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Testing Weak-Form Efficient Capital Market Case Study: TSE and DJUS Indices

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Abstract:
The present study investigated weak-form market information efficiency in Tehran security exchange (TSE) as an emerging market and in Dow Jones United States security exchange (DJUS) as a developed market based on random walk model. In each market, random walk model was examined using daily and monthly returns of a set of indices. The results of parametric and non-parametric tests indicated that daily returns are not independent and identically distributed in TSE. Moreover, according to the results of variance ratio test, a trending behaviour in daily returns and mean-reversion behaviour in monthly returns were observed. In DJUS, however, the daily returns were found to be independent and identically distributed and the results of variance ratio test did not confirm that the returns follow a particular pattern in this market.
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JEL classification**:** C14, G14, G15

Keywords: *Emerging Markets, Mean-Reversion Behaviour, Random Walk Model, Trending Behaviour, Variance Ratio Test*

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1. Introduction

Considering the key role of capital market in funding economic firms, the health of informational, operational, and allocative mechanisms of this market is considered crucial. Efficient markets hypothesis (EMH) test that is the subject of the present study shows the accuracy and efficiency of these mechanisms and how economic resources are allocated. More specifically, EMH is an attempt to provide evidence for efficient resource allocation in the capital market based on an investigation of the stock price behaviour. Fama (1970) defined efficient market based on teachings of classical economics and his experience of The United States market as "a market that quickly adjusts itself to the new information". In other words, all traders make their final decisions in a highly competitive environment and based on most recent information so that there is not a possibility for earning excess returns.

In the past few decades, with the development of free market economy and implementation of privatization policies in transitional economies, capital markets have been developed in such economies so as to facilitate the funding of companies (Hranaiova, 1999). These markets face numerous limitations including people`s lack of sufficient experience and unfamiliarity with investment in capital markets, information asymmetry, undeveloped legal institutions, weak supervision, weak law enforcement, and low level of liquidity. Samuels (1981) stated that market participants cannot be expected to have an accurate interpretation of information in these markets and the prices are adjusted only based on the existing information. Also, companies can easily control the price of their stocks in the market. In such markets, major stockholders influence pricing trends and move them in the desired direction.

Just like other emerging markets, TSE has many negative functions and this has made the examination of its weak-form information efficiency an area of interest for researchers. Long-term trading time lags in some symbols, low degree of competition among participants, lack of information transparency, low percentage of free float shares, negative structural and institutional characteristics, and eventually lack of stock holding culture are among the most evident negative functions of TSE.

The present study examines EMH in Tehran security exchange as an emerging market and in Dow Jones US security exchange as a developed market by taking the relativity of the capital markets efficiency into account. This comparison can help us understand the status and relative performance of TSE better. The following hypotheses were formulated:

H.1. TSE is efficient at a weak level.

H.1.1.Stock returns in TSE are independent and identically distributed.

H.1.2. The distribution of stock returns in TSE doses not show autocorrelation.

H.2. Stock prices in TSE have a trending behaviour in the short term and exhibit mean reversion in the long term.

H.3.It is expected for information efficiency to be confirmed in a larger part of TSE with increased return frequency.

H.4. DJUS is efficient at a weak level.

H.4.1. Stock returns in DJUS are independent and identically distributed.

H.4.2.The distribution of stock returns in DJUS does not show autocorrelation.

H.5.Stock prices in DJUS have a trending behaviour in the short term and exhibit mean reversion in the long term.

H.6. It is expected for information efficiency to be confirmed in a larger part of DJUS with increased return frequency.

2. Review of the Related Literature

The first studies examining EMH were often conducted in developed markets in the 1950s and 1960s and were based on serial correlation tests in the time series of prices. The main question addressed in these studies was concerned with the predictability of the stocks future prices by analyzing prices from the past. Some of these studies include Osborne (1959, 1962), Larson (1960), Working (1960), Alexander (1961) and Fama (1965, 1970). Findings of these studies generally confirmed the market weak-from information efficiency due to low serial autocorrelation and low transaction costs. Although the two concepts of market efficiency and random walk model have remained unchanged, newer statistical methods and econometric methodologies have been employed to test EMH since the 1980s. Findings of the studies in this period provided evidence for the rejection of random walk model and predictability of prices. Poterba and Summers (1988) and Fama and French (1988), for example, examined The USA weak-form market efficiency using variance ratio test (Lo-MacKinlay,1988). Findings of these studies showed lack of returns independence and rejected weak-from market efficiency. However, it needs to be noted that these studies do not explicitly confirm the profitability of transactional methods.

Since the early 1990s, with the collapse of the Soviet Union, capital markets efficiency in transitional economies has also attracted the attention of researchers. It is generally believed that in emerging markets, there is a higher possibility for price manipulation due to low trading volume. Therefore, weak-form information efficiency is rejected in these markets. However, as noted by Mobarek (2000), Findings of research on the emerging markets are inconsistent.

