efficiency level of ISE market using fifteen minutes and session frequency data for the period 03 January 2003-30 December 2005. According period to application they found that ISE is weakly efficient market. Awad and Daraghma (2009) examined the efficiency of the Palestine Security Exchange (PSE) at the weak-level for 35 stocks listed in the market by using daily observations of the PSE indices: Alquds index, general index, and sector indices. According test results the PSE is inefficient at the weak level; as a result, this is likely to be evidence that the prudent investor who deals with the PSE will achieve abnormal returns using historical data of stock prices, and trading volume. Lazar and Nouroul (2009) tests the weak-form efficiency of Indian capital market. The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests concluded that the Indian capital market is weak-form efficient. Jawad (2010) examines the weak-form market efficiency of Muscat Securities Market. Daily and monthly observations are employed over the period (2005-2009) for Muscat Securities Market general index and nine stocks from different sectors. Results reveal that stock and index returns show significant departure from random walk according to daily data. However, monthly data show some signs of market efficiency. The study concludes that the Muscat Securities Market is inefficient in the weak-form. The reasons for market inefficiency can be due to infrequent trading and market imperfections. Hamid et al. (2010) examined the weak-form market efficiency of the stock market returns of Pakistan, India, Sri Lanka, China, Korea, Hong Kong, Indonesia, Malaysia, Philippine, Singapore, Thailand, Taiwan, Japan and Australia. Monthly observations are taken for the period January 2004 to December 2009. They concluded that the monthly prices do not follow random walks in all the countries of the Asian-Pacific region. The investors can take the stream of benefits through arbitrage process from profitable opportunities across these markets. Schindler et al. (2010) tested of the random walk hypothesis and market efficiency for 14 national public real estate markets. Empirical evidence shows that weekly stock prices in major securitized real estate markets do not follow a random walk. The empirical findings of return predictability suggest that investors might be able to develop trading strategies allowing them to earn excess returns compared to a buy-and-hold strategy. Korkmaz and Akman (2010) was tested weak form market efficiency of efficient market hypothesis in Istanbul Stock Exchange (ISE). For this purpose, an analysis was resorted by selecting 2 indices from Istanbul Stock Exchange. These indices are ISE 100 and ISE Industrial indices. It was concluded after the implementation that ISE was weak form efficient. Also there was not a co-integration among indices in the long term. Xianming et al. (2010) analyzed whether the opportunity for excess returns in China's stock markets exists, and tested the randomness of the returns' series in China's stock market. They concluded that China's two stock markets in Shenzhen and Shanghai have not reached the significant excess rate of return opportunities, but the stock markets as a whole have not reached the level of the weak-form efficiency.

Alexeev and Tapon (2011) a model-based bootstrap is used to generate a series of simulated trials and a modified chart pattern recognition algorithm is applied to all stocks listed on the Toronto Stock Exchange (TSX). Conclusions are drawn on the relative efficiency of some sectors of the economy. Although the null hypothesis of weak form efficiency on the TSX cannot be rejected, some sectors of the Canadian economy appear to be less efficient than others. In addition, pattern frequencies appear to be negatively dependent on the two moments of return distributions, variance and kurtosis. Roy and

Table 1. Description of data sample.

Notations	Index	Sample period	Observations
ISE-100	ISE National 100	23.10.1987-15.07.2011	5921
SER	Services	02.01.1997-15.07.2011	3622
FIN	Financial	02.01.1991-15.07.2011	5117
IND	Industrial	02.01.1991-15.07.2011	5117
TEC	Technology	30.06.2000-15.07.2011	2766

Lakshmi (2011) attempted to examine the random movements in stock indices in Indian equity market. The results of this research indicate that there are no random changes in share prices. However, when they applied Lo and MacKinlay variance ratio test under the assumptions of both homoskedasticity and heteroskedasticity, interestingly, they observed opposite results, where null hypothesis of random walk can not be rejected at 5% level of significance. It is also found that sometimes heteroskedasticity is the source of non random behavior in share prices.

Overall, empirical results from both the developed and developing markets show contrasting evidence on weak form efficiency. Mixed results from literature on emerging stock market efficiency are not surprising since it is observed that emerging stock markets are generally less efficient than developed markets.

DATA AND METHODOLOGY

Data description and hypotheses

The data used in this study primarily consist of daily price series of the market index (ISE-100) and the sector indices that include four sub-indices which are services index, financial index, industrial index and technology index listed on the Istanbul Stock Exchange (ISE). Specifically, the market index, namely ISE-100, can be considered as a large diversified portfolio that covers the stocks of 100 leading firms, which are being treaded in the ISE. Hence, the index sufficiently represents the ISE. The index values cover 5922 workdays of approximately 24 years for the period 23.10.1987-15.07.2011.

