Variance Ratio Test of Random Walk in Indian Stock Market

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Abstract. We conduct tests of the null hypothesis of a random walk at the aggregate level of market indices and disaggregate level of individual shares to the Indian stock market over various data periods and a comparison of two sub-periods namely the pre liberalization and the post liberalization period. For this, we use the Lo-MacKinlay (1988) variance ratio test. Although the oldest test i.e. the serial correlation coefficient test is also applied to the same data to establish the relationship between the two tests but its results are not elaborated in this paper. The strength of this paper lies in the voluminous data base and a powerful testing tool that it makes use of. It is observed that the market is highly inefficient at daily returns level, thus imbibing high degree of predictability in stock returns, and even the weekly returns show the existence of trend. Monthly returns, however, support the random walk hypothesis across all periods. Thus it is concluded that further refinement of reform measures is required.

Keywords: Variance Ration test, Random Walk, Indian Stock Market

1 Introduction and Literature Review

The financial sector in India has developed quite significantly in both size and sophistication. A major fillip to strengthen the financial system was given by the rapid expansion of the stock market, especially in the later part of the 1980s and subsequently by initiating financial sector reforms on the recommendation of the high-powered Narasimham Committee in 1992-93. Wide ranging financial reform measures were implemented since then to make the financial system more market oriented, thereby aiming at increasing its efficiency. In the capital market, for instance, some of these reforms included repealing the Capital Issues (Control) Act of 1947; setting up the Securities Exchange Board of India (SEBI) to protect investors and to enhance transparency of the capital market; freeing the companies to approach capital market after clearance by SEBI; allowing the foreign institutional investors (FIIs) an access to the domestic capital market on registration with SEBI; permitting private sector to set up mutual funds; commencing the operations of Over the Counter Exchange of India (OTCEI) and National Stock Exchange of India with nationwide stock trading and electronic display, clearing and

settlement facilities; introduction of derivatives; permitting Indian companies an access to international capital markets through Euro equity issues and liberalisation of the investment norms for NRIs so that NRIs and overseas corporate bodies can buy shares and debentures without prior permission of RBI. The Indian capital market in general and stock market in particular has witnessed metamorphic changes, which have occurred in response to these domestic initiatives coupled with the emerging liberal and deregulated global financial environment.

Since the financial reforms were implemented as an integral part of the overall programme of economic reforms, with an objective to improve the productivity and efficiency of the capital market, this paper addresses the question of whether Indian stock market has evolved and has become relatively more efficient in the wake of a shift from the controlled to the liberalised era. The interest to pursue this study is guided by several implications of the stock market being efficient or inefficient. Stock markets do respond to the changes affecting the economy in general and specific industries and companies in particular. An important issue to be addressed is: 'How efficient, prompt & unbiased is this response?'

Market Efficiency means that stock prices can effectively signal the sectors or enterprises to which capital is most productively employed. Market efficiency is reflected in either operational efficiency or informational efficiency, both of which summarize the interactions and outcomes of a myriad of market activities. Since the establishment of Efficient Market Hypothesis (EMH) theory, vast amounts of papers on market efficiency have been published. Research on the efficiency of India's stock market has received a lot of attention from the researchers as well as from the press in recent years.

Scientific inquiry is a continuous cycle of creating new hypotheses, testing them, and creating better hypotheses. Continued testing is imperative before definite conclusions can be drawn on either side of efficiency. The present study is also an attempt in this direction. The perennially significant and interesting question of whether or not the major stock markets are 'efficient' is going to be examined for the Indian Stock Market, taking a variety of data series and using a comprehensive gamut of testing tools. More specifically the objectives of this study are to test the efficiency of the Indian Stock Market at the weak level and to have a comparative

analysis of the stock market efficiency in the pre liberalization period and the post liberalization period.