The assessment of market efficiency in TSE like other transitional economies has been studied since the early 1990s. Sinaei (1994), for example, provided evidence for the rejection of semi-strong efficient markets hypothesis using descriptive statistics of indices under study. In another study, Fadainejad (1974) presented some pieces of evidence for the rejection of both weak and semi-strong efficient markets hypotheses using serial correlation and normal distribution test. Employing arbitrage model and regression analysis, Ismailzadeh (1999) showed that despite the fact that the stock return of non-metallic minerals industrial companies does not follow the normal distribution, TSE is efficient enough to determine their stock prices. Namazi et al. (1999) presented evidence against weak-from market efficiency using serial correlation analysis, normal distribution function, and filter rules. In another study, Qalibafasl and Nateqi (2006), using ARCH and GARCH models, showed that none of the industries are efficient at a weak level. Samadi et al. (2008) tested TSE efficiency using the filter rule and capital assets pricing model. The results showed the inefficiency of TSE at a weak level during the period under study. Mohamadi et al. (2010) studied the collective behaviour of market participants in TSE using state-space approach and concluded that investors in this market followed market factors collectively and continuously and overlooked fundamental variables. This makes the market move towards inefficiency. Salehabadi and Mehranrad (2011) compared the performance of the optimal portfolio of Sharpe`s one-factor model and TSE index and presented evidence for weak-form market efficiency in the medium term. Fattahi et al. (2012) provided evidence for the rejection of random walk model and weak-from market efficiency in TSE using a variety of variance ratio tests. Besides, Findings of the study showed the total return index mean reversion. Fallahpouret al. (2012) examined weak-form market efficiency in sub-divisions of 50 top companies from 2006 to 2010, 30 large companies from 22 August 2010 to 20 March 2011, and general policies of Article 44 companies during the period 14 February 2007 to 20 March 2011. The results of autocorrelation test, runs test, unit root, and Dickey-Fuller test rejected the market efficiency hypothesis. In a more recent study, Abbasian and Zulfiqari (2012) examined weekly amounts of TSE total index using the GARCH model and concluded that TSE weak-from efficiency was improving in the 2000s.

3. Data and Summary Statistics

The population for the present study consisted of a set of indices from TSE and DJUS. The sample selected from TSE comprised indices of ten groups with the highest gain in market value in 2014. The ten groups constituted 85 percent and 64 percent of market value and transactions value in 2014, respectively. These groups include:

Chemical Products (44), Banking & Other Monetary Institutions (57), Basic Metals (27), Telecommunications (64), Industrial Contracting (39), Refined Petroleum Products & Nuclear Fuel (23), Metal Ores Mining (13), Motor Vehicles & Auto Parts (34), Medicals (43) and finally, Transportation & Storage (60).

The time period understudy in TSE was from 12 August 2008 to 29 August 2015 including 1617 daily data and 81 monthly data.

In addition, the sample under study in DJUS included its ten indices, which consist of all indexed corporations. Each index represents a huge industrial area, which includes different sectors. Based on market value, they are:

Financial (^DJUSFN), Technology (^DJUSTC), Consumer Services (^DJUSCY), Health Care (^DJUSHC), Consumer Goods (^DJUSNC), Industrials (^DJUSIN), Oil & Gas (^DJUSEN), Telecommunications (^DJUSTL), Basic Materials (^DJUSBM), and Utilities (^DJUSUT).

Table 1: Descriptive Statistics

Tehran Security Exchange										
	44	57	27	64	39	23	13	34	43	60
Mean	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.002	0.001
	0.033	0.024	0.022	0.021	0.028	0.029	0.021	0.019	0.030	0.021
S.D.	0.011	0.011	0.012	0.015	0.011	0.023	0.014	0.016	0.007	0.056
	0.078	0.077	0.083	0.091	0.082	0.115	0.103	0.105	0.067	0.266
Skew.	0.439	0.536	0.540	7.001	0.728	-10.97	-0.261	0.318	1.752	3.277
	0.519	0.796	0.388	0.911	0.401	-0.110	0.373	0.495	1.363	0.717
Kurt.	11.38	5.344	8.257	1.145	5.509	363.2	20.02	3.842	15.57	99.33
	3.406	3.432	2.654	4.242	3.453	4.564	3.239	2.960	5.065	19.80
Dow Jones United State Security Exchange										
	BM	CY	EN	FN	HC	IN	NC	TC	TL	UT
Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.000	-0.000	0.000

	0.004	0.005	0.004	0.001	0.005	0.003	0.005	-0.000	-0.003	0.002
S.D.	0.018	0.013	0.019	0.019	0.011	0.014	0.011	0.018	0.015	0.013
	0.075	0.054	0.065	0.069	0.043	0.062	0.038	0.082	0.059	0.045
Skew.	-0.438	-0.134	-0.372	-0.158	-0.165	-0.247	-0.056	0.343	0.179	0.099
	-0.714	-0.555	-0.738	-1.583	-0.814	-0.704	-1.026	-0.504	-0.016	-1.030
Kurt.	10.29	9.701	13.22	17.33	9.899	8.969	60.63	9.344	16.7	21.65
	6.139	4.600	4.015	9.971	6.342	4.807	5.938	5.061	4.919	4.850

In each statistic,the first row and the second row represent the daily and monthly, respectively.

The time period understudy for DJUS was between 30 August 2000 to 28 August 2015, which consisted of 3775 daily data and 181 monthly data. In both markets, research hypotheses were tested using daily and monthly data. Monthly returns were calculated on Tuesdays. Daily and monthly frequency index returns for each market were calculated using the following equation:

$$r_{it} = ln\frac{P_{it}}{P_{it-1}} = p_{it} - p_{it-1} \quad (1)$$

Where $p_{it} \equiv ln\, P_{it}$, P_{it}represents index value at t, and P_{it-1}represents index value at $t-1$. Table 1 presents descriptive statistics for TSE and DJUS. The first and the second rows represent daily and monthly statistics, respectively.

