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# Testing Weak- Form Efficiency of Indian Stock Market using High Frequency Data

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**Abstract**

This paper attempts to re-verify weak form of efficient market hypothesis using 5-minute interval return data for the Nifty 50 and top 10 frequently traded stocks for the period of 1st January 2009 to 31st March 2011. Earlier studies investigating the weak form efficiency have used daily data, however, re-testing the weak form of efficiency using high frequency data is required to capture the intraday predictability characteristics of the stock market. Statistical analysis has been done with help of Augmented Dickey and Fuller (ADF) test, ARMA model and GARCH(1,1) model. The outcome of these statistical models present evidence for the nonexistence of the weak-form of efficiency, thereby providing an opportunity to traders or investors towards exploiting the predictable characteristics of market through trading.

**Keywords:** Autocorrelation, Weak form of market efficiency, Intraday predictability.

## Introduction

Eugene Fama in 1965 has discussed three forms of financial market efficiency: the weak form, the semi-strong form and the strong form efficiency. The weak form of efficiency is defined by the situation when current asset prices reflect all the information enclosed in the past price movement. Hence, future price movement cannot be forecasted by examining the past price movement. This also implies that it is not possible to obtain excess returns by studying the assets' prices history. (Ahmad, Ashraf, & Ahmed, 2006). If financial market does not follow weak form efficiency, it becomes predictable in nature. (Bessembinder and Chan, 1995). This predicable characteristics of the financial market provides the opportunity to investors or traders to earn supernormal profits. Various scholastic studies found asset market's to be least weak form efficient (Bessembinder and Chan, 1995; Coutts and Cheung, 2001). These studies bring out the success of technical trading strategies based on this inefficiency to produce abnormal profits to investors.

Previous studies related to weak form efficiency have mostly used the daily data. However, problem associated with the daily data is that it is an average of last 30 minutes of the trade, consequently, it is not suitable to bring out the dynamics of complete trading session. But, advent of high speed electronic technology available these days have made the high quality intraday data accessible. This high quality high

frequency data is expected to reveal limitations related to efficiency of markets, thereby providing a way of (legally) making an excess return from trading (Goodhart and Hara, 1997). Therefore, the present study tries to re-examine the weak form efficiency of Indian Stock Market using the 5-minute interval intraday return data.

**Review of Existing Literature**

Majority of the previous studies provide an evidence for the financial markets to be weak form inefficient. However, some of the studies have found some markets to be weak form efficient which include Taiwan share market by Fawson et al. (1996); Hong Kong Stock market by Cheung & Andrew (2001); Hungary, Germany, Ireland, Portugal, Sweden and the United Kingdom markets by Worthington & Higgs (2003); Dhaka Stock Market by Rahman et al. (2004); Australia and Taiwan markets by Worthington & Higgs (2005); Insurance sector of Abu Dhabi Securities Market by Squalli (2006); Bahrain Stock Market by Asiri (2008). Table 1 depicts the existing literature that have examined weak form of efficiency in various financial markets.

The associated literature demonstrates various linear and non-linear dependencies in asset price behaviour. Nonlinear serial dependence has been recognized across various financial markets with different market structural systems (Al-Loughani & Chappell; 1997; Lim, 2009; Lim, Brooks, & Hinich; 2008). Various studies observed linear serial dependencies in financial data using simple serial correlation tests (Brown & Easton, 1989; Poshakwale, 1996; Laurence et al., 1997; Abrosimova et al., 2002; Hameed et al., 2006; Awad & Daraghma, 2009; Irfan et al., 2010; Gupta & Basu; 2011 etc.). Some studies used variance ratio test to investigate serial interdependence among various financial market asset's returns, return volatility, volume etc. (Urrutia, 1995; Cheung & Andrew, 2001; Buguk & Brorsen, 2003; Worthington & Higgs, 2003; Islam & Khaled, 2005; Worthington & Higgs, 2005; Squalli, 2006; Ntim, Opong, & Danbolt, 2007; Hamid et al., 2010). Various studies investigated weak form efficiency using GARCH models which include Milionis & Moschos (2000); Abrosimova et al. (2002); Ahmad et al. (2006); Hameed et al. (2006); Magnus (2008); Guidi et al. (2011); Alexeev & Tapon (2011); Mishra (2011) and Lean & Smyth (2015).