Lo and MacKinlay (1988) proposed the variance ratio test for the random walk hypothesis. They suggested that the variance ratio test is more powerful than the well known *Dickey-Fuller unit root* or the *Box-Pierce Q tests*. They applied the test on weekly returns on portfolios of New York Stock Exchange stocks, grouped according to size and found some evidence to reject the random walk model for the sample period of 1962 to 1985. They found positive autocorrelation, which was stronger for portfolios of smaller stocks. Almost similar conclusion were drawn by **J.C. Sharma (2002)** sought to examine whether Indian stock market became relatively more efficient in the wake of financial sector reforms, especially in the capital market, implemented with an objective to improve its efficiency. The time series data of excess and real returns on RBI's ordinary share prices for two-sub period, 1948-49 to1984-85 and 1985-86 to 1998-99 were used for this purpose. To detect that the short-term fluctuations dominate the stochastic trend components, Variance Ratio approach was used. It was evident from the empirical application of VR approach on Indian stock returns that they did not follow the random walk in the first sub period and also for the full sample period. During the second sub period, which had also witnessed the major reforms in financial sector, a tendency in VR statistic to move towards unity was generally observed but due to limited size of the sample it was difficult to predict with confidence whether stochastic trend dominated the movements of stock market prices or returns. Thus the market remained largely inefficient even after the liberalisation as per the empirical findings of this study.

T.P. Madhusoodanan (1998) analysed the mean reverting tendencies of share prices in the Indian stock market. He argued that the investors tend to overreact to information about the company and market, and hence stock prices will revert back in the future. He tested it under the null hypothesis of homoscedasticity as well as hetroscedasticity. He used the technique of variance ratios to test the mean reversion behaviour. The study was carried out using aggregate level of market indices and disaggregated level of individual companies. The weekly data on 120 stocks traded on the Bombay Stock Exchange (BSE) and two market indices, BSE sensitive index of 30 stocks and BSE National Index of 100 stocks were taken for the analysis. The data pertained to the period from January 1987 to December 1995. The results showed that there were

a number of auto-correlations significant at different lags, and most of them at higher lags were negative. This indicated the possibility of long-term mean reversion in the Indian Stock Market. The variance ratio tests suggested that at the aggregate level of BSE sensitive and national indices, the random walk hypothesis cannot be accepted, and the movements appeared to be persistent. From the analysis, it could be argued that hetroscedasticity did not seem to be playing an important role in the Indian stock market. At the disaggregated level of individual stocks, all of them except one showed significant auto-correlations, positive at lower lags and negative at higher lags. The variance ratios were significantly different from one (1) for a vast majority of the cases. Only 16 out of 120 stocks showed random behaviour. The persistent behaviour shown by the market indices was shown by a majority of the individual stock also. In a recent study variance ratio methodology was applied by Shiguang Ma (2004) for Chinese Stock Market. The q-periods taken in this study were 2,4,8,12 and 16. The daily behaviour of two markets (Shanghai and Shanzhen) in Ma's study departs markedly from randomness. The variance ratios of daily returns in both the markets increase successively as the length of the interval q increases. All the estimates of the variance ratios of weekly returns are larger than one, and most of them increase as the interval length of q enlarges. The monthly returns of three main indices of Shanghai Market follow a random walk.

2. Research Methodology

Under the study each price series (index as well as individual) is transformed into its natural logarithm price series. In view of the inherent heteroscedasticity of price changes it is considered advisable to transform it into log price changes. Log transformation is likely to render the price changes to be homoscedastic and thereby make the series stationary. To smooth the price changes this transformation is done as it depicts the rate of change rather than actual change. The first differences of log prices are referred log returns that are used throughout the study. The simple return is frequently found in the literature before 1980, and the log return has been popularly employed in the literature after 1980. The logarithmic return will be applied in all the empirical tests in this study. Unless otherwise specified, the returns used from now are logarithmic returns measured as:

$$r_t = \log_e (p_t / p_{t-1}),\ t = 1,2\text{-----},n$$

where r_t is the rate of return for the period t, and p_{t-1} and p_t are the prices for two successive periods t-1 and t and $\log_e$ is the natural logarithm to the base e. The Variance Ratio (VR) methodology was developed by Lo and Mackinlay (1988) to test the random walk theory and is based on the assumption that the variance of the random walk increments is linear in the sampling interval. Specifically, the variance estimated from the q-period returns should be q times as large as the variance estimated from one-period returns. To understand this proposition we use the following methodology.