4. The Random Walk Hypotheses

The statement that in an efficient market, prices "fully reflect" available information is so general that it has no empirically testable implications (Fama, 1970). To make the model testable, the process of price formation must be specified in more details. Perhaps the earliest model of financial asset prices was "martingale model", whose origin lies in the history of games of chance and the birth of probability theory (Campbell et al., 1997). "Fair game" is the essence of a martingale, a stochastic process p_t that satisfies the following condition:

$$E(p_{t+1} | p_t, p_{t-1}, \cdots) = p_t \tag{2}$$

or, equivalently,

$$E(p_{t+1} - p_t | p_t, p_{t-1}, \cdots) = 0. \tag{3}$$

If p_t represents one`s wealth at date $t$ from playing some game of chance each period, then a fair game is one for which the expected wealth in the next period is simply equal to this period`s wealth, conditioned on the history of the game. Alternatively, a game is fair if the expected incremented wealth at any stage is zero when conditioned on the history of the game.

If p_t is taken to be an asset`s price at date t, then martingale hypothesis states that tomorrow`s price is expected to be equal to today`s price, given the asset`s entire price history. Alternatively, the asset`s expected price change is zero when conditioned on the asset`s price history; hence, its price is just as likely to rise as it is to fall. Another aspect of martingale hypothesis is that non-overlapping price changes are uncorrelated at all leads and lags, which implies the ineffectiveness of all linear forecasting rules for future price changes based on historical prices alone.

In fact, martingale was long considered to be a necessary condition for an efficient asset market; one in which the information contained in past prices is instantly, fully, and perpetually reflected in the asset`s current price. If the market is efficient, then it should not be possible to profit by trading on the information contained in the asset`s price history. This notion of efficiency has a wonderfully counterintuitive and seemingly contradictory flavour to it: The more efficient the market, the more random is the sequence of price changes generated by the market, and the most efficient market of all is one in which price changes are completely random and unpredictable. Moreover, martingale led to the development of a closely related model that has now become an integral part of virtually every scientific discipline concerned with dynamics: random walk hypothesis.

Campbell et al (1997) mentioned that a useful way to organize various versions of random walk and martingale models is to consider various kinds of dependence that can exist between an asset`s returns r_t and r_{t+k} at two dates t and $t+k$. To do this, random variables $f(r_t)$and $g(r_{t+k})$ should be defined where $f(.)$ and $g(.)$ are two arbitrary functions, and situations in which

$$Cov[f(r_t), g(r_{t+k})] = 0 \quad (4)$$

Should be considered for all t and for $k \neq 0$. For appropriately chosen $f(.)$ and $g(.)$, virtually all versions of random walk and martingale are captured by eq. 4, which may be interpreted as an orthogonality condition.

For example, if $f(.)$ and $g(.)$are restricted to be arbitrary linear functions, then eq. 4 implies that returns are serially uncorrelated, corresponding to Random Walk 3 model. Alternatively, if $f(.)$ is unrestricted but $g(.)$ is restricted to be linear, then eq. 4 is equivalent to martingale hypothesis. Finally, if eq. 4 holds for all functions $f(.)$ and $g(.)$, this implies that returns are mutually independent, corresponding to the Random Walk 1 and Random Walk 2 models.

Although there are several other ways to characterize various random walk and martingale models, condition eq. 4 and tab. 2 are particularly relevant for economic hypotheses since almost all equilibrium asset-pricing models can be reduced to a set of orthogonal conditions.

Table 2: Classification of Random Walk and Martingale Hypotheses

$0\mathrm{Cov}[f(r_t), g(r_{t+k})] =$	$g(r_{t+k}), \forall g(.)$ Linear	$g(r_{t+k}), \forall g(.)$
$f(r_t), \forall f(.)$ Linear	Uncorrelated Increments, Random Walk 3•: $\mathrm{Proj}[r_{t+k} \mid r_t] = \mu$	-
$f(r_t), \forall f(.)$	Martingale/Fair Game: $E[r_{t+k} \mid r_t] = \mu$	Independent Increments, Random :Walks 1 and 2 $\mathrm{pdf}(r_{t+k} \mid r_t) = \mathrm{pdf}(r_{t+k})$

•"$E[y|x]$" denotes the linear projection of y onto x, and "$\mathrm{pdf}()$" denotes the probability density function of its arguments.
source: Campbell et all. (1977).

4.1. The Random Walk1: IID Increments

According to EMH, current prices of a security have been adjusted fully to the extant information when the security return is independent and identically distributed (Fama, 1970). Perhaps the simplest version of the random walk hypothesis is the independently and identically distributed (IID) increments case in which the dynamics of p_t is obtained by the following equation:

$$r_t \equiv p_t = \mu + p_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim \mathrm{IID}(0, \sigma^2) \qquad (5)$$

Where r_t represents stock returns, μ is the expected price change or drift, and $\mathrm{IID}(0, \sigma^2)$shows that ε_t is independently and identically distributed with mean 0 and variance σ^2. The independence of the increments ε_t implies that random walk is also a fair game, but in a much stronger sense than martingale. Independence implies not only are increments uncorrelated, but also nonlinear functions of the increments are also uncorrelated. This is called the Random Walk 1 model, or RW1.

4.2. The Random Walk 2: Independent Increments

Despite the elegance and simplicity of RW1, the assumption of identically distributed increments is not plausible for financial asset prices over long time spans. Therefore, we relax the assumptions of RW1 to include processes with independent but not identically distributed (INID) increments. This is called the Random Walk 2 model or RW2. RW2 clearly contains RW1 as the special case. It also contains considerably more general price processes.

4.3. The Random Walk 3: Uncorrelated Increments

An even more general version of random walk hypothesis may be obtained by relaxing the independence assumption of RW2 to include processes with dependent but uncorrelated increments. This is the weakest form of random walk hypothesis, which is referred to as the Random Walk 3 model or RW3, and contains RW1 and RW2 as special cases. A simple example of a process that satisfies the assumptions of RW3 but not of RW1 or RW2 is any process for which $Cov(\varepsilon_t, \varepsilon_{t-1}) = 0$ for all $k \neq 0$, but where $Cov(\varepsilon_t^2, \varepsilon_{t-1}^2) \neq 0$ for some $k \neq 0$. Such a process has uncorrelated increments, but it is clearly not independent since its squared increments are correlated.