From table 1, it is clearly evident that most of the previous studies have used low frequency data (daily data) to test weak form efficient market hypothesis. With accessibility of high frequency data from few years have grabbed the attention of researchers to re-test the efficiency of financial markets. Few studies have tried to re-examine the weak form efficiency using high frequency data which includes Niarchos and Alexakis (2003); Strawinski and Slepaczuk (2008); Schulmeister (2009); Shmilovici et al. (2009); Wang and Yang (2010); Reboredo et al. (2012). Majority of these studies found financial markets to be weak form inefficient, except the study of Wang and Yang (2010) and Shmilovici et al. (2009). However, Wang and Yang (2010) have scrutinized the intraday efficiency of futures market using four major energy futures: crude oil, heating oil, gasoline, natural gas. Out of these four futures, crude oil and gasoline futures were found to weak form efficient. Commenting on weak form efficiency, Shmilovici et al. (2009) observed that intraday forex market tend to predictable above random. But, this predictability of the model is not enough to produce profitable trading strategy.

The present study endeavours to re-test the weak form efficiency using high frequency data in Indian Stock Market. High frequency literature is novel for Indian financial markets and have not yet been extensively researched. Therefore, this study contributes to the high frequency literature through re-testing basic weak form efficient market hypothesis in Indian financial markets.

**Table 1: Empirical evidence for weak form of efficiency.**

| S. No. | Author | Market under study | Period of Study | Techniques used | Frequency of data used | Weak Form Efficient/ Inefficient |
|---|---|---|---|---|---|---|
| 1 | Brown & Easton (1989) | London Stock Market | 1821-1860 | Runs test, Serial correlation test | Low Frequency | Inefficient |
| 2 | Urrutia (1995) | Latin American emerging equity market | 1975-1991 | Variance-ratio tests | Low Frequency | Inefficient |
| 3 | Fawson et al. (1996). | Taiwan share market | 1967 - 1993 | Ljung-Box Q test, Binomial distribution test, Runs test and Unit root test | Low Frequency | Efficient |
| 4 | Poshakwale (1996). | Indian Stock Market | 1987-1994 | Kolmogorov Smirnov Goodness of Fit Test, Runs Test, Serial Correlation Coefficients Test | Low Frequency | Inefficient |
| 5 | Al-Loughani & Chappell (1997) | London Stock Market | 1983-1989 | GARCH- M model, BDS test | Low Frequency | Inefficient |
| 6 | Laurence et al. (1997) | Chinese Stock Market | 1993-1996 | Serial Correlations and Ljung-Box Statistics | Low Frequency | Inefficient |
| 7 | Milionis & Moschos (2000) | London Stock Market | 1990-1997 | GARCH-M model, Auto correlation function | Low Frequency | Inefficient |
| 8 | Mobarek & Keasey (2000) | Dhaka Stock Market | 1988 - 1997 | Non-parametric and run test and parametric test | Low Frequency | Inefficient |

