Testing Random Walk Hypothesis for Indian Stock Market Indices

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Abstract:
In this paper we have analyzed the behavior of daily and weekly returns of five Indian stock market indices for random walk during April-1996 to June-2001. We have tested the indices for normality, autocorrelation using Q-statistic & Dickey-Fuller test and analyzed variance ratio using homoscedastic and heteroscedastic test estimates. The results support that Indian stock market indices do not follow random walk. Heteroscedasticity is not a cause of non-random behavior while autocorrelation is a minor source of no random walk indicating thereby that mean reverting behavior of stock indices is the major cause of random walk. While results of variance ratio test and autocorrelation test are similar and reject random walk in Indian stock market indices, the results from Dickey-Fuller test fail to reject the null hypothesis of random walk. Since variance ratio test is more powerful then the other tests performed in the study, we go by the results of variance ratio test.

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Introduction:

The concept of 'efficient' stock market has been hotly debated ever since Eugene Fama first introduced it around thirty-five years ago. Under the weak form of market efficiency, the price of a security reflects all the available information about the economy, the market and the specific security, and that prices adjust immediately to new information. For a long time the conformation of random walk is considered to be a sufficient condition for market efficiency. However, rejection of random walk model does not necessarily imply the inefficiency of stock-price formation.

Random Walk is the path of a variable over time that exhibits no predictable patterns at all. If a price, p, moves in a random walk, the value of p in any period will be equal to the value of p in the period before, plus or minus some random variable. The random walk hypothesis (RWH) states that the present market price is the best indicator of the future market prices with an error term that is stochastic in nature. Hence the next time period price is anybody's guess. In an efficient market it is not possible to make profit based on the past information hence the prediction of future price conditional on the past prices on an average should be zero. The more efficient a market is the more random and unpredictable the market returns would be. In the most efficient market the future prices will be totally random and the prices formation can be assumed to be a stochastic process with mean in price change equal to zero.

The objective of this paper is to investigate whether prices in Indian stock markets follow a random-walk process as required by market efficiency. The presence or absence of random walk in the price generation process in a stock market is evaluated using stock market indices. The study is made comprehensive by including five stock market indices from two major stock markets in India. The stock indices are tested for random walk using three different methodologies. Firstly, the behavior of indices for first order serial correlation is analyzed using autocorrelation coefficients at various lags and corresponding Q-statistics. This is followed by popular Dickey-Fuller unit root test. The variance ratio test as suggested by Lo & MacKinlay in 1988 is used as the powerful tool to test random walk in the stock market indices for homoscedastic and heteroscedastic assumptions.

1. 0. Literature Survey:

The random walk model was first developed by Bachelier (1900) in which he asserted that successive price changes between two periods is independent with zero mean and its variance is proportional to the interval between the two time periods. Accordingly, the variance of weekly changes should be five times the variance of the daily changes (assuming the market remains closed on weekends). This concept is exploited in the variance ratio tests, which has been widely used to test the random walk hypothesis in various markets. The study of rejection of random walk in the share prices due to mean reverting tendency which is a consequence of persistence of one sided volley in share prices was first presented by De Bondt & Thaler (1985). The presence of mean reverting tendency and absence of random walk in US stocks was confirmed by the studies of De Bondt & Thaler (1989) and Poterba & Summers (1988).

The variance ratio test was proposed by Lo and MacKinlay in 1988 to test the random walk hypothesis. The study compared variance estimators derived from data at various levels of frequencies for weekly stock market returns in the New York Stock Exchange and American Stock Exchange for a period of over 32 years. They improved the variance ratio statistic by taking overlapping period and corrected the variances used in estimating the statistic for bias. They also proposed a test statistic Z*, which is robust under the heteroscedastic random walk hypothesis, hence can be used for a longer time series analysis. An extensive Monte Carlo simulation was conducted by Lo & MacKinlay (1989) to find out the size and power of these tests in infinite samples. They identified that the variance of random walk increments was linear in all sampling intervals. Their findings provided evidence to reject the random walk model for the entire sample period of 1962-1985 and for all sub-periods for a variety of aggregate returns indexes and size-sorted portfolios. Their results also indicated positive autocorrelation for weekly holding-period returns not only for the entire sample but also for all sub-periods. The rejection of the random walk model by Lo & MacKinlay (1988) was mainly due to the behavior of small stocks. But this could not be attributed entirely to the effects of infrequent trading or time-varying volatilities. They used simple specification test based on variance estimators to prove that stock prices did not follow a random walk.