5. The Research Tests

In this study, Ljung-Box test, runs test, Lo-MacKinlay variance ratio test, and Wright`s variance ratio test were employed to test the independent and identically distribution of the returns according to random walk hypotheses (Campbell et al., 1997).

5.1. Ljung-Boxtest

Statistical independence requires that the distribution of the joint probability of a time series, i.e. the total *T* random variables, to be defined as the product of marginal distributions of *T* random variables. Like:

$$F[x(t_1), x(t_2), \cdots, x(T)] = f[x(t_1)]\, f[x(t_2)] \cdots f[x(T)]. \qquad (6)$$

If a time series (like a price time series) is distributed independently, then auto-correlation coefficients for all time lags of the differenced series (such as return time series) will be zero. $\rho(k)$is a measure which establishes a relationship between the value of the variable at t and its value in k recent periods. For example, if the variable u_t represents changes in the logarithm of a certain stock price from the end of day $t-1$ to the end of day t, then the autocorrelation coefficient for k is:

$$\rho(k) = \frac{covariance(u_t, u_{t-k})}{varince(u_t)} \tag{7}$$

Ljung and Box (1978) proposed a statistical test to examine time series independence instead of calculating autocorrelation coefficients. Ljung-Box test is defined as follows:

$$Q(k) = T(T+2)\sum_{m=1}^{k}(T-m)^{-1}\rho^2(m) \tag{8}$$

where up to k lags of the sample autocorrelation coefficient are present. The null hypothesis of Ljung-Box test indicates the linear independence of $x(t)$

Table 3: Ljung-Box Independence Test Results, Lag 20

								Tehran Security Exchange		
	44	57	27	64	39	23	13	34	43	60
Daily	0.048	0.010	-0.003	0.036	0.010	0.014	-0.012	-0.015	0.116	-0.003
	281.3	241.2	259.9	113.9	323.3	21.16*	259.4	189.7	1027.1	2.99*
Monthly	-0.060	-0.055	-0.012	0.011	0.142	-0.135	-0.017	-0.071	-0.113	0.041
	15.85*	33.55	16.19*	10.82*	27.02*	25.05*	32.60	29.19*	59.09	186.8
							Dow Jones United State Security Exchange			
	BM	CY	EN	FN	HC	IN	NC	TC	TL	UT
Daily	0.051	0.022	0.059	0.048	0.014	0.039	0.000	0.008	0.019	0.000
	71.68	67.51	683.7	142.3	76.74	142.3	1744.7	83.77	41.97	92.69
Monthly	-0.081	-0.059	0.014	-0.046	-0.002	-0.065	0.049	-0.131	-0.103	0.038
	34.34	31.53*	19.11*	51.41	23.26*	32.82	33.68	35.06	39.65	21.14*

Note: In each frequency,the first row and the second row represent the autocorrelation coefficient and the test statistic, respectively. (*) indicates significance at the 5% level.

Therefore, null hypothesis and alternative hypothesis of autocorrelation test are defined as follows:

$$\begin{cases} H_0: \rho(1) = \rho(2) = \cdots = \rho(k) = 0 \\ H_1: at\ least\ one\ \rho(k)\ is\ nonzero \end{cases} \tag{9}$$

If null hypothesis is true, Q has an asymptotic distribution $\chi^2(k)$ with k degrees of freedom. Null hypothesis is rejected if the test statistic is greater than the critical value of chi-square distribution with k degrees of freedom.

5.2. Runs Test

Runs test aims to recognize the independence of the sequencer_t. To this end, it examines the frequency of certain repetitive patterns in the sequencer_t. In this test, run refers to a sequence of changes with the same sign in the sequencer_t.A positive run with length i is a sequence of consecutive positive price changes. Such a definition also holds true in the case of negative and zero runs. For example, take the 12-element-long variable r_t with positive and negative signs in the following. If the signs of any value substitute the value itself, then we will have:

$(+)(+)(+)(-)(+)(-)(-)(-)(-)(+)(-)(+)$

The number of actual runs in the above sequence is equal to the frequency counts of shifts from (+) to (-) and vice versa, i.e. from (-) to (+). In this example, there are 7 runs including 4 runs of positive values with the number of elements of these runs 3,1,1,1; and 3 runs of negative values with the number of elements of these runs 1,4,1. In fact, runs test aims to compare the actual number of runs in the sequence r_t with the number of expected runs in a random process.The expected number of runs is calculated as follows:

$$m = \frac{[T(T+1) - \sum_i n^2(i)]}{T} \tag{10}$$

Where *T* is the total number of observations and the*n* (i) are the number of changes in positive, negative or zero signs, hence$i = 1, 2, 3$. Variance for *m* is calculated using the following equation:

$$\sigma^2(m) = \frac{\sum_i n^2(i)[\sum_i n^2(i) + T(T+1)] - 2T\sum_i n^3(i) - T^3}{T^2(T-1)} \tag{11}$$

For large *T*, the sampling distribution of *m* is approximately normal. Standard value of *m* can be calculated using the standard normal distribution as follows:

$$Z = \frac{[(R + 0.5) - m]}{\sigma(m)} \quad (12)$$

Where$R$ is the actual number of runs. To test null hypothesis which states that the sequence $r_t$is independent, Z value is compared with critical values of the standard normal, $\mathrm{N}(0,1)$.If $|Z| < |\tau|$, null hypothesis is confirmed.