Let X_t denote stochastic process satisfying the following recursive relation:

$$X_t = \mu + X_{t-1} + \epsilon_t, \quad E[\epsilon_t] = 0, \text{ for all } t, \ldots\ldots\ldots\ldots(1)$$

where μ is an arbitrary drift parameter and the random disturbance term ϵ_t has a zero mean and a zero auto covariance, $E[\epsilon_t, \epsilon_{t-k}] = 0$, for any non zero k. Under the random walk hypothesis, the variance of X_t increments must grow linearly with the size of the interval. That is, consider a q^{th} lag difference of X_t, where q is any integer greater than one. The ratio of the $(1/q)^{th}$ of the variance of $(X_t - X_{t-q})$ to the variance of $(X_t - X_{t-1})$ is equal to one. As long as the increments are uncorrelated this relationship holds asymptotically even in the presence of heteroscedasticity.

Suppose that one obtains nq+1 sample observation, $(X_o, X_1, \ldots\ldots, X_{nq})$ of the log of the stock prices. The variance ratio of q observations, VR (q) is defined as,

$$VR(q) = \frac{Var(r_t^q)}{Var(r_t)} \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where Var (r_t^q) is an unbiased estimator of 1/q of the variance of the q –period return and Var (r_t) is an unbiased estimator of the variance of one –period returns. More specifically,

$$Var(r_t^q) = \frac{1}{m}\sum_{t=q}^{nq}(x_t - x_{t-q} - q\mu)^2 \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$Var(r_t) = \frac{1}{nq-1}\sum_{t=1}^{nq}(x_t - x_{t-1} - \mu)^2 \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where $m = q(nq-q-1)(1-(q/nq))$ with $\mu = (1/nq)(X_{nq} - X_0)$ and $(Er_t^q) = \mu q$

Cochrane (1988) shows that this variance ratio is asymptotically equivalent to a weighted sum of serial autocorrelation coefficient estimator such that:

$$VR(q) = 1 + 2\sum_{k=1}^{q-1}(1-\frac{k}{q})\,\rho(k) \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where ρ (k) is the estimator of k^{th} autocorrelation coefficient. It is apparent in (5), that when the returns of the security are uncorrelated the serial correlation coefficient in lag one to q should be simultaneously near zero and the VR (q) should be 1. Therefore, **we set up the null hypothesis as H_0: VR (q)=1, and the alternative hypothesis H_a: VR(q)≠1.** The test will be carried out at significance level of α=0.05 and α=0.01. If the absolute value of test–statistics is less than the critical value, 1.96 or 2.576, we accept the null hypothesis at the 5% significance level or at the 1% significance level, which states that the returns are uncorrelated. Otherwise, we reject the null hypothesis, which means that the returns are serially correlated. The standard normal test statistics for the variance ratio test under the assumption of homoscedasticity Z(q) and heteroscedasticity Z*(q) were constructed by Lo and MacKinlay (1988). As data under study is not heteroscedastic, therefore, the test statistics under the assumption of heteroscedasticity are not calculated. The standard Z test statistics for testing the equality of VR (q) to be unity is :

$$Z(q) = \frac{\sqrt{nq}\,[VR(q)-1]}{\phi(q)^{1/2}} \approx N(0,1) \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

where $\phi(q)=[2(2q-1)(q-1)]/3q$, which is the asymptotic variance of the variance ratio under the assumption of homoscedasticity. In order to facilitate comparison of this study with previous researches (Lo and MacKinlay 1988 and Shiguang Ma 2004) on other markets, the q is selected as 2, 4, 8 and 16.

Most researchers estimate the variance ratio and the test statistics under the two alternate assumptions of heteroscedasticity and homoscedasticity. But in the present paper the assumption of heteroscedasticity has been dropped since it has been established that the data under analysis is not heteroscedastic. Spearman's rank correlation test is used to detect the heteroscedasticity of the data. For that, first we fit a regression to the data and obtain the residuals. The regression is given by

$$X_t = \alpha + \beta X_{t-1} + \mu_t$$

where α is intercept,β is slope and μ_t is the error term .The series (X_t) which is used represent logarithm of the stock prices. After ranking both $|X_{t-1}|$ and $|\mu_t|$ according to an ascending or descending order, we compute the **Spearman's rank correlation coefficient** between the two.