The Lo & MacKinlay finding of positive autocorrelation was inconsistent with the negative serial correlation found by Fama & French (1988). Fama & French discovered that for the U.S. stock market, 40 percent of the variations of longer holding-period returns were predictable from the information on past returns. Campbell in 1991 used variance decomposition method for stock returns and concluded that the expected stock return changes through time in a fairly persistent fashion.

Parameswaran (2000) performed variance ratio tests corrected for bid-ask spread and non-synchronous trading on the weekly returns derived from CRSP daily returns file for a period of 23 years. His results show that eight out of ten size sorted portfolios do not follow a random walk. He observed that non-trading is not a source of serial correlation in the large sized firms.

Kim, Nelson & Startz (1991) examined the random walk process of stock prices by using weekly and monthly returns in five Pacific-Basin stock markets. The findings provided evidence that the mean-reversion was only a phenomenon of the pre-World War II period, and not a feature of the post-war period. They found that the variance ratio tests produced positive serial correlation.

Studies based on the Lo & Mackinlay's simple volatility based specification test have indicated rejection of random walk in the stock markets of developing countries and newly developed countries as well. Pan, Chiou, Hocking & Rim (1991) applied the variance ratio test on daily and weekly returns for a five-year sample period in five Asian stock markets, namely, Hong Kong, Japan, Singapore, South Korea, and Taiwan. They rejected the null hypotheses of randomness for both daily and weekly market returns for Korea and Singapore and accepted the null hypothesis in case of Japan. The null hypotheses for Hong Kong daily returns index and the Taiwan weekly returns index were also rejected. Their results indicated that all the returns based on the five market indices were positively auto correlated except for Japan. Barman & Madhusoodanan (1993) used variance ratio test to find out the temporary and permanent components in the stock market. Their study based on industry wise indices concluded that in general Indian market is mean reverting. Ayadi & Pyun (1994) showed that South Korean market does not follow random walk when tested under homoscedastic error term assumption and follows random walk when the test statistic is corrected for heteroscedasticity. In his further study Madhusoodanan (1998) concluded that RWH can-not be accepted for BSE sensitive index and BSE national index and observed that heteroscedasticity does not seem to be playing an important role in the Indian stock market. Ming, Nor & Guru (2000) showed that variance ratio and multiple variance ratio tests reject random walk for Kuala-Lampur stock exchange. They further show that trading rules like variable length moving average (VMA) and fixed length moving average (FMA) have predictive ability of earning profits over and above the transaction costs. Darrat & Zhong (2000) examined random walk hypothesis for the two newly created stock exchanges in China. They followed two different approaches-the variance ratio test and comparison of NAÏ VE model (based on assumption of random walk) with other models like ARIMA and GARCH. They rejected the random walk in newly created Chinese stoke exchanges using both the methodologies. They further suggested artificial neural network (ANN) based models as strong tools for predicting prices in the stock exchanges of developing countries. Grieb & Reyes (1999) employed variance ratio on weekly stock returns to re-examine the Brazilian and Mexican stock markets. The findings indicated non-random behavior in the Mexican market while the Brazilian market indicated evidence in favor of the random walk. Koh & Goh (1994) tested the random walk hypothesis by extending the framework of Cochrane (1988) on Malaysian stock indices. The results revealed that the Malaysian stock market followed random walk in the long run.

For a long time the empirical testing of the efficient market hypothesis was based on the rejection of forecastability of asset returns. Ability of any model to predict future stock prices fairly accurately itself proves that the market does not follow random walk. The studies based on technical analysis and neural networks disprove random walk hypothesis by proving that future prices can be accurately forecasted. Mitra (2000) developed ANN model based on past stock market prices as parameters and showed that network performs very well in forecasting developments in BSE sensitive index, thus rejecting the criteria of un-forecastability of stock prices in Bombay stock exchange. Ming, Nor & Guru study (mentioned earlier) also tries to disprove random walk by establishing the predictive capability of technical rules like VMA and FMA.