Table 4: Runs Test Results

										Tehran Security Exchange
	44	57	27	64	39	23	13	34	43	60
Daily	164	552	428	449	25	85	258	564	49	123
	-3.57	-11.00	-13.01	-14.21	0.31*	5.38	-6.94	-10.42	-5.18	-8.72
Monthly	39	37	33	42	35	27	37	29	24	2
	-0.18*	-0.77*	-1.73*	0.61*	-1.23*	-2.76	-0.71*	-2.44	-3.32	-8.83
							Dow Jones United State Security Exchange			
	BM	CY	EN	FN	HC	IN	NC	TC	TL	UT
Daily	1761	1598	1307	1720	947	1933	1869	1254	761	772
	-0.78*	-1.55*	-1.61*	2.52	-0.05*	1.52*	2.68	0.88*	-4.07	-2.91
Monthly	102	47	94	81	85	92	84	89	61	85
	1.66*	0.93*	0.56*	-0.81*	-0.71*	0.32*	-0.89*	-0.17*	-0.92*	-0.54*

Note: In each frequency, the first row and the second row represent the number of runs and the test statistic, respectively. (*) indicates significance at the 5% level.

5.3. Variance Ratio Tests

According to random return series (Eq. 2),the basic assumption in variance ratio test is that when the two conditions of random walk $\mathrm{E}(\varepsilon_t) = 0$ and$\mathrm{E}(\varepsilon_t \varepsilon_{t-j}) = 0$ are met, the variance of $r_t + r_{t+1}$should be twice the variance ofr_t. Therefore, the variance ratio $VR(2)$ is calculated as follows:

$$VR(2) = \frac{Var[r_t(2)]}{2Var[r_t]} = \frac{Var[r_t + r_{t-1}]}{2Var[r_t]} = \frac{2Var[r_t] + 2Cov[r_t, r_{t-1}]}{2Var[r_t]} \quad (13)$$

Thus, the variance ratio in two consecutive periods is defined as follows:

$$VR(2) = 1 + \rho(1) \tag{14}$$

Where $\rho(1)$ is the return first order autocorrelation coefficient and $r_t(2) \equiv r_t + r_{t-1}$ represents the return for two consecutive periods. In random walk where autocorrelation coefficients are zero, we have $VR(2) = 1$. If the returns have a positive autocorrelation, then $VR(2) > 1$ and if the returns have a negative autocorrelation, then $VR(2) < 1$.

5.3.1. Lo-MacKinlay variance ratio test

According to Wright (2000), Lo-MacKinlay variance ratio is defined as follows:

$$VR(x;k) = \overbrace{\left\{\frac{1}{Tk}\sum_{t=k}^{T}(x_t + x_{t-k} + \cdots + x_{t-k+1} - k\hat{\mu})^2\right\}}^{\frac{1}{k}\text{variance of } k-\text{period return}} \div \overbrace{\left\{\frac{1}{T}\sum_{t=1}^{T}(x_t - \hat{\mu})^2\right\}}^{\text{variance of one period return}} \tag{15}$$

Where x_t is stock returns at time t and $t = 1, \cdots, T$ and $\hat{\mu} = T^{-1}\sum_{t=1}^{T} x_t$. The variance ratio of each population is the ratio of $1/k$ times the variance of k periods return to the variance of one period return.

Lo and MacKinlay (1988) showed that if x_t is independent and identically distributed, then $VR(k) = 1$. Statistic of Lo-MacKinlay variance ratio test has an asymptotic standard normal distribution and is defined as follows:

Table 5: Lo-MacKinlay Variance Ratio Test Results

											Tehran Security Exchange
	lags	44	57	27	64	39	23	13	34	43	60
Daily	2	1.321	1.323	1.303	1.213	1.346	1.092	1.309	1.304	1.442	1.023*
		1.323	1.324	1.304	1.215	1.347	1.093	1.311	1.305	1.444	1.024
	4	1.618	1.617	1.609	1.446	1.736	1.166	1.665	1.509	2.060	1.045*
		1.624	1.623	1.616	1.451	1.742	1.170	1.671	1.514	2.068	1.048
	8	1.981	1.961	1.939	1.549	2.196	1.238	2.054	1.686	2.955	1.049*
		1.999	1.979	1.956	1.563	2.215	1.249	2.072	1.701	2.981	1.064
	16	2.441	2.369	2.399	1.624	2.664	1.221	2.462	1.907	4.208	1.083*
		2.487	2.414	2.445	1.654	2.714	1.244	2.509	1.943	4.287	1.117
Monthly	2	1.176	1.125	1.202	0.894	1.282	1.133	1.161	1.129	1.391	1.059*
		1.206	1.153	1.233	0.917	1.315	1.162	1.191	1.159	1.426	1.086*
	4	1.235	1.200	1.332	0.771	1.286	1.430	1.405	1.030	1.837	1.177*
		1.334	1.296	1.439	0.832	1.389	1.544	1.517	1.112	1.984	1.271
	8	1.376	1.599	1.259	0.786	1.200	1.687	1.334	1.216	2.376	0.878*
		1.655	1.924	1.515	0.945	1.443	2.029	1.604	1.463	2.857	1.056*
	16	1.434	1.423	1.273	0.797	1.103	1.855	1.435	1.139	2.104	0.832*
		2.179	2.161	1.934	1.211	1.676	2.818	2.179	1.730	3.196	1.264*
											Dow Jones United State Security Exchange
	lags	BM	CY	EN	FN	HC	IN	NC	TC	TL	UT
Daily	2	0.971*	0.979*	0.816	0.879	0.973*	0.988	0.812	0.982*	0.963	0.921
		0.971*	0.979*	0.817	0.879	0.974*	0.958*	0.812	0.982*	0.964*	0.921*
	4	0.929	0.911	0.734	0.799	0.893	0.909	0.687	0.901	0.872	0.842
		0.931*	0.913*	0.736	0.801	0.895*	0.911	0.688	0.902*	0.874*	0.844*
	8	0.865	0.845	0.661	0.669	0.793	0.857	0.602	0.849	0.809	0.791
		0.868*	0.848*	0.663	0.672	0.796	0.859*	0.604	0.853*	0.812*	0.704*
	16	0.814	0.837	0.611	0.609	0.763	0.848	0.559	0.823	0.746	0.725
		0.821*	0.843*	0.616	0.613	0.769	0.855	0.564	0.829*	0.752*	0.731*
Monthly	2	1.029*	1.056*	0.978*	1.053*	1.003*	1.048*	1.035*	1.032*	1.018*	1.044*
		1.040*	1.068*	0.989*	1.065*	1.014*	1.059*	1.047*	1.044*	1.029*	1.056*
	4	1.097*	0.968*	0.941*	1.049*	0.989*	1.011*	0.987*	1.044*	0.988*	1.068*
		1.135*	1.001*	0.973*	1.085*	1.023*	1.046*	1.021*	1.080*	1.021*	1.105*
	8	1.103*	0.977*	0.979*	1.169*	1.026*	1.095*	1.031*	0.999*	1.030*	1.222*
		1.195*	1.058*	1.059*	1.296*	1.111*	1.186*	1.117*	1.081*	1.116*	1.324*
	16	0.749*	0.979*	0.880*	1.213*	1.083*	1.027*	0.888*	0.837*	1.288*	1.422*
		0.892*	1.166*	1.048*	1.444*	1.289*	1.222*	1.058*	0.997*	1.533*	1.694*