| | | | | | | |
|---|---|---|---|---|---|---|
| 9 | Cheung & Andrew (2001) | Hong Kong Stock exchange | 1985-1997 | Variance ratio tests | Low Frequency | Efficient |
| 10 | Abrosimova et al. (2002) | Russian Stock Market | 1995-2001 | Autocorrelation, variance ratio tests, ARIMA, GARCH | Low Frequency | Inefficient |
| 11 | Buguk & Brorsen (2003) | Istanbul Stock Market | 1992 - 1999 | Variance ratio test, Rank- and sign-based variance ratio tests | Low Frequency | Inefficient |
| 12 | Worthington & Higgs (2003) | 16 developed and emerging stock markets | 1986-2003 | Serial correlation coefficient, Runs tests, KPSS test and MVR test. | Low Frequency | Hungary, Germany, Ireland, Portugal, Sweden and the United Kingdom are found to efficient rest inefficient |
| 13 | Niarchos, N. A. & Alexakis, C. A.(2003) | Greek Stock Market | June 1998-September 1998 | ARCH test | High Frequency | Inefficient |
| 14 | Rahman et al. (2004). | Dhaka Stock Market | 1990-2003 | ADF and PP test | Low Frequency | Efficient |
| 15 | Onour (2004) | Saudi Stock Market | 2003-2004 | Mean square of successive difference test, Runs test | Low Frequency | Inefficient |
| 16 | Moustafa (2004). | Unites Arab Emirates (UAE) Stock Market | 2001-2003. | Nonparametric runs to test for randomness | Low Frequency | Inefficient |
| 17 | Robinson (2005) | Jamaica Stock Market | 1992- 2001 | Auto-correlation test, Runs test | Low Frequency | Inefficient |
| 18 | Islam & Khaled (2005) | Dhaka Stock Market | 1992 -2001 | Variance Ratio Tests | Low Frequency | Inefficient |
| 19 | Worthington & Higgs (2005) | 10 emerging and 5 developed markets | 1986-2003 | Serial correlation coefficient, Runs tests, KPSS test and MVR test. | Low Frequency | Australia and Taiwan found to efficient, rest Inefficient |
| 20 | Ahmad Ashraf & Ahmed (2006) | Indian Stock Market | 1999-2004 | Auto-correlation Function, GARCH model, non parametric Kolmogrov–Smirnov test | Low Frequency | Inefficient |
| 21 | Squalli (2006) | Dubai and Abu Dhabi Securities Market | 2000-2005 | Runs test, Variance-ratio tests | Low Frequency | Insurance sector stocks in the ADSM is only weak-form efficient , rest Inefficient |
| 22 | Hameed et al. (2006). | Pakistan stock market | 1998- 2006 | Auto-correlation, GARCH(1,1) | Low Frequency | Inefficient |
| 23 | Rahman & Hossain (2006) | Dhaka Stock Market | 1994 - 2005 | Non-parametric tests and parametric-tests. | Low Frequency | Inefficient |
| 24 | Ntim, Opong, & Danbolt (2007) | Ghana Stock Market | 1990- 2005 | Variance Ratio Test | Low Frequency | Inefficient |
| 25 | Loh, E (2007) | Asian-Pacific stock markets | 1990-2005 | Break even cost test | Low Frequency | Inefficient |
| 26 | Mollah (2007) | Botswana Stock Market | 1989–2005 | Non-parametric and parametric test | Low Frequency | Inefficient |
| 27 | Elango & Hussein (2008) | GCC countries stock markets | 2001-2006 | Kolmogorov-Smirnov test, Runs test | Low Frequency | Inefficient |
| 28 | Asiri (2008) | Bahrain Stock Market | 1990-2000 | ARIMA and Exponential smoothing methods | Low Frequency | Efficient |
| 29 | Magnus (2008) | Ghana Stock Market | 1999-2004 | Random walk test, GARCH(1,1) | Low Frequency | Inefficient |
| 30 | Lim, Brooks, & Hinich (2008) | 10 Asian Stock markets | 1992-2005 | Hinich correlation and bicorrelation tests, Rank correlation, Tsay test, BDS test. | Low Frequency | Inefficient |
| 31 | Strawinski and Slepaczuk (2008) | Warsaw Stock Market | 2003- 2008 | Robust Regression | High Frequency | Inefficient |
| 32 | Lim, K. P. (2009). | Middle East and African stock market | 1992-2005 | McLeod–Li test, Engle LM test, BDS test, Tsay test, Hinich bicorrelation test, and Hinich bispectrum test | Low Frequency | Inefficient |
| 33 | Lim et al. (2009) | Shanghai and Shenzhen Stock Market | 1991-2003 | Linear and Non Linear Serial dependence test | Low Frequency | Inefficient |
| 34 | Awad & Daraghma (2009) | Palestinian Securities Market | 1998-2008 | Unit roost test, Runs Test and Autocorrelation test | Low Frequency | Inefficient |
| 35 | Schulmeister, S. (2009). | US spot and Futures | 1983–2007 | Based on success of technical | High Frequency | Inefficient |
| | | Market | | trading strategies | | |
| 36 | Shmilovici et al. (2009). | Foreign exchange Market | Jan 2000-Dec 2000 | Universal Variable Order Markov (VOM) test | High Frequency | Efficient |
| 37 | Hamid et al.(2010) | 14 Asia-Pacific nation's stock market | 2004-2009 | Autocorrelation, Ljung-Box Q-statistic Test, Runs Test, Unit Root Test and Variance Ratio | Low Frequency | Inefficient |
| 38 | Srinivasan (2010) | Indian Stock Market | 1997-2010 | ADF and PP test | Low Frequency | Inefficient |
| 39 | Korkmaz & Akman (2010). | Istanbul Stock Market | 2003-2009 | Unit root test | Low Frequency | Inefficient |
| 40 | Irfan et al.(2010) | Pakistan Stock Market | 1999-2009 | Unit root, Auto-correlation test, ARIMA model | Low Frequency | Inefficient |
| 41 | Wang and Yang (2010) | New York Energy Futures Market | 2000-2007 | Neural network, semiparametric functional coefficient model, nonparametric kernel regression, GARCH | High Frequency | Heating oil and natural gas futures- Inefficient. Crude Oil and Gasoline futures- Efficient |