Well-known Dickey-Fuller unit root test and Box-Pierce Q tests are also widely used in literature. Ramasastri (1999) tested Indian stock markets for random walk during post liberalization period using three Dickey-Fuller hypotheses. Contrary to other studies he could not reject the null hypothesis that stock prices are random walks. Lo & Mackinlay (1989) have indicated that the variance ratio test is more powerful than the well-known Dickey-Fuller unit root or the Box-Pierce Q tests. According to Ayadi & Pyun (1994) the variance ratio test has more appealing features and hence it has been used several times in the literature on random walk.

2. 0. Data and Methodology:

There are various indices available that are widely used as the indicator of the performance of the stock markets in India. These indices are constructed based on different methods and hence are expected to behave differently. Five different indices related to Indian stock exchanges are used in the study. These indices are:

1. BSE sensitive index (Sensex)
2. BSE national index of 100 stocks (BSE-100)
3. BSE national index of 200 stocks (BSE-200)
4. S&P CXN NIFTY (Nifty)
5. S&P CNX 500 (NSE-500)

Sensex was a natural choice for including in this study, as it is the most popular market index and widely used by market players for benchmarking. Existence of available data on Sensex for a larger period of time is an added advantage for the study. BSE-100 and BSE-200, the other Bombay Stock Exchange (BSE) related indices are included because they have much broader market base. Nifty is another popular market index. As against 30-company portfolio in Sensex it follows a size of 50 firms and is based upon the 'impact cost' criteria. NSE 500 is included in the study to represent a broad-based market index from National Stock Exchange (NSE). It represents more than the ¾th of the total market capitalization and thus reflects the overall performance of capital matter in a better way. The study spans more than five years, starting from 23-April-96 and extending till 7-June-01 and measures the variance ratio and other statistics for daily & weekly returns.

The span of time period in sampling of data was restricted due to the availability of data. Data on NSE related indices is limited due to short span of the existence of NSE. The data on NSE related indices were available only from 23-April-96. Incidentally it corresponds to the time when NSE emerged as the largest equity market in India. Also, during this time Sensex was changed substantially. The data on India stock market indices is obtained from the Prowess (the CMIE information software). Non-trading is not a major problem since market indices are bound to fluctuate (at least by a marginal value) on every trading day. The daily closing prices of respective indices are used as the source data, which is used to arrive at weekly and monthly data. The weekly price series are based on the closing value for Wednesday of each week. If the Wednesday observation is missing, then the Tuesday's closing price (or Thursday's if Tuesday's is also missing or Monday's if Thursday's is also missing or finally Friday if observation on any of the other week days is not available) is used instead. The monthly price series are based on the closing price of the last working day of the exchange in a month. The return is calculated as the logarithmic difference between two consecutive prices in a series, yielding continuously compounded returns. The sample generates 268 weekly observations for all the indices. For the same time period the number of daily observations vary between 1275 for Nifty and 1259 for BSE-200. Lo & MacKinlay (1988) suggest that weekly and monthly data are superior to daily figures since they are free from sampling problems of biases due to bid-ask spreads, non-trading, etc. inherent in the daily prices. Chow & Denning (1993) have stressed that the variance ratio test required a sample size of at least 256 observations to have reasonable power against other alternative tools. Under these considerations the weekly observations is the most appropriate data for variance ratio test. In-spite of the limitations the daily observations is also included in the study.

2. 1. Box & Pierce Q-Statistic:

Box & Pierce (1970) gave Q-statistic as an alternative to various hypotheses of autocorrelation with different time lags. Box-Pierce Q-statistic is a linear combination of squared autocorrelations with all the weights set identically equal to unity. It is defined as:

$$Q_m = T\, S_{k=1}^{m}\ r^2(k) \qquad \text{(i)}$$

Where, $\rho(k)$ is autocorrelation with k lags and T is the sample size.

To test the validity of market efficiency the Q-statistic is tested for various values of m, for the following null hypothesis:

$$\mathbf{H_0: \quad Q_m \sim c^2(m)} \qquad \textbf{(ii)}$$

Q-statistic can capture departure from no autocorrelation in either direction and at all time lags (governed by m). It follows a chi-square distribution with m degrees of freedom. Here m is the number of autocorrelations included in the Q-statistic. Selection of m requires careful balancing as small value of m would miss the higher order autocorrelations while a high value of m would reduce the test power due to insignificance of higher order autocorrelations. Finite-sample behavior of the Q-statistic is not comparable to that of variance ratios and under the null hypothesis Q-statistic have very different power properties under various alternatives, as explained by Lo & MacKinlay (1987).