The data of daily price indices are collected from the electronic data delivery system of Central Bank of Turkey (http://tcmbf40.tcmb.gov.tr/cbt-uk.html) and the observation period ranges from October 23, 1987 to July 15, 2011. The empirical analysis of this study used daily data of closing prices for the five indices for the indicated sample periods, which are presented in Table 1.

Then, a natural logarithmic transformation is performed for the primary data. To generate a time series of continuously compounded returns, daily returns are computed as follows:

$$R_t = ln\left(\frac{p_t}{p_{t-1}}\right) \quad (1)$$

Where p_t and p_{t-1} represent the closing prices of an index at time t and $t-1$, respectively and ln is natural logarithm.

The main objective of this study is to examine whether the Turkish stock market follows a random walk or is weak form efficient. In order to determine the efficiency of the Turkish stock market in the weak form, this study tests two hypotheses. The first hypothesis involves determining whether the stock returns follow a normal distribution or not. The null and alternative hypotheses are:

H_0: The stock returns in Turkish stock market follow a normal distribution.
H_1: The stock returns in Turkish stock market do not follow a normal distribution.

The second hypothesis involves determining, whether the stock returns are random across time. The null and alternative hypotheses are:

H_0: The Turkish stock market follows a random walk/is a weak-form efficient.
H1: The Turkish stock market doesn't follow a random walk/is a weak-form efficient.

Though hypothesis of normality and randomness are complementary, we used them simultaneously in order to establish the robustness of the analysis. Besides, some specified hypotheses have taken into consideration while using several parametric and nonparametric tests.

METHODOLOGY

In this paper, we followed previous empirical work and employed the most familiar econometrics methods used in the literatures to test the independence of prices data. However, we used parametric and non-parametric methods to test the random walk hypothesis through employing four different statistical methods, unit root tests, runs test, autocorrelation test and variance ratio test.

Unit root tests

The stationary status of series should be detected when investigating the random walk nature of stock prices. In this context, we perform Augmented Dickey-Fuller (ADF) (1979) and Phillips- Perron (PP) (1988) unit root tests in order to check whether the time series are stationary or not. These unit root tests provide evidence on whether the stock prices in Turkish stock market follow a random walk. Therefore, it is also a test of the weak-form market efficiency. The ADF unit root test is based on the following regression:

$$\Delta P_t = \gamma P_{t-1} + \sum_{i=1}^{q} \rho_i \Delta P_{t-i} + \varepsilon_t \quad (2)$$

$$\Delta P_t = \mu + \gamma P_{t-1} + \sum_{i=1}^{q} \rho_i \Delta P_{t-i} + \varepsilon_t \qquad (3)$$

$$\Delta P_t = \mu + \alpha_1 t + \gamma P_{t-1} + \sum_{i=1}^{q} \rho_i \Delta P_{t-i} + \varepsilon_t \qquad (4)$$

where Δ represents first differences and P_t is the log of the price index, μ is the constant, γ and ρ are coefficients to be estimated, q is the number of lagged terms, t is the trend, α_1 is the estimated coefficient for the trend and the error term ε_t is assumed to be white noise.

The first Equation (2) is a pure random walk model without constant and time trend, the second with constant without time trend and third includes both constant and time trend. Accordingly, Equation (3) tests for the null hypothesis of a random walk against a stationary alternative, while Equation (4) tests for the same null against a trend stationary alternative. Performing PP test we use ADF equations without non-augmented form ($P_{t-i},\ i = 1, 2, ...$ are not included, in the DF equation).

The null hypothesis in ADF and PP tests is that a series has a unit root ($\rho = 0$), which means a stationary series should have significant ADF and PP statistics. Before conducting the unit root tests, an optimal lag length needs to be determined as a prior step. The optimal lag lengths for ADF test were chosen based on the Akaike Information Criterion (AIC), while for PP test; it is based on the automatic selection procedure of Newey-West (1994) for Bartlett Kernel. Also, whether residuals are white noise is taken into consideration in selecting proper lag length.