We find that the calculated values are less than the critical values and hence the correlations are not statistically important. This test proves that our data is not heteroscedastic and therefore the test statistics (z*(q)) are not estimated under the assumptions of heteroscedasticity. Variance ratio test is much more powerful and reliable than the usual tests of random walk models. A variance ratio of less than one implies that the returns of short intervals tend toward mean reversion over a long interval. On the other hand a variance ratio of exceeding one implies that the returns of short interval are inclined to trend over a longer interval. There is a systematic relationship between the serial correlation coefficient and the variance ratio test. The significant positive serial correlation of return leads to the relevant variance ratio being larger than one, therefore, implies that a trend exists in a time series of security prices. Whereas a significant negative serial correlation coefficient leads to the relevant variance ratio being less than one, therefore, indicates the existence of reversal in price movement.

3. The Database

The study uses the market index data as well as the individual share price data. To facilitate the comparison of pre-liberalization and post- liberalization period, the data covers a fairly long period of time. The dates of observations, however, vary from series to series according to the data availability.

As a proxy for the market portfolio, the study uses the BSE-Sensex and NSE- S&P CNX Nifty price indices. The Sensex price data under study consists of daily market-close prices, weekly market- close prices (i.e. week-end) and monthly market-close prices (i.e. last Friday of the month) from January 1, 1980 to October 20, 2005. The relevant data is collected from the different issues of The Stock Exchange Review, Bombay Stock Exchange, Mumbai and from the web site of BSE (www.bseindia.com). However, weekly data is self-developed with the help of daily data, as it was not available in any of these sources. Further the data is divided into two sub-periods viz. Sub-period I (1980-1990) and Sub-period II (1991-2005). All the tests are conducted for these two Sub-periods as well as on the full sample period to observe as to whether Indian stock market confirms to the belief that it has become more efficient in the post-liberalization period. The rational for using 1991 as the cut off year was that starting this year major policy initiatives were taken by the Government of India towards economic liberalization. The second index used in the study is S&P CNX Nifty. Again Daily, Weekly and Monthly closing values are

taken for the period from July 5, 1990 to October 7, 2005. The data is available on the web site of NSE (www.nseindia.com). However, these series are not divided into any sub-periods and only full sample period is studied.

Besides the index data, the individual share data is also employed in the study. All the fifty-seven individual scripts that have been chosen for the study have remained the part of BSE-SENSEX for three years or more. The composition of BSE-SENSEX keeps on changing and therefore, over the long period covered under the study many companies kept moving in-and-out of the Sensex. Therefore, to have a balanced representation of different industries over the entire period of the study, and to study the most significant individual scrips, this criterion of three years' inclusion in the Sensex is adopted for selecting the scrips. Thus, most of the scripts are from 'A' group. The list of the companies and the period for which the data is analysed is given in Table 1. For individual shares also, daily, weekly and monthly closing prices are considered and all the tests are conducted for two sub-periods (wherever data permits) as well as on the full sample periods. Moreover, we have ignored the days with no trading and have used return data only for the trading days. There are two reasons for doing that. Firstly, non-trading is not a common feature for the scrips we have selected as they all are actively traded scrips. Secondly, revisions of expectations, which take place during non-trading days, automatically get reflected in the opening price of the next trading day. Data relating to the individual scrips could not be found before 1988 and for some of the scrips the data was not available even from 1988. For scrips whose data is available since January 1988 the period of study has been divided into two sub periods, i.e. Sub period I (up to December 1990) and Sub Period II (January 1991 till the end).

Table 1: List of the Individual Share Studied

Company	**Period for which the data is analysed**
1. A.C.C	4/1/88 to 17/2/06
2. ASIAN CABLE	1/1/90 to 28/11/97
3. BAJAJ AUTO	4/1/88 to 17/2/06
4. BALARPUR IND	1/1/90 to 17/2/06
5. BHARTI TELE	18/2/02 to 17/2/06
6. BHEL	12/10/92 to 17/2/06
7. BOMBAY BURMAH	1/1/90 to 17/2/06
8. BOMBAY DYEING	4/1/88 to 17/2/06
9. CASTROL	4/1/88 to 17/2/06
10. CEAT LTD	4/1/88 to 17/2/06
11. CENTURY TEXTILES	4/1/88 to 17/2/06