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|---|---|---|---|---|---|---|
| 42 | Gupta & Yang. (2011) | Indian Stock Market | 1997-2011 | Augmented Dickey-Fuller test, the Phillips-Perron test and KPSS test | Low Frequency | Inefficient |
| 43 | Guidi et al. (2011) | Central and Eastern Europe (CEE) equity markets | 1999–2009. | Generalised Autoregressive Conditional Heteroscedasticity in Mean (GARCH-M) model | Low Frequency | Inefficient |
| 44 | Khan & Mehtab (2011) | Indian Stock Market | 2000-2010 | Non para-metric runs test | Low Frequency | Inefficient |
| 45 | Alexeev & Tapon (2011) | Toronto Stock Exchange | 1980-2010 | Pattern Recognition, EGARCH | Low Frequency | Inefficient |
| 46 | Gupta & Basu (2011) | Indian Stock Market | 1991-2006 | Durbin-Watson (DW) statistics | Low Frequency | Inefficient |
| 47 | Ntim et al. (2011). | African Stock Market | 2000-2007 | Variance-ratio tests based on ranks and signs | Low Frequency | Inefficient |
| 48 | Mishra (2011). | 8 emerging and developed stock markets | 2007-2010 | Unit root and GARCH(1,1) | Low Frequency | Inefficient |
| 49 | Ajao & Osayuwu (2012) | Nigerian Stock Market | 2001–2010 | Box-Ljung statistic, Runs test | Low Frequency | Inefficient |
| 50 | Gimba (2012). | Nigerian Stock Market | 2005-2009 | Variance Ratio test, Auto-correlation test, Runs test | Low Frequency | Inefficient |
| 51 | Stănculescu & Mitrică (2012). | Romanian capital market | 1997-2000 | Augmented Dickey-Fuller test, the Phillips-Perron test | Low Frequency | Inefficient |
| 52 | Al-Saleh & Al-Ajmi (2012) | Saudi Stock Market | 1994-2007 | Run test, and rank- and sign-based single and multiple variance ratio test | Low Frequency | Inefficient |
| 53 | Nisar & Hanif (2012) | South Asian markets | 1997-2011 | Runs test, Serial correlation, Unit root and Variance ratio test | Low Frequency | Inefficient |
| 54 | Patel (2012) | Asian Stock Markets | 2000-2011 | Runs Test, Unit Root Test, Variance | Low Frequency | Inefficient |
| | | | | Ratio, Auto Correlation test | | |
| 55 | Al-Ahmad (2012) | Damascus Securities Exchange Market | 2009-2011 | Variance Ratio, Auto Correlation test | Low Frequency | Inefficient |
| 56 | Reboredo et al. (2012). | US Stock Market | April 2006 -August 2006 | Simple Random Walk model, Auto regressive model, Nonlinear regression models | High Frequency | Inefficient |
| 57 | Rabbani et al. (2013) | Pakistan Stock Market | 1999-2010 | Augmented Dickey-fuller test, Auto-correlation function test, Phillip Perron test and Runs test | Low Frequency | Inefficient |
| 58 | Shaker (2013) | Finnish and Swedish Stock Market | 2003-2012 | Serial Correlation test, Variance ratio test | Low Frequency | Inefficient |
| 59 | Mazviona & Nyangara (2013). | Zimbabwe Stock Market | 2009-2012 | Auto-correlation, Runs test and the Q-statistic test | Low Frequency | Inefficient |
| 60 | Mobarek & Fiorante (2014) | Equity markets of BRIC countries | 1995-2010 | Serial correlation test, Variance ratio test | Low Frequency | Inefficient |
| 61 | Jiang, Xie & Zhou (2014) | West Texas Intermediate Oil Futures Market | 1983-2012 | De-trended fluctuation and De-trending moving average analysis | Low Frequency | Inefficient |
| 62 | Jamaani & Roca (2015). | Gulf Stock Market | 2003-2013. | Augmented Dickey Fuller test, Variance Ratio test | Low Frequency | Inefficient |
| 63 | Lean & Smyth (2015). | Crude Palm Oil Future and Spot Market | 1999-2014 | ADF test, and GARCH model | Low Frequency | Inefficient |
| 64 | Guney & Komba (2016) | Tanzania Stock Market | 2007-2014 | Variance-ratio, Ranks and Sign test | Low Frequency | Inefficient |