2. 2. Dickey-Fuller Test for Unit Root:

Dickey-Fuller statistic tests for the unit root in the time series data. P_t is regressed against P_{t-1} to test for unit root in a time series random walk model, which is given as:

$$\mathbf{P_t = r\ P_{t-1} + u_t} \qquad \textbf{(iii)}$$

If ρ is significantly equal to 1, then the stochastic variable P_t is said to be having unit root. A series with unit root is said to be un-stationary and does not follow random walk. There are three most popular Dickey-Fuller tests used for testing unit root in a series.

The above equation can be rewritten as:

$$\mathbf{DP_t = d\ P_{t-1} + u_t} \qquad \textbf{(iv)}$$

Here $\delta = (\rho - 1)$ and here it is tested if δ is equal to zero. P_t is a random walk if δ is equal to zero. It is possible that the time series could behave as a random walk with a drift. This means that the value of P_t may not center to zero and thus a constant should be added to the random walk equation. A linear trend value could also be added along with the constant to the equation, which results in a null hypothesis reflecting stationary deviations from a trend.

To test the validity of market efficiency, random walk hypothesis has been tested. Unit root test has been conducted on P_t, natural log values of indices price data by running the regression equations of the following type:

$$\mathbf{DP_t = d\ P_{t-1} + u_t} \qquad \textbf{(v)}$$

$$\mathbf{DP_t = a + d\ P_{t-1} + u_t} \qquad \textbf{(vi)}$$

$$\mathbf{DP_t = a + dP_{t-1} + b\ t + u_t} \qquad \textbf{(vii)}$$

where, α is constant term and β is the coefficient of trend term. The null hypothesis for each is:

$$\mathbf{H_0: \quad d = 0} \qquad \textbf{(viii)}$$

The null hypothesis that P_t is a random walk can be rejected if calculated τ is greater than the tabulated τ. Calculation of τ is similar to the estimation of t-statistic but this value is compared with tabulated τ statistic, whose critical values have been tabulated by Dickey & Fuller on the basis of Monte Carlo simulations. The null hypothesis that P_t is a random walk can be rejected if calculated τ is greater than the tabulated τ.

2. 3. Variance Ratio Tests:

The robust variance ratio test developed by Lo & Mackinlay (1988) is used on the eight market indices selected for the study for observations from 23-April-96 to 7-June-01. Lo & Mackinlay (1989) have indicated that the variance ratio test is more powerful than the well-known Dickey-Fuller unit root or the Box-Pierce Q tests.

The first null hypothesis is stated as follows:

H_0: The variance ratio at lag *q* is defined as the ratio of the variance of the q-period return to the variance of the one-period return divided by q, which is unity under the random walk hypothesis:

i.e. $$\mathbf{VR(q) = Var[r_t(q)] / (q.\ Var[r_t]) = 1} \qquad \textbf{(ix)}$$

The alternative hypothesis will be VR (q) is not equal to one. To explain the hypothesis, let us suppose that (nq+1) observations of daily return are obtained. The daily returns are calculated as natural logarithm of stock price relatives, which starts from R_0, R_1, R_2, R_3, R_4, ……., R_{nq} at equally spaced intervals. If *q* were any integer greater than one, the ratio of 1/q of the variance of $(R_t - R_{t-q})$ to the variance of $(R_t - R_{t-1})$ would be equal to unity. Lo & Mackinlay (1988) stated that in a finite sample the increments in the variance are linear in the observation interval for a random walk. The variance of its q-differences is q times the variance of its first difference for a random walk series. In other words, if the logarithms of the stock prices are generated by a random walk return, the variance of the returns should be proportional to the sample interval. As noted by Lo & Mackinlay (1988), the variance of weekly price changes must be five times the variance of a daily price change.