Company	Period for which the data is analysed
12. CIPLA LTD	1/1/90 to 17/2/06
13. COLGATE PALMOLIVE (India)	9/1/88 to 17/2/06
14. CROMPTON GREAVES	2/1/90 to 17/2/06
15. CUMMINS (India)	4/1/88 to 17/2/06
16. G.E.SHIPPING	4/1/88 to 17/2/06
17. GLAXO SMITHKLINE	4/1/88 to 17/2/06
18. GRASIM IND	9/1/88 to 17/2/06
19. GUJ. STATE FERTILISERS	4/1/88 to 17/2/06
20. GUJ. AMBUJA CEMENT	4/1/88 to 17/2/06
21. HDFC	2/1/90 to 17/2/06
22. HERO HONDA	4/1/88 to 17/2/06
23. HINDALCO	4/1/88 to 17/2/06
24. HINDUSTAN MOTORS	4/1/88 to 17/2/06
25. HINDUSTAN LEVER	4/1/88 to 17/2/06
26. HINDUSTAN PETROLEUM	11/9/92 to 17/2/06
27. ICICI BANK	24/9/97 to 17/2/06
28. ICICI LTD	3/1/90 to 30/5/02
29. IDBI LTD	20/9/95 to 17/2/06
30. INDIAN HOTEL	4/1/88 to 17/2/06
31. INFOSYS TECHNOLOGIES	14/6/93 to 17/2/06
32. IPCL	20/11/92 to 17/2/06
33. ITC LTD	4/1/88 to 17/2/06
34. LARSEN & TOUBRO	4/1/88 to 17/2/06
35. MAHINDRA & MAHINDRA	4/1/88 to 17/2/06
36. MUKAND LTD	4/1/88 to 17/2/06
37. NESTLE (India)	4/1/88 to 17/2/06
38. NIIT LTD	24/5/93 to 17/2/06
39. NOVARTIS	4/1/88 to 17/2/06
40. ONGC CORPORATION	1/8/95 to 17/2/06
41. PHILIPS (India)	4/1/88 to 29/8/03
42. PREMIER AUTO	4/1/88 to 17/2/06
43. RANBAXY LAB	4/1/88 to 17/2/06
44. DR. REDDY'S LAB	1/1/90 to 17/2/06
45. RELIANCE IND LTD	4/1/88 to 17/2/06
46. RELIANCE ENERGY	1/1/90 to 17/2/06
47. STEEL AUTHORITY	1/10/92 to 17/2/06
48. SATYAM COMUTERS	26/11/92 to 17/2/06
49. STATE BANK	4/3/94 to 17/2/06
50. SIEMENS LTD	4/1/88 to 17/2/06
51. TATA CHEMICALS	4/1/88 to 17/2/06
52. TATA MOTORS	4/1/88 to 17/2/06
53. TATA POWER	4/1/88 to 17/2/06
54. VOLTAS LTD	4/1/88 to 17/2/06
55. WIPRO	25/1/91 to 17/2/06
56. ZEE TELE	25/11/93 to 17/2/06
57. ZENITH BIRLA	4/1/88 to 17/2/06

4. The results and Discussion

4.1 Variance Ratio Tests applied on the Returns of Two Market Indices of the Indian Stock Market

The results of variance ratio test on returns in the two main indices of the Bombay Stock Exchange and National Stock Exchange are arranged in Table 2. Tests on daily, weekly and monthly returns are reported for two sub periods and the overall period for BSE-Sensex in the first part of the table. Similarly daily, weekly and monthly returns for the overall period for NSE-Nifty are reported in the second part of the table. As described above, VR (q) represents the variance ratio of the returns and Z(q) represents the standard normal test statistics of the variance ratio test under the assumption of homoscedasticity.

The results of the variance ratio test of the **daily** returns section of the table indicates that the daily price behaviour of both the indices depart tremendously from randomness. Except the results of the sub period I of BSE-Sensex, all the test statistics of Z(q) reject the null hypothesis at 5% as well as at 1% significance level. Furthermore the rejections of the null hypothesis are robust in all intervals. During the sub period I of BSE-Sensex, only 'q' of 2 intervals rejects the hypothesis and results at all other intervals are not statistically significant to reject the hypothesis.