Runs test

The runs test is a non-parametric test that is designed to examine whether successive price changes are independent. Unlike the parametric tests, runs test has a considerable advantage that it doesn't require the stock returns to be normally distributed. The test is based on the premise that if a series of a data is random, the observed number of runs in the series should be close to the expected number of runs. A run can be defined as a sequence of consecutive price changes with the same sign. The null hypothesis of randomness is tested by observing the number of runs or the sequence of successive price changes with the same sign, positive, zero or negative (Campbell et al., 1997). To assign equal weight to each change and to identify direction of consecutive changes, each change in return is classified according to its position with respect to the mean return. Hereby, it is a positive change when return is greater than the mean, a negative change when the return is less than the mean and zero when the return equals to the mean (Worthington and Higgs, 2004).

The runs can be carried out by comparing the actual runs (R) to the expected number of runs (m) using following equation:

$$m = \frac{N(N+1) - \sum_{i=1}^{3} n_i^2}{N} \qquad (5)$$

where *N* denotes the number of observations, *i* is the signs of plus, minus, and no change, n_i is total numbers of changes of each category of signs. For a larger number of observations (*N*>30), the expected number of runs m is approximately normally distributed with a standard deviation σ_m of runs as specified in the following formula:

$$\sigma_m = \left[\frac{\sum_{i=1}^{3} n_i^2 \left[\sum_{i=1}^{3} n_i^2 + N(N+1) \right] - 2N \sum_{i=1}^{3} n_i^3 - N^3}{N^2(N-1)} \right]^{\frac{1}{2}} \qquad (6)$$

Then the standard normal Z-statistic used to conduct a run test is given by:

$$Z = \frac{R - m \pm \left(\frac{1}{2} \right)}{\sigma_m}, \quad Z \sim N(0,1) \qquad (7)$$

where *R* is the actual number of runs, and ½ denotes the correction factor for continuity adjustment, in which the sign continuity adjustment is positive if $R \le m$, and negative if $R \ge m$. A negative *Z* value indicates a positive serial correlation, whereas a positive *Z* value indicates a negative serial correlation. The positive serial correlation implies that there is a positive dependence of stock prices, therefore indicating a violation of random walks. Since the distribution *Z* is *N(0,1),* the critical value of *Z* at the 1, 5 and 10% significance levels are ±2.58, ±1.96 and ±1.65, respectively.

Autocorrelation test

As noticed in the literature, autocorrelation (serial correlation coefficient) test is the most commonly used as the first tool for randomness. Autocorrelation test measures the correlation coefficient between the stock return at current period and its value in the previous period, whether the correlation coefficients are significantly different from zero. Serial correlation coefficient is given as follows:

$$\rho_k = \frac{\sum_{t=1}^{N-k} (r_t - \overline{r})(r_{t+k} - \overline{r})}{\sum_{t=1}^{N} (r_t - \overline{r})^2} \qquad (8)$$

where ρ_k is the serial correlation coefficient of stock returns of lag k; N is the number of observations; r_t is the stock return over period t; r_{t+k} is the stock return over period $k+t$; r is the sample mean of stock returns; and k is the lag of the period. The test aims to determine whether the serial correlation coefficients are significantly different from zero. Statistically, the hypothesis of weak-form efficiency should be rejected if stock returns (price changes) are serially correlated (ρ_k is significantly different from zero).

The Ljung–Box (1979) portmanteau statistic (Q) is also used to test the joint hypothesis that all autocorrelations are simultaneously equal to zero. The Ljung-Box test provides a superior fit to the chi- square (χ^2) distribution for small sample sizes. The Ljung–Box Q statistics (Q_{LB}) are given by:

$$Q_{LB} = N(N+2)\sum_{k=1}^{m} \frac{\rho^2(k)}{N-k}, \quad \sim \chi_m^2 \qquad (9)$$

where $\rho(k)$ is the estimated autocorrelation coefficients, k is a given lag and N is the number of observations. If the calculated value of Q_{LB} exceeds the critical value of χ^2 with m degrees of freedom, then at least one value of $\rho(k)$ is statistically different from zero at the specified significance level.

Variance ratio test

After both tests for serial independence in the series have been introduced, another important property of random hypotheses has to be considered. That is linearity in random walk series increments. We use the variance ratio test proposed by Lo and MacKinlay (1988) to examine whether the increments in the random walk series is linear in the sample interval. The variance ratio test is used to test for a random walk in returns, that is, returns are independently and identically distributed with a constant mean and finite variance that is a linear function of the holding period. The variance ratio test of Lo and MacKinlay (1988) examined the uncorrelated residuals in series, under assumptions of both homoscedastic and heteroskedastic random walks.