The random walk model assumes a fixed drift in the price change from one period to another with a component of increments that are independently and identically distributed. The increment term has zero mean and a fixed variance as specified in the following equation.

$$\mathbf{P_t = \mu + P_{t-1} + \varepsilon_t, \qquad \varepsilon_t \sim IID(0, \sigma^2)} \qquad \textbf{(x)}$$

$$\mathbf{R_t = \mu + \varepsilon_t} \qquad \textbf{(xi)}$$

Where μ is the expected price drift,

ε_t is the increment term that is independently and identically distributed with mean zero and constant variance (homoscedasticity).

$R_t = P_t - P_{t-1}$ (so R_t is stock return).

The variance ratio of *q* grows linearly with the size of q. That is, the variance of $R_t - R_{t-2}$ is twice the variance of $R_t - R_{t-1}$. To calculate variance ratios, we obtain nq+1 observations R_0, R_1, R_2, R_3, R_4, ……., R_{nq}, at equally spaced intervals, where q is any integer greater than 1 and nq is the number of observations of R_t. The variance ratio is defined as follows:

$$\mathbf{VR(q) = \sigma_c^2(q) / \sigma_a^2} \qquad \textbf{(xii)}$$

Where $\sigma_c^2(q)$ is an unbiased estimator of 1/*q* of the variance of the qth difference of R_t and σ_a^2 is an unbiased estimator of the variance of the first difference of R_t.

The estimates of unbiased q period ($\sigma_c^2(q)$) and one period (σ_a^2) variances are calculated as follows:

$$\mathbf{\sigma_a^2 \equiv (1/nq-1)\ \Sigma_{k=1}^{nq} (P_k - P_{k-1} - \mu)^2} \qquad \textbf{(xiii)}$$
$$\mathbf{\sigma_c^2 \equiv (1/m)\ \Sigma_{k=q}^{nq} (P_k - P_{k-q} - q\mu)^2} \qquad \textbf{(xiv)}$$
$$\mathbf{m \equiv q(nq-q+1)(1-1/n)} \qquad \textbf{(xv)}$$
$$\mathbf{\mu \equiv (P_{nq} - P_0) / nq} \qquad \textbf{(xvi)}$$

After deriving an asymptotic distribution of the variance ratios, two alternative test statistics are derived to test the null hypothesis for different specifications of error term behavior. The first test statistic, *Z* (q), assumes an independent and identical distributed normal error term. Then, the standard normal *Z* test statistic is computed as follows:

$$\mathbf{Z(q) = [VR(q)-1] / \sqrt{[\phi(q)]} \approx N(0,1)} \qquad \textbf{(xvii)}$$

Where, $$\mathbf{[\phi(q)] = [2(2q-1)(q-1)] / [3q(nq)]} \qquad \textbf{(xviii)}$$

The second test statistic, *Z*(q)*, allows for a general heteroscedasticity of error term. The heteroscedasticity consistent standard normal test statistics relaxed the assumption of normality. The formula is given as follows:

$$\mathbf{Z^*(q) = [VR(q)-1] / \sqrt{[\phi^*(q)]} \approx N(0,1)} \qquad \textbf{(xix)}$$

Then, $\phi^*(q)$, the heteroscedasticity consistent asymptotic variance of the variance ratio is computed as follows:

$$\mathbf{\phi^*(q) = (\theta \,/\, nq)} \qquad \textbf{(xx)}$$

$$\text{where, } \mathbf{\theta = 4 \sum_{k=1}^{q-1} [\{1-(k/q)\}\, \delta_k]} \qquad \textbf{(xxi)}$$

$$\mathbf{\delta_k = [\, nq \sum_{j=k+1}^{nq} (p_j - p_{j-1} - \mu)^2 (p_{j-k} - p_{j-k-1} - \mu)^2] \,/\, [\, \sum_{j=1}^{nq} (p_j - p_{j-1} - \mu)^2]^2} \quad \textbf{(xxii)}$$

Both test statistics, Z(q) and Z*(q) are shown to be asymptotically standard normal. In this paper, both, VR(q*)*, homoscedasticity test statistic, Z(q) and heteroscedasticity-robust test statistic, Z*(q) are presented.

3. 0. Results and Analyses:

This section reports all the analyses of the tests that had been conducted in this study. The unit degree autocorrelation tests and the Box-Pierce Q-statistic performed at different lags will be reported and analyzed in section 3.1. It is then followed by three Dickey-Fuller tests for unit root in section 3.2. The section 3.3.will present and analyze Variance ratio tests.