**Where, ADF test- Augmented Dickey-Fuller (ADF) test, ARCH- AutoRegressive Conditional Heteroskedasticity, ARIMA - Autoregressive Integrated Moving Average models, BRIC countries -Brazil, Russia, India and China, EGARCH-exponential GARCH, GARCH- Generalized AutoRegressive Conditional Heteroskedasticity, GARCH- M - GARCH in mean, GCC countries -Gulf Co-operation Council countries, KPSS tests - Kwiatkowski–Phillips–Schmidt–Shin, MVR- multiple variance ratio, PP test- Phillips-Perron (PP) test**

**Source**: Compiled from various research studies.

## Database And Methodology

The sample used for the study is Nifty 50 and top 10 frequently traded stocks for the period 1st January 2009-31st March 2011 using 5-minute interval data for prices. During the period of our study, the stock market in India have seen two major significant structural changes in stock trading which are as follows:

1. On 1st January 2010: Advancement of trading hours (market opening changed from 9:55am to 9:00am).
2. On 18th October 2010: Pre-opening session (Pre-auction period) launched. This pre-open session lasts for 15 minutes from 9:00 AM to 9:15 AM.

The intention of these major structural changes in the stock market is to make market more liquid, less volatile and more efficient. Therefore, with the prevalence of these changes in stock market, re-testing the market efficiency theories has become the need of an hour. Consequently, complete data period was divided into 3 parts

**Sub period 1:** 1st January 2009-31st December 2009 (Before the change in trading time)

**Sub period 2:** 1st January 2010-17th October 2010 (After the change in trading time/ Before the launch of pre-opening session)

**Sub period 3:** 18th October 2010-31st March 2011(After the launch of pre-opening session)

Further, out of top 50 frequently traded stocks only top 10 frequently traded stocks are selected based on following filters:

1) Stocks whose prices are adjusted due to any corporate action such as issue of bonus shares, stock splits, merger or acquisition during the sample period are excluded.

2) Then top 10 stocks which have highest turnover (trading volume multiplied by share price) are included in the study.

Database for high frequency data for the Capital Market segment has been purchased from Dotex International Limited, a subsidiary of National Stock Exchange. This database is managed in two steps using software Visual Fox Pro:

1) Company Based Management: Data set includes complete transaction book for each trading date separately. In this step, the complete database is arranged company wise using Microsoft visual fox pro. Results output contains tick by tick information for each company separately.

2) Time Based Management: The second step of database management is time based management, in which proper interpolation rule is used to extract data at fixed intervals. Using nearest value and trading volume adjusted weighted average prices, desired companies or indices have been extracted at required fixed intervals (5-minute interval).

Statistical tests are applied in two steps, the first step includes preliminary analysis, which forms the basis of every time series statistical analysis. It includes the summary statistics using Mean, Standard Deviation, Skewness and Kurtosis. Unit Root test or Augmented Dickey Fuller (ADF) test has been used to check stationarity of the series. In a weak-form efficient market, there is no correlation between successive prices. Hence, the second step is applying the main time series statistics tools to check interdependence.

Various statistical analysis such as ARMA (Auto-regressive Moving Average) model and GARCH(1,1) is used to check presence of interdependence. An ARMA model is a special type of regression model in which the dependent variable has been stationarized and the independent variables are all lags of the dependent variable and/or lags of the errors. The model consists of two parts, an autoregressive (AR) lags of the dependent variable part and a moving average (MA) part.