The variance ratio test exploits the fact that the variance of the increments in a random walk is linear in the sampling interval such that if the return series follows a random walk model, the variance of its q-differences would be q times the variance of its first differences. More generally, if time series follows a random walk process, the variance of q period returns should be q times as large as the one-period returns:

$$VR(q) = \frac{Var\left[r_t(q)\right]}{Var\left[r_t\right]} = q \qquad (10)$$

Then, the variance ratio for a general q can be rewritten as $VR(q)$ and satisfies the following relation:

$$VR(q) = \frac{Var\left[r_t(q)\right]}{q \times Var\left[r_t\right]} = 1 + 2\sum_{k=1}^{q-1}\left(1-\frac{k}{q}\right)\hat{\rho}(k) \qquad (11)$$

where $r_t(k) = r_t + r_{t-1} + ... + r_{t-k+1}$ and $\hat{\rho}(k)$ is the k^{th} order autocorrelation coefficient of r_t .

This results into $VR(q)$ is a particular linear combination of the first $k-1$ autocorrelation coefficients of r_t with linearly declining weights. Under the random walk, the variance ratio should equal to one $\left[VR(q)=1\right]$ and in this case $\rho(k)=0$ for all $k \geq 1$.

Lo and MacKinlay (1988) derive asymptotic standard normal test statistic for their variance ratio. As a result, the null hypothesis of no autocorrelation coefficient can be tested by computing the standardized statistic. Under the null hypothesis of homoscedastic, the standard normal test statistic $Z(q)$ is defined as:

$$Z(q) = \frac{VR(q)-1}{\Phi(q)^{1/2}} \quad \sim N(0,1) \qquad (12)$$

where

$$\Phi(q) = \frac{2(2q-1)(q-1)}{3q(nq)} \qquad (13)$$

Here nq is the number of observations and $\Phi(q)$ is the asymptotic variance of the variance ratio under the assumption of homoscedasticity. The rejection of random walk under homoscedasticity may result from either heteroscedasticity and/or autocorrelation existence in series. It is observed by the financial economists that volatilities change over, a rejection of the random walk hypothesis because of heteroscedasticity. As long as returns are uncorrelated, even in the presence of heteroscedasticity the variance ratio still approach unity as the number of observations increases without bound, for the variance of the sum of uncorrelated increments still equal the sum of the variances. To allow general forms of heteroscedasticity, Lo and MacKinlay (1988) recommended heteroscedasticity-consistent method. The heteroscedasticity-consistent standard normal test statistic $Z^*(q)$ is then defined as:

$$Z^*(q) = \frac{VR(q)-1}{\Phi^*(q)^{1/2}} \quad \sim N(0,1) \qquad (14)$$

where the standard error term is

$$\Phi^*(q) = 4\sum_{k=1}^{q-1}\left[1-\frac{k}{q}\right]^2 \hat{\delta}(k) \qquad (15)$$

and

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

(16)

where $\hat{\delta}(k)$ is the heteroscedasticity-consistent estimator, p_j is the price of the security at time t and $\hat{\mu}$ is the average return. Under the null hypothesis, the value of the variance ratio is one. If the heteroskedastic random walk is rejected, then there is evidence of autocorrelation presences in series. Furthermore, if calculated variance ratio is less than one then it would imply negative serial correlation, whereas a variance ratio greater than one would indicate positive serial correlation. We conclude that returns are predictable if variance ratio is greater than one.

Table 2. Descriptive statistics of Turkish security exchange daily index returns.

	ISE-100	SER	FIN	IND	TEC
Mean	0.001509	0.001005	0.001562	0.001463	0.000184
Median	0.001299	0.000851	0.001178	0.001550	0.000933
Maximum $\left[\text{Max}\,(R_t)\right]$	0.217108	0.173327	0.174553	0.180447	0.186384
Minimum $\left[\text{Min}\,(R_t)\right]$	-0.199785	-0.192559	-0.208422	-0.180142	-0.197497
Std. Dev. $\left[\sigma_{R_t}\right]$	0.028033	0.025979	0.030559	0.025364	0.026003
Skewness	0.034645	0.014343	-0.006598	-0.124825	-0.127051
Kurtosis	6.928717	9.573568	6.364555	7.615261	11.54444
Jarque-Bera	3809.083***	6521.504***	2413.605***	4554.762***	8421.542***
Probability	0.000000	0.000000	0.000000	0.000000	0.000000
Studentized Range[a]	14.87151	14.08391	12.53231	14.21657	14.76295
Observations[b]	5921	3622	5117	5117	2766

[a] Studentized range is $\left(\frac{\text{Max}\,(R_t) - \text{Min}\,(R_t)}{\sigma_{R_t}}\right)$, [b] Number of observations differs because indices were established in different dates, Asterisk (***) indicates rejection of the null hypothesis of normality at the 1% level.