3. 1. Results from Autocorrelation and Box-Pierce Statistics:

Table (i) reports the means, standard deviations, and the Box-Pierce Q-statistics for daily & weekly returns on the eight indices selected for the study from 23-April-96 to 7-June-01. Under the IID random walk null hypothesis RW1, the asymptotic sampling distribution of $\rho(k)$ is normal with mean 0 and standard deviation $T/(\sqrt{T-k})$.

For the daily returns all the indices show significant first order autocorrelation at 5% level of significance. The daily data seems has strong first order autocorrelation and higher order autocorrelations are non-significant for almost all the indices. Auto correlation is calculated until 4 lags and Q-statistics are calculated from m = 5 to 10. Q-statistic is composite measure of autocorrelation for m lags. For all indices auto correlations seem to die down for lags greater than 1. All the Q-statistics measured are significant for BSE-100, BSE-200 & NSE-500 mainly due to high order of first lag autocorrelation. Interestingly Sensex does not show significant Q-statistic for lower values of m. The Q-statistic for Sensex is significant at m=9 & 10 and it is significant for nifty at m=10. The auto correlation coefficients for Sensex are significant at a lag of 6 and 9. For Nifty, the coefficient is significant at a lag of 6, 9 & 10.

For the weekly returns none of the indices show significant autocorrelations of first-order. This could be due superiority of weekly figures over daily figures, which have sampling problems of biases due to bid-ask spreads, non-trading. Three broad based Indian indices namely BSE-100, BSE-200 and NSE-500 show significantly high level of autocorrelation at a lag of 2. The Q-statistics are not significant for any of the indices.

Table (i): Autocorrelation and Box-Pierce Q-Statistics

A. Daily Returns

	Sample Size	Mean	S.D.	ρ_1	ρ_2	ρ_3	ρ_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Sensex	1258	-0.00006	0.01859	0.053*	0.003	0.008	0.004	5.564	11.558	11.804	12.360	20.019*	21.309*
BSE-100	1259	-0.00001	0.03019	-0.27*	0.023	0.022	-0.023	94.205*	94.206*	94.762*	95.822*	106.028*	106.392*
BSE-200	1257	-0.00003	0.01831	0.097*	0.023	0.011	0.004	12.706*	16.651*	17.206*	19.218*	33.088*	39.977*
Nifty	1270	0.00001	0.01803	0.047*	-0.023	0.001	0.003	3.860	10.633	10.848	10.849	13.423	21.156*
NSE-500	1265	-0.00002	0.01828	0.108*	0.015	0.022	0.006	15.711*	18.390*	18.604*	21.521*	28.267*	42.225*

B. Weekly Returns

	Sample Size	Mean	S.D.	ρ_1	ρ_2	ρ_3	ρ_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Sensex	266	-0.00042	0.042548	-0.096	0.078	-0.036	-0.03	4.6714	9.6828	9.8005	10.4950	13.0072	13.5721
BSE-100	266	-0.00013	0.045950	-0.044	0.162*	-0.032	-0.005	0.0303	0.0440	0.0443	0.0448	0.0512	0.0544
BSE-200	266	-0.00027	0.04429	-0.041	0.163*	-0.026	-0.005	8.1155	11.3462	11.3785	11.5077	12.7789	13.5009
Nifty	266	-0.00009	0.040904	-0.078	0.076	-0.033	-0.022	3.6830	7.9894	8.1187	9.0481	10.6311	11.4097
NSE-500	266	-0.00022	0.045252	-0.045	0.172*	-0.018	0.013	9.2123	11.5216	11.5259	11.7063	13.3308	13.7163

* Indicates significant value at 5% level of significance. ρ_m is the autocorrelation coefficient of the index return series at lag m. Q_m is the Q-statistic of the index return series.

3. 2. Results from Dickey-Fuller Test:

The descriptive statistics and results of Dickey-Fuller tests for the daily & weekly observations are presented in Table (ii). Each row corresponds to a particular index. The first five columns present the descriptive statistics of data series namely, sample size, mean returns, standard deviation of returns, skew ness and kurtosis of the return series respectively. The next three columns present the results of Dickey-Fuller test results for no drift & no trend model, drift & no trend model and drift & trend model respectively. The first entry is the value of δ, which is equal to zero under null hypothesis. The value below this statistic in parenthesis is the corresponding test statistic called τ-statistic. The test statistic is tested at 5% level of significance and a value significantly different from tabulated value is indicated by a star mark.