When the Intraday returns variances are dependent of time, then above models were adjusted to take into account these Autoregressive Conditional Heteroscedasticity (ARCH) effects. A natural extension of an ARCH(q) model is a Generalized Autoregressive conditional heteroscedastic (GARCH) model, which is widely employed in practice. From GARCH model volatility clustering can be observed. High persistent volatility clustering represent the inefficiency of a stock returns. GARCH (1,1) is employed in present study, which is represented as follows:

$$R_t = c + u_t$$

$$\sigma_t^2 = \alpha_o + \alpha_1 u_{t-1}^2 + \beta \sigma_{t-1}^2$$

Where Rt= Residuals from ARMA model, c represents constant of mean equation and represents error term, σ2t is conditional variance ,α0 represents the constant of variance equation, (α1 u2t -1) is lag of the squared residual from the mean equation and (β σt-12) is forecasted variance the model during the previous period. Sum of α1 and β represents the persistence of volatility clustering.

**Preliminary Analysis**

This section deals with preliminary analysis through unit root test and descriptive statistics.

**a) Unit Root Test**

Present study deals with the time series data, it becomes the major concern if the time series data is non-stationarity. In the nonexistence of stationarity, outcome of time series statistical analysis will become spurious. In order to check the presence of unit root and determining the order of differencing required to bring stationarity, this study has used the Augmented Dickey-Fuller (ADF) test.

Table 2 reveals that all price series are non-stationary. The null hypothesis of a unit root for price series is not accepted at the 1%, 5% and 10% level of significance. However, null hypothesis of a unit root for price series at first difference is accepted at the 1% level of significance.

Transformed series of 5-minute interval return data is taken as a logarithmic transformation of the price series is taken for further analysis. The returns are calculated as the difference of the

logarithmic prices i.e

Rp = Ln (Pt - Pt-1)

Where Rp= Returns, Pt= Price at interval t and Pt-1 =Price at interval t-1

**b) Descriptive Statistics**

Descriptive statistics for entire sample are computed to study the distribution pattern. Descriptive statistics include analysis of mean, maximum values, minimum values, standard deviation, skewness and kurtosis. Further, normality has been checked by applying the Jarque bera test. Skewness and kurtosis helps to understand the characteristics of a distribution.

From table 3, 4 and 5, it is observed that mean returns are positive for complete sample in sub-period 1. In sub-period 2, mean returns are positive for Nifty, I C I C I Bank Ltd., State Bank Of India, Infosys Ltd., H D F C Bank Ltd., Axis

Bank Ltd., D L F Ltd., Bharat Heavy Electricals Ltd., Hindalco Industries Ltd. However, NTPC Ltd. and Sesa Goa Ltd have negative returns for this period. However, in sub-period 3, negative returns are observed for complete sample. Standard deviation is a measure of the variability or dispersion of a statistical population. From descriptive statistics, it is clearly evident that all returns series have low standard deviation which depicts the fluctuation of a security around its mean or average return (the mean reverting behavior).

The coefficient of the Jarque-bera is significant at 1 percent for complete sample in three periods. It documents that the trading returns are asymmetric and do not have the normal distribution. Leptokurtic distribution (kurtosis>3) of all the trading returns for Nifty and all companies is evident.

**Table 2: Unit Root test- Augmented Dickey-Fuller test statistic**

| | Sub- Period 1 | | Sub- Period 2 | | Sub- Period 3 | |
|---|---|---|---|---|---|---|
| | At Level | 1st Difference series | At Level | 1st Difference series | At Level | 1st Difference series |
| Nifty | -0.713391 | -126.9683* | 0.080932 | -126.026* | -1.398241 | -96.32451* |
| I C I C I Bank Ltd. | -0.766293 | -134.2486* | -0.436839 | -133.7734* | -1.669042 | -93.50274* |
| State Bank Of India | -0.402951 | -136.7036* | 0.959741 | -132.8746* | -1.645768 | -103.0971* |
| Infosys Ltd. | -0.402229 | -141.2799* | -1.031055 | -94.50739* | -1.79807 | -94.68191* |
| H D F C Bank Ltd. | -0.804369 | -141.2906* | -0.196054 | -96.74844* | -1.868907 | -96.77029* |
| Axis Bank Ltd. | -0.659084 | -141.861* | -0.979043 | -142.5101* | -1.87294 | -92.90322* |
| D L F Ltd. | -1.001687 | -137.6104* | -1.259605 | -131.0396* | -2.092678 | -92.95216* |
| Bharat Heavy Electricals Ltd. | -1.223485 | -136.7467* | -2.785598 | -139.3929* | -1.608481 | -95.88289* |
| Hindalco Industries Ltd. | 0.258444 | -134.7131* | -0.302803 | -139.9682* | -2.078518 | -94.7373* |
| N T P C Ltd. | -1.599286 | -102.5966* | -3.432994 | -99.90094* | -1.843396 | -98.03349* |
| Sesa Goa | 0.566967 | -141.7578* | -1.468415 | -132.9205* | -2.425756 | -94.36965* |