EMPIRICAL RESULTS

Descriptive statistics

Various descriptive statistics are calculated of the stock returns series under study in order to describe the basic characteristics of these series. Table 2 presents the descriptive statistics of the data containing sample means, medians, maximums, minimums, standard deviations, skewness, kurtosis, the Jarque-Bera statistics and probabilities (p-values) as well as studentized range.

From the Table 2, it can be seen that all indexes have positive mean returns. Financial index has the highest mean returns of 0.001562, while technology index has the lowest mean return of 0.000184. The standard deviations of returns range are from 0.025364 (industrial index) to 0.030559 (financial index). On this basis, the returns of industrial index are the least volatile, with financial index being the most volatile.

In general, values for skewness zero and kurtosis value three represents that observed distribution is normally distributed. As can be seen in Table 2, the skewness and kurtosis values indicate that returns of all indexes are not normally distributed. Skewness is positive for two series, indicating the fat tails on the right-hand side of the distribution comparably with the left-hand side. On contrary, financial index, industrial index and technology index have a negative skewness, which indicates the fat tails on the left-hand side of the distribution. Kurtosis value of all indexes also show data is not normally distributed because values of kurtosis are deviated from three. The calculated Jarque-Bera statistics and corresponding p-values in Table 2 are used to test the null hypotheses that the daily distribution of Turkish market returns is normally distributed. All p-values are smaller than the 1% level of significance suggesting the null hypothesis can be rejected.

Fama (1965) suggests that the studentized range is another test of the degree to which the data deviates from normality. If the studentized range is greater than six, then the null hypothesis of normal distribution is rejected. All the values in the table are larger than six further suggesting that the stock returns of Turkish market are not normally distributed. Therefore, none of these return series is then well approximated by the normal distribution.

To confirm the distributional pattern of the returns, we also used a Kolmogrov-Smirnov goodness of fit test. Kolmogorov-Smirnov goodness of fit test is a non-parametric test and compares the observed cumulative distribution function for a variable with a specified theoretical distribution, which may be normal, uniform, Poisson, or exponential. This goodness-of-fit test tests whether the observations could reasonably have come from the specified distribution. Table 3 shows probability of (0.000) for the Z value for all indices. Hence it is clearly evident that daily price indices of Turkish stock market do not fit by normal distribution. Thus we reject the null hypothesis of normality.

Unit root tests results

Since a unit root is a necessary condition for a random

Table 3. Results of one-sample Kolmogorov-Smirnov test.

		ISE-100	SER	FIN	IND	TEC
Most Extreme Differences	Absolute	0.057	0.078	0.055	0.068	0.079
	Positive	0.057	0.078	0.052	0.066	0.076
	Negative	-0.057	-0.076	-0.055	-0.068	-0.079
Kolmogorov-Smirnov Z		4.405***	4.672***	3.903***	4.859***	4.165***
Asymp. Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000

Test distribution is Normal; Asterisk (***) indicates rejection of the null hypothesis of normality at the 1% level.

Table 4. Results of unit root tests.

Variable	ADF Unit Root Test (at level)			PP Unit Root Test (at level)		
	None	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend
ISE-100	-19.09588***	-22.12653***	-22.17697***	-69.44002***	-69.31652***	-69.31418***
SER	-14.08652***	-14.22418***	-14.25738***	-59.77313***	-59.84105***	-59.85886***
FIN	-14.87107***	-15.16390***	-15.22064***	-67.29730***	-67.24746***	-67.25481***
IND	-17.39272***	-17.67793***	-17.72837***	-66.61312***	-66.50233***	-66.46556***
TEC	-11.29956***	-11.30131***	-11.39644***	-51.67366***	-51.66713***	-51.71990***

ADF is the Augmented Dickey-Fuller and PP is the Phillips-Perron test; Asterisk (***) indicates rejection of the null hypothesis of non-stationary at the 1% level; The proper lag order for ADF test is chosen by considering Akaike Information Criterion (AIC) and white noise of residuals; For PP tests, the bandwidth is chosen using Newey–West method and spectral estimation uses Bartlett-Kernel; MacKinnon (1996) critical values are used for ADF and PP tests. The 1%, 5% and 10% critical value for the ADF and PP tests is -2.565353, -1.940878 and -1.616664 for none, - 3.431277, -2.861834 and -2.566969 for intercept and -3.959589, -3.410564 and -3.127055 for intercept and trend respectively.

walk, the Augmented Dickey-Fuller (parametric test) and Phillips-Perron (non-parametric test) tests are used to test the null hypothesis of a unit root. The results of Augmented Dickey-Fuller (ADF) and Phillips-Peron (PP) tests for a unit root for Turkish stock price indices are presented in Table 4. ADF and PP unit root tests were performed including without intercept and time trend, intercept, and intercept and time trend.