The variance ratio exceeds one for all other cases in the daily returns section, and most of them are relatively large. Referring to the equation (given by Cochrane), variance ratio of interval q=2 is approximately equal to one plus the first order serial correlation coefficient estimator[1]. Our results show that variance ratios in interval q=2 are approximately equal to one plus the first order serial correlation coefficient estimator 7(to avoid the lengthy statistics, the results of serial correlation coefficient are not shown over here). Z(q) of 7.1906 (BSE overall) and Z(q) of 6.9003 (NSE-overall) of interval q=2 reject the random walk hypothesis resoundingly. The variance ratio of daily returns in both the indices increases successively as the length of the interval q increases. For example the variance ratio of daily return of BSE sensex (overall period) climbs from 1.0953 for interval q=2 to1.2173 for interval q=16, and similar patterns can be found in the other results also.

[1] $VR(q) = 1 + 2\sum_{k=1}^{q-1}(1-\frac{k}{q})\rho(k)$ when q=2, VR(q)=1+ ρ(1)

The compatibility of the results of variance ratio test and autocorrelation test indicates that the non-random behavior of the market is not because of the heteroscedasticity, but because of genuine autocorrelations. The serious violation of randomness found in the test of serial correlation is evidenced again in the variance ratios test.

Table 2: Variance Ratio Test applied on the Two Market Indices

BSE-Sensex	**Obs.**	**q=2**	**q=4**	**q=8**	**q=12**	**q=16**
Daily Returns						
Sub Period I						
VR(q)	2201	1.093116	1.075482	1.013281	1.047586	1.09024
Z(q)		4.3665**	1.891148	0.21026	0.59385	0.958309
Sub Period II						
VR(q)	3497	1.096212	1.142864	1.184948	1.21966	1.258027
Z(q)		5.6878**	4.5132**	3.6931**	3.4588**	3.45856**
Overall Period						
VR(q)	5698	1.095276	1.121599	1.139873	1.177114	1.217341
Z(q)		7.19066**	4.9046**	3.5668**	3.5623**	3.7219**
Weekly Returns						
Sub Period I						
VR(q)	556	0.974361	1.043847	1.121712	1.129087	1.106571
Z(q)		-0.60348	0.55065	0.963204	0.803079	0.562619
Sub Period II						
VR(q)	766	1.085269	1.170141	1.278592	1.355447	1.333706
Z(q)		2.3568*	2.5105*	2.59298**	2.6034**	2.07622*
Overall period						
VR(q)	1322	1.085269	1.170141	1.278592	1.355447	1.333706
Z(q)		2.3568*	2.5105*	2.59298**	2.60337**	2.07622*
Monthly Returns						
Sub period I						
VR(q)	132	1.076407	1.02242	1.05144	1.085023	1.054617
Z(q)		0.871176	0.135585	0.193645	0.248428	0.13364
Sub period II						
VR(q)	178	1.07864	1.17291	1.191018	1.167151	0.935461
Z(q)		1.043284	1.219162	0.841968	0.574433	-0.18662
Overall Period						
VR(q)	310	1.089124	1.141975	1.154833	1.164424	1.130883
Z(q)		1.564127	1.32751	0.909628	0.757095	0.509842
NSE-Nifty						
Daily Returns						
VR(q)	3611	1.114861	1.144245	1.195469	1.223829	1.278042
Z(q)		6.90029**	4.6306**	3.96649**	3.5816**	3.78737**
Weekly Returns						
VR(q)	791	1.104068	1.208867	1.347712	1.401441	1.33834
Z(q)		2.92317**	3.13201**	3.28925**	2.9886**	2.13985*
Monthly Returns						
VR(q)	184	1.119182	1.154437	1.121392	1.082491	0.984985

Z(q)		1.607849	1.107523	0.544429	0.288569	-0.04421

Notes:

1. VR(q) is the variance ratio; q is the interval of the observations. Z(q) is distributed as a standard normal under the assumption of homoscedasticity.
2. "*", "**" Indicate significance at 5% and 1% respectively.