For daily returns calculated value of τ is less than tabulated τ value under all three hypotheses for all the indices. For weekly returns the null hypothesis that stock prices are random walks cannot be rejected for all the indices.

The unit root tests strongly accept the null hypothesis of random walk for all the indices.

Table (ii): Results of Dickey-Fuller Test

A. Daily Returns								
	N	Mean	S.D.	Skew ness	Kurtosis	δ (NDNT)	δ (DNT)	δ (DT)
Sensex	1258	-0.00006	0.01859	-0.13988	1.65633	0.00000 (-0.00213)	-0.00638 (-2.12667)	-0.00732 (-1.83000)
BSE-100	1259	-0.00001	0.03019	-1.38828	211.87242	0.00001 (0.00174)	-0.00936 (-2.34000)	-0.01330 (-2.66000)
BSE-200	1257	-0.00003	0.01831	-0.22133	1.73432	0.00000 (-0.00018)	-0.00382 (-1.91000)	-0.00491 (-1.63667)
Nifty	1270	0.00001	0.01803	-0.10229	2.29880	0.00000 (0.00193)	-0.00514 (-1.71333)	-0.00739 (-2.46333)
NSE-500	1265	-0.00002	0.01828	-0.22814	1.85703	0.00000 (0.00025)	-0.00306 (-1.53000)	-0.00447 (-1.49000)
NDNT-No Drift & No Trend, DNT-Drift & No Trend, DT-Drift & Trend								
B. Weekly Returns								
	N	Mean	S.D.	Skew ness	Kurtosis	δ (NDNT)	δ (DNT)	δ (DT)
Sensex	266	-0.00042	0.04255	0.12212	0.88954	-0.00004 (-0.00743)	-0.03340 (-2.08750)	-0.03990 (-2.21667)
BSE-100	266	-0.00014	0.04595	-0.31308	1.13490	0.00000 (-0.00002)	-0.02170 (-1.66923)	-0.03050 (-1.90625)
BSE-200	266	-0.00028	0.04429	-0.32479	1.14779	-0.00002 (-0.00271)	-0.02240 (-1.72308)	-0.03070 (-1.91875)
Nifty	266	-0.00010	0.04090	0.14498	0.41760	0.00000 (0.00052)	-0.02650 (-1.89286)	-0.03960 (-2.32941)
NSE-500	266	-0.00022	0.04525	-0.37340	1.15971	-0.00001 (-0.00163)	-0.01870 (-1.55833)	-0.02900 (-1.93333)
NDNT-No Drift & No Trend, DNT-Drift & No Trend, DT-Drift & Trend								

The null hypothesis is tested for δ=0, for the three models. The values in the parenthesis below the δ values are corresponding calculated τ values. * Indicates that the figure is significant at 5% level of significance.

3. 3. Results from Variance Ratio Test:

Tables (iii) and (iv) report the variance ratios, homoscedasticity test statistic z(q) and heteroscedasticity test statistics z*(q) for daily & weekly observations respectively. The values reported in the main rows are the actual variance ratios, the entries below the variance ratios are z(q) and the entries in parentheses are the z*(q) statistics. Each row presents results for one market index. The results are presented for five Indian indices. The results of all the indices presented here are for the same time period - 23-April-96 to 7-June-01. The sample size for the daily data varies across the indices in accordance with the number of working days in respective exchange during the selected time period. The sample size for the weekly data match across the indices.

The entries in the first column correspond to variance ratios with an aggregation value *q* of 2. Under null hypothesis the variance ratio should be approximately equal to 1. If the value is not equal to one then it means that the series is autocorrelated in first-order and the variance ratio is sum of first-order autocorrelation coefficient estimator and unit value. The test statistics do not show any pattern with increase in *q*, but the magnitudes of variance ratios decline with increase in q.

For the daily observations the random walk null hypothesis is rejected at 5% level of significance and at all aggregation levels (2,4,8 & 16) for all the indices except for BSE-100 at aggregation value *q* of 2. Under assumption of homoscedasticity the null hypothesis of random walk is rejected for Bse-100 at q=2, but the null hypothesis is accepted when the test statistic is corrected for heteroscedasticity. The non-randomness in BSE-100 daily data can be attributed to the heteroscedasticity in the data series. While for all other cases heteroscedasticity is not the source of randomness. The rejections in these cases are not due to changing variances since the *z*(q)* statistics are robust to heteroscedasticity.