Note: In each lag, the first row represents the test statistic under the assumption of homoscedastic error term and the second row represents the test statistics under the assumption of heteroscedastic error term. (*) indicates significance at the 5% level.

$$M_1(x;k) = (VR(x;k) - 1)\left(\frac{2(2k-1)(k-1)}{3kT}\right)^{-1/2} \quad (16)$$

If x_t is heteroscedastic, then Statistic of Lo-MacKinlay variance ratio test is calculated as follows:

$$M_2(x;k) = (VR(x;k) - 1)\left(\sum_{j=1}^{k-1}\left[\frac{2(k-j)}{k}\right]^2 \delta_j\right)^{-1/2} \tag{17}$$

and

$$\boldsymbol{\delta_j} = \left\{\sum_{t=j+1}^{T}(x_t - \hat{\mu})^2(x_{t-j} - \hat{\mu})^2\right\} \div \left\{\left[\sum_{t=1}^{T}(x_t - \hat{\mu})^2\right]^2\right\}. \tag{18}$$

5.3.2. Wright Variance Ratio Test

Wright (2000) tested variance ratios using two different null hypotheses about the distribution of ε_t. He presented the rank and sign statistics as follows:

In the first, he considered $r(\Delta p_t)$ as the rank of Δp_t among $\Delta p_t s$. The standard value of each rank is calculated as follows:

$$\boldsymbol{r_{1t}} = \frac{r(\Delta p_t) - 0.5(T+1)}{\sqrt{(T-1)(T+1)/12}}, \tag{19}$$

In null hypothesis, Δp_t is considered as a sequence with an independent and identical distribution and $r(\Delta p_t)$is the permutation of the numbers $1, \dots, T$ with equal probability. The null hypothesis of Wright`s (2000) ranked-based variance ratio test states that the logarithm of prices follows the random walk model and ε_t is independent and identically distributed. Variance ratio test statistics $R1$ and $R2$ under null hypothesis, assuming homoscedastic error term and $VR(q) = 1$ are as follows:

$$\boldsymbol{R_1} = \left(\frac{Tk^{-1}\sum_{t=k}^{T}(r_{1t} + r_{1t-1} + \cdots + r_{1t-k+1})^2}{T^{-1}\sum_{t=1}^{T} r_{1t}^2} - 1\right)\left(\frac{2(2k-1)(k-1)}{3kT}\right)^{-1/2}. \tag{20}$$

Moreover, r_{2t} is a standardized rank and Φ is the standard normal cumulative distribution function

$$r_{2t} = \Phi^{-1}\left[\frac{r(x_t)}{(T+1)}\right], \tag{21}$$

Accordingly, the statistic R2 is calculated as follows:

$$R_2 = \left(\frac{Tk^{-1}\sum_{t=k}^{T}(r_{2t} + r_{2t-1} + \cdots + r_{2t-k+1})^2}{T^{-1}\sum_{t=1}^{T} r_{2t}^2} - 1\right)\left(\frac{2(2k-1)(k-1)}{3kT}\right)^{-1/2}. \tag{22}$$

In the second, Wright (2000) substituted Δp_t for the statistic itself under the assumption of homoscedastic error term so as to improve Lo-MacKinlay test statistic. In this case, the test statistic holds true according to the null hypothesis of martingale difference sequence. In effect, the null hypothesis of Wright`s sign-based variance ratio test states that the logarithm of the price follows random walk model.

In this statistics, we have $s_t = 2u(\Delta p_t, 0)$ and $u(\Delta p_t, 0) = 1(\Delta p_t > 0) - 0.5$. $1(.)$ is a sign function. If the condition in parentheses is met, then it is equal to 1 and $u(\Delta p_t, 0) = +0.5$. Otherwise, it is equal to zero and $u(\Delta p_t, 0) = -0.5$.