Results from the Table 4 indicate that all index series are stationary in levels. Hence the null hypothesis of non-stationary for all index series is rejected, as the test statistic is more negative than the critical value, suggesting that these indices do not show characteristics of random walk and as such are not efficient in the weak form. For all index series, the results are statistically significant one percent significance level and the results of ADF and PP unit root tests are consistent suggesting these indices are not weak form efficient.

Runs test results

As reported in Tables 2 and 3, the Jarque-Bera test, studentized range value and Kolmogorov-Smirnov goodness of fit test for normality reject the normality of all Turkish market indices and hence runs test might detect serial dependencies that cannot be captured by the parametric tests (autocorrelation test and variance ratio test). The results of the runs test for returns on indices for the Turkish market are reported in Table 5. The runs test clearly shows that ISE-100, financial and industrial indices are weak form inefficient. The estimated Z-values are significant at the 1% level for returns on both ISE-100 index and industrial index, and at the 5% level for returns on financial index. So, we reject the null hypothesis of random walk at 1% for ISE-100, industrial indices and at 5% for financial index. However, these results fail to reject the null hypothesis for services index and technology index. The significant negative Z-values for returns on all indexes indicates that the actual number of runs falls short of the expected number of runs under the null hypothesis of return independence as shown in Table 5.

Autocorrelation test results

To test the weak form of efficient market hypothesis for the Turkish stock market, the autocorrelation test with twelve lags are performed for daily returns of five indices. The results of the sample autocorrelation coefficients and the Ljung-Box statistics for the daily returns on the indices for the Turkish stock market are summarized in Table 6.

Table 5. Results of runs test.

	ISE-100	SER	FIN	IND	TEC
Test value (Mean)	0.001509	0.001005	0.001562	0.001463	0.000184
Cases < Test value	2984	1823	2584	2543	1344
Cases >= Test value	2937	1799	2533	2574	1422
Total cases	5921	3622	5117	5117	2766
Number of runs	2820	1800	2486	2449	1347
Z - Statistic	-3.674***	-0.396	-2.048**	-3.087***	-1.367
P-value	0.000	0.692	0.041	0.002	0.172

Asterisks (***), (**) and (*) indicate statistical significance at the 1, 5 and 10% levels.

As can be seen from the Table 6, the autocorrelation coefficient at lag one is lowest for services index (0.0058) and highest for ISE-100 index (0.1089). Except both services and technology indices, significant positive autocorrelation is detected at a lag of one period for return series in Turkish stock market. It is worth to note here that positive autocorrelation indicates predictability of returns in short horizon, which is the general evidence against market efficiency. On the other hand, negative autocorrelation, indicating mean reversion in returns, with mean reversion being higher in services index. Services index appears the significant negative autocorrelation at lags 5, 6 and 11. Both industrial and technology indices also show significant negative autocorrelation at lag 6. Overall, for returns on indices of Turkish stock market, except for a very few lags the autocorrelation coefficients for most lags are non-zero at the 1, 5 and 10% significance levels.

Ljung-Box Q-statistics also provide evidence of possible dependence in the first and higher moments of the return distributions. The Ljung-Box Q-statistics show that the null hypothesis of no autocorrelation is rejected for ISE-100, financial and industrial indices at lag 1 through 12 at the 1% level of significance. For services index, except the autocorrelation coefficient for lags 1, 2, 3 and 4 and that lag 5 are equal to zero are rejected by Ljung-Box Q -statistics at the 10% significance level and lags 6, 7, 8, 9, 10, 11 and 12 at the 1% level of significance. For technology index, except the autocorrelation coefficient for lags 1 and 5 and that lags 2, 3 and 4 are equal to zero are rejected by Ljung-Box Q -statistics at the 10% significance level, lag 7 at the 5% level of significance and lags 6, 8, 9, 10, 11 and 12 are also at the 1% level of significance. The non-zero autocorrelation of the series associated with Ljung-Box Q-statistics, which are jointly significant at 1% level at 1 and 12 degrees of freedom, clearly suggest that all return series do not follow a random walk model. On the basis of the empirical results obtained from autocorrelation tests, presented Table 6, it can be concluded that the null hypothesis of random walk is rejected for all indices.