The **weekly** returns section of Table IV.1 indicates that the results of the varianc tests on weekly return are similar in some aspects to the results of the tests on daily returns. Except the results of the sub period I (BSE-Sensex), all the estimates of the variance ratios are larger than one, and most of them increase as the interval length of q is increased. The feature that variance ratios, which are derived from weekly returns of the two indices, are over one and increasing with enlarged interval length of q conforms to the findings of the study by Lo & MacKinlay (1988) on the CRSP index.

On the other hand, the results of variance ratio tests on weekly returns differ somewhat from those of daily returns. **The weekly returns of shares show less dependency than daily returns.** Almost all Z(q) derived from weekly returns are smaller in comparison with the corresponding statistics from daily returns. Only the sub period I of BSE-Sensex conforms to the random walk, demonstrating that before liberalization weekly prices were less predictable than after liberalization. Weekly price dependency has increased after the beginning of the process of economic reforms.

The variance ratios of **monthly** returns in both the indices are greater than one and in most of the cases increasing with increase in the interval length, similar to the feature of the tests on daily and weekly returns. But monthly results have a unique pattern that is different from those of daily and weekly returns. All estimated variance ratios are insignificant, indicating that the monthly behaviour of both the indices follows a random walk.

In a recent study variance ratio methodology was applied by Shiguang Ma (2004) for Chinese Stock Market. The q-periods taken in this study were 2,4,8,12 and 16. The results of Ma's study are similar to our study in many ways. Firstly, the daily behaviour of two markets (Shanghai and Shanzhen) in Ma's study departs markedly from randomness. Secondly, the variance ratios of daily returns in both the markets increase successively as the length of the interval q increases. Thirdly, all the estimates of the variance ratios of weekly returns are larger

than one, and most of them increase as the interval length of q enlarges. Lastly, the monthly returns of three main indices of Shanghai Market follow a random walk.

4.2 Variance Ratio Tests applied on Returns of Individual Shares of the BSE-Sensex

Variance Ratio tests are applied on the data of share prices of fifty-seven individual companies. To facilitate the meaningful comparison of pre and post liberalization periods, it was imperative that sufficient data was available for pre-1991 period. Therefore, out of the fifty-seven companies used for this study, returns of only thirty-two companies are compared for the two sub-periods through variance ratio test, as the data prior to 1990 is not available for the rest of the companies. The summary of results of variance ratio tests on **daily** returns, reported in Table 3, shows several features. Firstly the percentage of individual shares rejecting the null hypothesis for Sub- Period II is dramatically higher than the percentage of individual shares for Sub-Period I. The percentage of statistically significant Z(q) statistics of Sub period II are three times of those for Sub Period I. Hence, the daily returns of individual shares of Sub Period II are highly correlated. As far as overall period is concerned, its results are almost the same as for Sub Period II. It may be due to the reason that the overall period largely comprises of the Sub Period II. Next a high percentage of rejection of null hypothesis in Sub Period II by individual shares is consistent with the results of the variance ratio test on returns in BSE–sensex also. In addition, the percentage of the individual shares that have variance ratios greater than one in each interval of q in the Sub Period II is greater than the corresponding percentages in the Sub Period I. As a consequence, the daily returns in individual shares fluctuate slightly more strongly in the Sub Period II than in the Sub Period I.

The next part of the table reports that nearly 25% of individual shares, which have statistically significant test-statistics of variance ratios on **weekly** returns for different intervals, reject the null hypothesis. Thus even the weekly behaviour of individual shares cannot be regarded as consistent with the random walk hypothesis. The correlated weekly return pattern in individual shares has been confirmed by the results of the market indices also. In next part of the table, the percentage of individual shares that have statistically significant test statistics of variance ratios for **monthly** returns are drastically smaller than that of weekly returns. The percentage of rejections is around 5% only. **The variance ratio test provides the evidence that**

the monthly price behaviour of Indian stock market's individual shares follows the random walk.