Under null hypothesis, Δp_t is a martingale difference sequence with an unconditional mean of zero and s_t is a sequence with anindependent and identical distribution, a mean of zero, and a variance of 1 that takes values 1 and -1 with an equal probability of 0.5.

Accordingly, Wright (2000) presented the sign-based test statistics under null hypothesis assuming homoscedastic error term and $VR(q) = 1$ as follows:

$$S_1 = \left(\frac{Tk^{-1} \sum_{t=k}^{T} (s_t + s_{t-1} + \cdots + s_{t-k+1})^2}{T^{-1} \sum_{t=1}^{T} s_t^2} - 1 \right) \left(\frac{2(2k-1)(k-1)}{3kT} \right)^{-1/2} \tag{23}$$

and

$$S_2 = \left(\frac{Tk^{-1} \sum_{t=k}^{T} \left(s_t(\hat{\mu}) + s_{t-1}(\hat{\mu}) + \cdots + s_{t-k+1}((\hat{\mu})) \right)^2}{T^{-1} \sum_{t=1}^{T} s_t^2(\hat{\mu})} - 1 \right) \left(\frac{2(2k-1)(k-1)}{3kT} \right)^{-1/2}. \tag{24}$$

Table 6: Wright Variance Ratio Test Results

											Tehran Security Exchange
	lags	44	57	27	64	39	23	13	34	43	60
Daily	2	1.396	1.310	1.361	1.381	1.348	1.334	1.415	1.309	1.457	1.430
		1.349	1.292	1.339	1.415	1.293	1.327	1.396	1.240	1.350	1.441
	5	1.899	1.659	1.813	1.984	1.824	1.735	2.082	1.609	2.391	2.214
		1.842	1.741	1.812	2.296	1.717	1.801	2.119	1.494	2.114	2.383
	10	2.402	2.029	2.299	2.251	2.225	2.087	2.749	1.771	3.461	3.011
		2.313	2.225	2.338	3.225	2.116	2.231	2.935	1.653	3.009	3.480
	30	3.445	2.893	3.119	2.662	3.102	2.425	3.688	2.178	6.221	4.623
		3.183	3.605	3.409	5.741	2.963	2.738	4.384	2.085	5.189	6.373
Monthly	2	1.223*	1.163*	1.231	0.928*	1.265	1.186*	1.211*	1.159*	1.281	1.208*
		1.300	1.225	1.175*	0.950*	1.175*	1.100*	1.075*	1.150*	1.200*	1.175*
	5	1.279*	1.409*	1.221	0.794*	1.165*	1.465*	1.335*	1.036*	1.687	1.492
		1.570	1.610	1.150*	0.650*	1.310*	1.230*	1.050*	1.050*	1.670	1.490
	10	1.511*	1.886	1.208*	0.957*	1.232*	1.521*	1.331*	1.241*	1.973	1.332*
		2.230	2.210	1.445*	0.705*	1.820*	1.095*	0.975*	1.245*	2.135	1.530*
	30	0.761*	0.355*	0.759*	0.327*	0.489*	0.960*	0.793*	0.433*	0.496*	0.948*
		2.698	1.465	2.018	0.232*	3.118	1.568*	0.488*	0.470*	2.012*	1.117*
											Dow Jones United State Security Exchange
	lags	BM	CY	EN	FN	HC	IN	NC	TC	TL	UT
Daily	2	0.984*	0.989*	0.954	0.931	0.959	0.988*	0.947	0.995*	0.983*	0.986*
		0.984*	0.999*	0.985*	0.945	0.968	0.988*	0.977*	1.008*	0.981*	0.980*
	5	0.956*	0.911	0.888	0.874	0.856	0.943*	0.879	0.955*	0.934*	0.949*
		0.978*	0.960*	0.960*	0.906	0.923	0.979*	0.970*	1.035*	0.965*	0.939*
	10	0.876	0.853	0.818	0.766	0.767	0.871*	0.787	0.905*	0.872	0.887*
		0.930*	0.957*	0.972*	0.873	0.899*	0.967*	0.951*	1.043*	0.938*	0.911*
	30	0.773	0.848*	0.764	0.760	0.696	0.845*	0.695	1.004*	0.825*	0.818*
		0.833*	1.039*	1.059*	0.975*	0.984*	1.082*	1.015*	1.272	0.935*	0.936*
Monthly	2	0.913*	1.013*	0.928*	0.999*	1.023*	0.976*	0.959*	1.048*	0.983*	1.021*
		0.889*	1.089*	0.956*	1.100*	1.056*	1.000*	1.044*	1.011*	1.022*	1.122*
	5	0.879*	1.001*	0.910*	0.894*	1.033*	1.013*	0.892*	1.079*	0.937*	1.004*
		0.818*	1.333*	1.004*	1.129*	1.004*	1.022*	1.218*	0.987*	1.022*	1.387*

10	0.724*	1.033*	0.831*	0.904*	1.128*	0.982*	0.881*	1.063*	1.101*	1.104*
	0.716*	1.524*	1.020*	1.411*	0.976*	1.018*	1.580*	1.116*	1.176*	2.024*
30	0.228	1.016*	0.683*	0.720*	1.236*	0.743*	0.649*	0.619*	0.943*	0.933*
	0.573*	2.233*	1.276*	2.021*	1.041*	1.377*	2.689*	1.010*	1.253*	3.867*

Note: In each lag, the first row represents the test statistic under the assumption of homoscedastic error term and the second row represents the test statistics under the assumption of heteroscedastic error term. (*) indicates significance at the 5% level.