For the weekly observations the random walk null hypothesis is rejected at 5% level of significance and at all aggregation levels (2,4,8 & 16) for all the indices. For all the indices the variance ratios are significantly different from unity even under the assumption of heteroscedasticity.

Table (iii): Results for Daily Observation

	Number nq of base observations	Number q of base observations aggregated to form variance ratio			
		2	4	8	16
Sensex	1258	1.5255	1.2648	1.1302	1.0672
		12.9837*	13.8821*	10.3882*	11.2291*
		(9.9434)*	(11.1800)*	(9.5071)*	(7.2613)*
BSE-100	1259	1.3839	1.2021	1.1022	1.0517
		16.8590*	15.0662*	10.7221*	11.4158*
		(1.8798)	(3.9171)*	(7.6885)*	(6.6771)*
BSE-200	1257	1.5405	1.2776	1.1340	1.0722
		12.5746*	13.6417*	10.3428*	11.1696*
		(9.5635)*	(10.7603)*	(9.3465)*	(7.2293)*
Nifty	1270	1.5388	1.2630	1.1323	1.0686
		12.7010*	14.0061*	10.4285*	11.2844*
		(8.8544)*	(11.8815)*	(9.4646)*	(7.2503)*
NSE-500	1265	1.5526	1.2797	1.1343	1.0734
		12.3211*	13.6891*	10.4047*	11.2265*
		(9.0747)*	(10.8867)*	(9.0246)*	(7.1051)*

The table gives the variance ratios at various q values. The figures below the variance ratio are Z(q) and the values below Z(q) in parenthesis are Z*(q) values. * Indicates significance of a value at 5% level of significance.

Table (iv): Results for Weekly Observation

	Number nq of base observations	Number q of base observations aggregated to form variance ratio			
		2	4	8	16
Sensex	266	1.4236	1.2396	1.1147	1.0599
		9.4006*	6.6043*	4.8629*	3.4172*
		(5.6516)*	(4.3541)*	(3.5584)*	(5.5391)*
BSE-100	266	1.4040	1.2457	1.1242	1.0642
		9.7201*	6.5508*	4.8104*	3.4015*
		(5.1072)*	(3.6464)*	(2.9327)*	(4.7606)*
BSE-200	266	1.4047	1.2461	1.1242	1.0640
		9.7091*	6.5472*	4.8104*	3.4024*
		(5.2456)*	(3.7611)*	(3.0344)*	(4.9277)*
Nifty	266	1.4312	1.2416	1.1155	1.0596
		9.2776*	6.5864*	4.8585*	3.4185*
		(6.0650)*	(4.6936)*	(3.7864)*	(5.7930)*
NSE-500	266	1.3988	1.2409	1.1234	1.0641
		9.8046*	6.5925*	4.8152*	3.4018*
		(5.3221)*	(3.8131)*	(3.0410)*	(4.9170)*

The table gives the variance ratios at various q values. The figures below the variance ratio are Z(q) and the values below Z(q) in parenthesis are Z*(q) values. * Indicates significance of a value at 5% level of significance.

4. 0. Conclusions:

The random walk hypothesis for daily and weekly market indices returns are rejected for Indian context using heteroscedasticity corrected variance ratio test. There are significant first order autocorrelation in daily returns, which are in general absent in weekly returns. Autocorrelation if present is significant at lag one & two and it tends to die out for higher lags. Heteroscedasticity is not a source of non-random behavior of the indices. The problem of changing variances is restricted to daily data for BSE-100. The rejections due to time-varying volatilities are absent and infrequent trading is ruled out for indices since indices are bound to fluctuate every day even if by a small margin. The rejection of null hypothesis of random walk can be explained by the mean reverting tendency of stock market prices. In absence of heteroscedasticity and non-trading problems, the variance ratio test turns out to be a test of stock index mean reversion behavior.

The results confirm the mean reverting behavior of stock indices and overreaction of stock prices in unitary direction in India. This provides an opportunity to the traders for predicting the future prices and earning abnormal profits.

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