Table 3: Summary of the Variance Ratio Test applied on Individual Shares of BSE-Sensex

Period	Total obs.	q = 2		q = 4		q = 8		q = 12		q = 16	
		No.	%	No.	%	No.	%	No.	%	No.	%
Daily Returns											
Sub Period I											
VR(q)	32	17	53.13	12	37.5	11	34.38	12	37.5	13	40.62
Z(q)	32	10	31.25	10	31.25	5	15.62	4	12.5	2	6.25
Sub Period II											
VR(q)	32	28	87.5	25	78.13	25	78.11	25	78.13	24	75.0
Z(q)	32	24	75.0	21	65.62	17	53.13	16	50	16	50
Overall Period											
VR(q)	57	40	70.17	41	71.92	38	66.67	40	70.17	41	71.92
Z(q)	57	38	66.67	34	59.65	32	56.14	28	49.12	27	47.36
Weekly Returns											
Sub Period I											
VR(q)	32	14	43.75	18	56.25	17	53.12	15	46.87	13	40.62
Z(q)	32	1	3.12	0	0	1	3.12	1	3.12	2	6.25
Sub Period II											
VR(q)	32	24	75.0	24	75.0	24	75.0	26	81.25	25	78.12
Z(q)	32	12	37.5	11	34.37	8	25.0	6	18.75	4	12.5
Overall Period											
VR(q)	57	38	66.67	42	73.68	49	85.96	48	84.21	45	78.95
Z(q)	57	18	31.57	18	31.58	15	26.32	15	26.32	12	21.05
Monthly Returns											
Sub Period I											
VR(q)	32	15	46.87	13	40.62	8	25.0	5	15.62	2	6.25
Z(q)	32	1	3.13	1	3.13	0	0	0	0	0	0
Sub Period II											
VR(q)	32	17	53.12	18	56.25	17	53.13	18	56.25	13	40.62
Z(q)	32	2	6.25	1	3.13	1	3.13	1	3.13	1	3.13
Overall Period											
VR(q)	57	37	64.91	41	71.93	40	70.17	37	64.91	37	64.91
Z(q)	57	8	14.03	7	12.28	8	14.03	6	10.53	5	8.77

5. Summary of Results

This study has comprehensively tested the random walk hypothesis to determine the validity of weak form efficiency for both the Bombay Stock Exchange and National Stock Exchange. The variance ratio test has been applied to the data pertaining to the daily returns, weekly returns and monthly returns. Further, the test has been conducted on the returns on the two main market indices and also on the individual share prices. The rejection is given under the following conditions:

- When the test is applied on an index, the test-statistics reject the null hypothesis at the 5% level of significance.
- When the test is applied on individual share prices, the test-statistics reject the null hypothesis at the 5% level of significance for more than 25% individual shares (lower than 36.36%, suggested by Fama in 1965). The criterion of 36.36% set by Fama (1965) 40 years ago may not be reasonable today. In modern market where information is communicated rapidly, the market predictability has improved with the availability of updated methodologies. This criterion, therefore, needs to be made more stringent. However, having said that, it must also be stated that any benchmark in this respect has to be a subjective estimate at best.

Several features of the test results can be deduced from above results. Firstly, the daily returns in the two main market indices are highly correlated. Moreover, our results show that the daily returns for sub-period I are less correlated than for sub-period II. Nevertheless, it is definitely demonstrated that the daily returns are correlated in the overall period. Secondly, results show the existence of trend in weekly returns as the number of positive serial correlation coefficients is more than negative ones and the relevant variance ratios are larger than one. All the results of index weekly return for sub-period I support the efficiency but we find mixed results for sub-period II and overall period. Thirdly, all the results of monthly returns support the random walk hypothesis across all periods.

Although individual data sets do not consistently permit rejection of the RWH at high significance level, yet the various data sets together strengthen the case against validity. The daily, weekly and monthly behaviour of stock prices vary remarkably. The properties of the returns in market indices and in individual stocks are different. At first glance it may appear that the conclusions lead us nowhere, yet the comprehensive analysis still gives rise to a discussion towards classifying the market as being efficient or not due to many assorted statistics. Therefore, this comprehensive analysis avoids a distorted view that may occur when only one model is used on just one particular type of data. In such a case, the results are more likely to be clearer and homogenous, but whether they would also be more reliable or conclusive cannot be said with any amount of certainty. A research with heterogeneous conclusions for different data sets cannot be undermined for it still captures the confusing, and often realistic, behaviour of the

markets. This would not only caution the market participants but would also motivate the policy makers and regulators to work towards greater measures aimed at creating more transparency and efficiency.

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