6. Research Findings

6.1. The First Hypothesis Test Results

The first hypothesis was concerned with the weak-form efficiency of TSE under two basic conditions of random walk hypothesis. Hypothesis (1-1) was concerned with the independent and identical distribution of stock returns in TSE and the hypothesis (1-2) tested the lack of autocorrelation of returns distribution. Accordingly, the results of runs test showed that only daily returns of the industrial multidisciplinary group index are distributed independently and identically and the distributions of other indices are not independent and identical. Therefore, it cannot be assumed that TSE return distribution is independent and identical; hence, hypothesis (1-1) is rejected. Moreover, the results of Ljung-Box test only confirmed the independent distribution of daily returns of petroleum products and transportation group`s indices.

The null hypothesis of Lo-MacKinlay variance ratio test is not confirmed regarding petroleum products whereas it is true forthe index of transportation group. Besides, the results of random walk variance ratio test do not confirm the random walk behaviour of petroleum products and transportation groups` indices. Given that the transportation group accounted for 2.3% of the market value in 2014, it cannot be stated that TSE is efficient at a weak level.

6.2. The Second Hypothesis Test Results

The second hypothesis was concerned with the patterned behaviour of stock prices in TSE. Under this hypothesis, stock prices have a trending behaviour in the short term and exhibits mean reversion in the long term in TSE. The results of Wright variance ratio test showed an increase in variance ratio values on daily returns at the 30th time lag compared to the second time lag. This is despite the fact that the results of this test showed a decline in the statistic at the 30th time lag compared to the first time lag on monthly returns. This means that the trending behaviour declines in TSE in the long term or the mean-reverting behaviour is formed. As a result, this characteristic of the market in Iran provides evidence for patterned returns and rejects weak-form market efficiency.

6.3. The Third Hypothesis Test Results

The third hypothesis is concerned with the impact of increasing the time period on the weak-form efficiency of TSE. In daily returns, the null hypothesis of runs test holds true for one index and, in monthly returns, it is true indices. The null hypothesis of the autocorrelation test is true for two and six indices in daily returns and monthly returns, respectively. Further, the null hypothesis of Lo-MacKinlay test is confirmed regarding one and six indices in daily and monthly returns, respectively. The null hypothesis of Wright variance ratio test isrejected about all indices in daily returns whereas it is confirmed about four indices in monthly returns. Therefore, it can be concluded that a larger part of the market is adjusted to the data by gradually extending the time within a month.

6.4. The Fourth Hypothesis Test Results

The fourth hypothesis was concerned with the weak-form efficiency of DJUS under two basic conditions of random walk model. Hypothesis (4-1) was concerned with the independent and identically distribution of stock returns in DJUS and hypothesis (4-2) tested the lack of autocorrelation of returns distribution. Runs test results showed that daily returns distributions indices of basic material (BM), customer services (CY), energy (EN), health care (HC), industrial (IN), and technology (TC) groups are independent and identical. These groups account for a total of 63% of the market value on 27 November 2015. Therefore, it can be concluded that the return distribution of most indices in DJUS is independent and identical and weak-form market efficiency is confirmed.

According to Ljung-Box autocorrelation test results, daily returns indices of all groups in DJUS show autocorrelation. The null hypothesis of variance ratio tests assuming homoscedastic error term of return model is rejected. However, taking heteroscedastic error term into account, the null hypothesis of variance ratio tests is confirmed in most indices. Therefore, due to the heteroscedastic error term, the test of the variance ratio indicates that the behaviour of prices follows the martingale model. It can be stated that market participants face with this proposition that the next day`s expected price will be equal to today`s price, according to the current news and information.

6.5. The Fifth Hypothesis Test Results

The fifth hypothesis examined the patterned behaviour of stock prices in DJUS based on trending behaviour of prices in the short term and mean reversion in the long term. The results of Wright variance ratio test on daily returns did not show a trending movement in the short term. For all indices, except for technology (TC) index, a decrease in variance ratio values on daily returns at the 30th time lag compared to the second time lag was observed. On the other hand, mean reversion behaviour was not observed in DJUS. Given the results of Wright variance ratio test on monthly returns, a decline in variance ratio values was not generally observed. Moreover, the null hypothesis of the test was confirmed regarding all indices except for basic materials (BM) and utilities (UT) groups` indices. The random walk behaviour was true for these indices, too. Therefore, it can be concluded that there is no such characteristic in DJUS. Besides, these results are confirmed based on Lo-MacKinlay variance ratio test statistics.

6.6. The Sixth Hypothesis Test Results

The sixth hypothesis examined the impact of extending the period on the weak-form efficiency of DJUS. The results showed that the independence and lack of autocorrelation are confirmed about a larger part of the market as return frequencies increase.

According to the results of runs test, monthly returns of all indices are independent and identically distributed and in daily frequencies the independence and identicalness of returns distribution of 63.13 % of the market (based on the market value) is confirmed.

7. Conclusion and Recommendations

According to the findings, there is positive autocorrelation in TSE in the short term as opposed to DJUS. Therefore, identifying trends and carrying out transactions in line with them can be profitable in the short term. Furthermore, due to inefficiency of TSE, using speculation and considering price volatility is profitable in the short term. In addition, given the repetitive patterns in short-tem volatilities in stock prices, using trading systems helps market participants estimate future stock prices. Besides, mean reversion behaviour or negative autocorrelation were observed in the long term in TSE unlike DJUS. This indicates that, in mid-term and long-term intervals, the current trend will reverse, thereby leading to investors` over-reaction in TSE that is a consequence of inefficiency of the market at weak level. The results of the present study are in line with the results of studies conducted on other developing markets as well as findings of studies on TSE (e.g. Fattahi et al., 2012; Mohammad et al., 2010; Namazi and Shooshtarian, 1999, and Fadainejad, 1994). In summary, the findings reject the weak-form EMH in TSE significantly different from that of developed markets.

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