Variance ratio test results

This study employs variance ratio test for both null hypotheses, namely the homoscedastic and heteroscedastic increments random walk. The results of the variance ratio test for the Turkish market indices are reported in Table 7. $VR(q)$ represents the variance ratio of the returns, $Z(q)$ and $Z^*(q)$ represent the statistics of the variance ratio under the assumption of homoscedasticity and heteroscedasticity, respectively. The variance ratio test is conducted for various lags of q (that is, 2, 4, 8, 12 and 16 days) for each index.

Empirical evidence obtained from the variance ratio test for daily returns indicates that the random walk hypothesis under the assumption of homoscedasticity is rejected for all series. In the case of ISE-100 index, for instance, the Z -statistics suggest that the variance ratios are significantly different from one for all values of q at the 1% level. Therefore, the null hypothesis of random walk is strongly rejected for the ISE-100 index. Similarly, the empirical findings reveal that the null hypothesis of random walk for services, financial, industrial and technology indices can not be accepted for all levels of q at the 1% level of significance. In addition, the heteroscedasticity-consistent variance ratio test provides consistent evidence that the null hypothesis of random walk can not be accepted for all daily observed return series. Indeed, all the test-statistics of $Z(q)$ and $Z^*(q)$ are larger than the critical statistic (2.58) at 1% level of significance.

This non-random walk pattern based on variance ratio test is also consistent with the findings of serial correlation and runs test for the full sample period. On the basis of empirical evidence provided above, it can be concluded that the null hypothesis of random walk is rejected for all Turkish stock market indices.

Conclusions

This study examines the random walk hypothesis and tests the weak-form efficiency of the Istanbul Stock Exchange (ISE) in Turkey by using daily data of five index series (ISE-100 index, services index, financial index, industrial index and technology index) from the period 1987 to 2011. Parametric and nonparametric tests for examining the randomness of the ISE stock prices

Table 6. Results of the sample autocorrelation coefficients and Ljung-Box Q-statistics.

Lags	ISE-100		SER		FIN		IND		TEC	
	ACF	Q- Stat	ACF	Q- Stat	ACF	Q- Stat	ACF	Q- Stat	ACF	Q- Stat
1	0.1089***	70.3000*** (0.000)	0.0058	0.1223 (0.727)	0.0660***	22.2829*** (0.000)	0.0813***	33.8222*** (0.000)	0.0187	0.9643 (0.326)
2	0.0095	70.8393*** (0.000)	0.0238	2.1847 (0.335)	0.0269*	25.9818*** (0.000)	0.0045	33.9271*** (0.000)	0.0403**	5.4718* (0.065)
3	-0.0108	71.5258*** (0.000)	-0.0124	2.7468 (0.432)	-0.0012	25.9894*** (0.000)	-0.0041	34.0135*** (0.000)	0.0199	6.5747* (0.087)
4	0.0333**	78.1024*** (0.000)	0.0341**	6.9585 (0.138)	0.0251*	29.2103*** (0.000)	0.0385***	41.5950*** (0.000)	0.0236	8.1237* (0.087)
5	-0.0093	78.6166*** (0.000)	-0.0319*	10.6524* (0.059)	-0.0121	29.9665*** (0.000)	-0.0069	41.8417*** (0.000)	-0.0195	9.1738 (0.102)
6	-0.0196	80.9051*** (0.000)	-0.0476***	18.8605*** (0.004)	-0.0199	31.9932*** (0.000)	-0.0253*	45.1273*** (0.000)	-0.0550***	17.5625*** (0.007)
7	0.0135	81.9916*** (0.000)	0.0137	19.5446*** (0.007)	0.0064	32.2004*** (0.000)	0.0260*	48.5895*** (0.000)	0.0115	17.9273** (0.012)
8	0.0151	83.3378*** (0.000)	0.0122	20.0847*** (0.010)	0.0061	32.3908*** (0.000)	0.0321**	53.8718*** (0.000)	0.0338*	21.1058*** (0.007)
9	0.0342***	90.2760*** (0.000)	0.0211	21.7081*** (0.010)	0.0403***	40.7239*** (0.000)	0.0309**	58.7707*** (0.000)	0.0225	22.5080*** (0.007)
10	0.0505***	105.3782*** (0.000)	0.0228	23.5976*** (0.009)	0.0532***	55.2159*** (0.000)	0.0472***	70.2014*** (0.000)	0.0817***	41.0520*** (0.000)
11	-0.0030	105.4322*** (0.000)	-0.0362**	28.3730*** (0.003)	-0.0120	55.9522*** (0.000)	-0.0038	70.2751*** (0.000)	-0.0171	41.8667*** (0.000)
12	0.0121	106.2970*** (0.000)	0.0105	28.7754*** (0.004)	0.0138	56.9314*** (0.000)	0.0186	72.0520*** (0.000)	0.0001	41.8668*** (0.000)

Asterisks (***), (**) and (*) indicate statistical significance at the 1, 5 and 10% levels; 2. Values in parentheses are *p*-values.