* 1% significance level

**Table 3: Descriptive statistics for period 1st January 2009-31st December 2009**

| | Mean | Median | Maximum | Minimum | Std. Dev. | Skewness | Kurtosis | Jarque-Bera | P-value of Jarque-Bera |
|---|---|---|---|---|---|---|---|---|---|
| Nifty | 3.43E-05 | 5.89E-05 | 0.11089 | -0.03012 | 0.002322 | 6.783139 | 335.6882 | 75795022 | 0.000* |
| I C I C I Bank Ltd. | 4.07E-05 | 3.33E-05 | 0.16806 | -0.0692 | 0.004723 | 2.479522 | 122.7614 | 9824291 | 0.000* |
| State Bank Of India | 3.27E-05 | 0.000 | 0.09115 | -0.03609 | 0.003577 | 2.380227 | 66.91133 | 2799652 | 0.000* |
| Infosys Ltd. | 5.18E-05 | 2.50E-05 | 0.04901 | -0.04637 | 0.003012 | 0.0206 | 42.25659 | 1052109 | 0.000* |
| H D F C Bank Ltd. | 3.28E-05 | 0.000 | 0.07495 | -0.05699 | 0.003481 | 1.154628 | 53.30064 | 1732477 | 0.000* |
| Axis Bank Ltd. | 4.03E-05 | 0.000 | 0.13293 | -0.10944 | 0.004569 | 1.300141 | 99.78504 | 6410326 | 0.000* |
| D L F Ltd. | 1.57E-05 | 0.000 | 0.17941 | -0.1654 | 0.006161 | 0.411079 | 120.0274 | 9365278 | 0.000* |
| Bharat Heavy Electricals Ltd. | 3.43E-05 | 0.000 | 0.0957 | -0.03356 | 0.003234 | 2.226727 | 69.92403 | 3076146 | 0.000* |
| Hindalco Industries Ltd. | 6.84E-05 | 0.000 | 0.07658 | -0.08657 | 0.004833 | -0.12941 | 29.81664 | 491812.5 | 0.000* |
| N T P C Ltd. | 1.64E-05 | 0.000 | 0.16415 | -0.06321 | 0.003137 | 8.017291 | 482.7048 | 1.58E+08 | 0.000* |
| Sesa Goa Ltd. | 9.48E-05 | 0.000 | 0.16000 | -0.11855 | 0.005426 | 1.099536 | 103.9483 | 6949431 | 0.000* |

* 1% significance level

**Table 4: Descriptive statistics for period 1st January 2010-17th October 2010**

| | Mean | Median | Maximum | Minimum | Std. Dev. | Skewness | Kurtosis | Jarque-Bera | P-value of Jarque-Bera |
|---|---|---|---|---|---|---|---|---|---|
| Nifty | 9.77E-06 | 5.84E-06 | 0.01175 | -0.01751 | 0.001082 | -0.69118 | 36.10491 | 712456.2 | 0.000* |
| I C I C I Bank Ltd. | 1.56E-05 | -1.08E-05 | 0.03257 | -0.034 | 0.002126 | -0.34396 | 36.47846 | 730654.3 | 0.000* |
| State Bank Of India | 2.13E-05 | -7.10E-06 | 0.02627 | -0.0456 | 0.001722 | -0.26168 | 58.577 | 2012663 | 0.000* |
| Infosys Ltd. | 1.07E-05 | 0.000 | 0.03549 | -0.0297 | 0.001725 | 0.263927 | 56.83744 | 1888776 | 0.000* |
| H D F C Bank Ltd. | 2.17E-05 | 0.000 | 0.03454 | -0.03512 | 0.001784 | -0.25482 | 42.42539 | 1012900 | 0.000* |
| Axis Bank Ltd. | 2.63E-05 | 0.000 | 0.03868 | -0.03132 | 0.002172 | 0.410178 | 37.83964 | 791280 | 0.000* |
| D L F Ltd. | 2.26E-06 | -3.23E-05 | 0.03143 | -0.03882 | 0.002528 | -0.06218 | 22.00318 | 235355.6 | 0.000* |
| Bharat Heavy Electricals Ltd. | 2.27E-06 | 0.000 | 0.02225 | -0.02028 | 0.00163 | 0.207371 | 21.56959 | 224826 | 0.000* |
| Hindalco Industries Ltd. | 1.75E-05 | 0.000 | 0.05848 | -0.05769 | 0.002844 | -0.06669 | 57.05449 | 1904230 | 0.000* |
| N T P C Ltd. | -9.76E-06 | 0.000 | 0.02481 | -0.02274 | 0.001596 | -0.43096 | 35.36726 | 683239.7 | 0.000* |
| Sesa Goa Ltd. | -5.64E-06 | -3.09E-05 | 0.02590 | -0.05886 | 0.002793 | -0.99289 | 35.77561 | 702616.7 | 0.000* |