Table 7. Results of variance ratio test.

INDEX	PERIOD (q)	2	4	8	12	16
ISE-100	VR(q)	0.555752	0.271157	0.138038	0.092255	0.069725
	Z(q)	-34.18111*** (0.0000)	-29.97513*** (0.0000)	-22.42048*** (0.0000)	-18.62949*** (0.0000)	-16.26115*** (0.0000)
	Z*(q)	-18.25544*** (0.0000)	-17.14029*** (0.0000)	-13.94756*** (0.0000)	-12.19955*** (0.0000)	-11.00865*** (0.0000)
SER	VR(q)	0.490878	0.242597	0.123992	0.082780	0.061697
	Z(q)	-30.63632*** (0.0000)	-24.36169*** (0.0000)	-17.82044*** (0.0000)	-14.72190*** (0.0000)	-12.82734*** (0.0000)
	Z*(q)	-13.45882*** (0.0000)	-11.59930*** (0.0000)	-9.505504*** (0.0000)	-8.461554*** (0.0000)	-7.757327*** (0.0000)
FIN	VR(q)	0.520565	0.260597	0.132641	0.087610	0.066360
	Z(q)	-34.29216*** (0.0000)	-28.26911*** (0.0000)	-20.97928*** (0.0000)	-17.40692*** (0.0000)	-15.17134*** (0.0000)
	Z*(q)	-18.19295*** (0.0000)	-16.44541*** (0.0000)	-13.48132*** (0.0000)	-11.80975*** (0.0000)	-10.64213*** (0.0000)
IND	VR(q)	0.541166	0.261168	0.130954	0.088299	0.067203
	Z(q)	-32.81863*** (0.0000)	-28.24728*** (0.0000)	-21.01376*** (0.0000)	-17.39376*** (0.0000)	-15.15765*** (0.0000)
	Z*(q)	-16.46742*** (0.0000)	-14.73133*** (0.0000)	-11.85426*** (0.0000)	-10.41522*** (0.0000)	-9.470678*** (0.0000)
TEC	VR(q)	0.488937	0.248356	0.122588	0.084495	0.060779
	Z(q)	-26.87336*** (0.0000)	-21.12643*** (0.0000)	-15.59721*** (0.0000)	-12.84057*** (0.0000)	-11.22004*** (0.0000)
	Z*(q)	-10.89270*** (0.0000)	-9.314357*** (0.0000)	-7.800491*** (0.0000)	-6.961177*** (0.0000)	-6.403527*** (0.0000)

Asterisks (***), (**) and (*) indicate statistical significance at the 1%, 5% and 10% levels; Values in parentheses are *p*-values.

were utilized. The parametric tests include Augmented Dickey-Fuller unit root test, serial autocorrelation test and variance ratio test. The nonparametric tests include Phillips-Peron unit root test and runs test. The study utilized nonparametric tests for investigating the efficiency of the ISE at the weak level, especially, the results of Jarque-Bera test, Studentized Range value and Kolmogorov-Smirnov goodness of fit test for normality showed that the daily returns of the ISE indices are not normally distributed. Both Augmented Dickey-Fuller and Phillips-Peron unit root tests suggest the weak-form inefficiency in the return series. The results obtained from autocorrelation and Ljung-Box Q-Statistic indicates that the null hypothesis of random walk is conclusively rejected for all ISE indices. In addition, runs test shows evidence to reject the null hypothesis of a random walk for daily observed returns of the ISE indices (except for services and technology indices). Moreover, the results of variance ratio test under both homoscedasticity and heteroscedasticity assumptions for observed returns fail to support the random walk hypothesis for the ISE indices. In general, it can be concluded that the Turkish stock market is inefficient in the weak form.

After our these findings it is worth noting that the acceptance or rejection of the Random Walk Hypothesis does not essentially entails that the Turkish stock market is efficient or inefficient respectively, because the conclusions of this research are based on samples.

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