* 1% significance level

**Table 5: Descriptive statistics for period 18th October 2010-31st March 2011**

| | Mean | Median | Maximum | Minimum | Std. Dev. | Skewness | Kurtosis | Jarque-Bera | P-value of Jarque-Bera |
|---|---|---|---|---|---|---|---|---|---|
| Nifty | -5.57E-06 | 1.90E-05 | 0.01390 | -0.02103 | 0.00141 | -0.32273 | 20.1968 | 103046.6 | 0.000* |
| I C I C I Bank Ltd. | -7.86E-07 | 0.000 | 0.02413 | -0.03062 | 0.00251 | 0.121985 | 16.20857 | 62167.54 | 0.000* |
| State Bank Of India | -1.62E-05 | -6.88E-06 | 0.04024 | -0.04204 | 0.00224 | -0.82987 | 52.9939 | 875959 | 0.000* |
| Infosys Ltd. | 6.26E-06 | 0.000 | 0.02282 | -0.03182 | 0.00176 | -1.27713 | 38.32065 | 446711.2 | 0.000* |
| H D F C Bank Ltd. | -5.49E-07 | 4.67E-06 | 0.01518 | -0.02578 | 0.00210 | -0.3955 | 12.33624 | 31275.58 | 0.000* |
| Axis Bank Ltd. | -6.02E-06 | -8.06E-06 | 0.02290 | -0.02397 | 0.00243 | 0.024135 | 12.42489 | 31642.27 | 0.000* |
| D L F Ltd. | -3.73E-05 | -2.71E-05 | 0.02180 | -0.0331 | 0.00291 | -0.36293 | 14.40844 | 46549.1 | 0.000* |
| Bharat Heavy Electricals Ltd. | -2.37E-05 | 0.000 | 0.01650 | -0.03203 | 0.00190 | -0.60522 | 21.22814 | 118877.5 | 0.000* |
| Hindalco Industries Ltd. | -2.11E-06 | 0.000 | 0.04096 | -0.0329 | 0.00288 | -0.10208 | 20.6578 | 111079.8 | 0.000* |
| N T P C Ltd. | -6.70E-06 | 0.000 | 0.01926 | -0.01568 | 0.00176 | 0.201118 | 13.6081 | 26452.47 | 0.000* |
| Sesa Goa Ltd. | -2.91E-05 | 0.000 | 0.0210 | -0.02521 | 0.00268 | -0.21432 | 14.57414 | 47783.38 | 0.000* |

* 1% significance level

## V) Tests For Presence of Autocorrelation

The Auto-correlation coefficient depicts the relationship between the values of a random variable at time t and its value in the preceding period. Kendall (1953), Fama (1965), Nordhaus (1987), Chen (1996), Mobarek & Keasey (2000) and many more researchers applied autocorrelation test in a variety of speculative markets over diverse periods.

### Auto Regressive Moving Average (ARMA) Model.

Auto-correlations are confirmed using ARMA Model. The auto-correlation (ACF) and partial auto correlation (PACF) functions are used from correlogram to recognize appropriate ARMA model. An ARMA model is a special type of regression model in which the dependent variable has been stationarized and the independent variables are all lags of the dependent variable and lags of the errors. Table 6 reveals significant AR and MA terms in returns of sample understudy.

In 1st sub period, AR(1) is significant for Nifty, I C I C I Bank Ltd, H D F C Bank Ltd., Bharat Heavy Electricals Ltd returns. Whereas, MA (1) is significant for State Bank Of India, Infosys Ltd. Axis Bank Ltd. D L F Ltd. Bharat Heavy Electricals Ltd. Hindalco Industries Ltd. N T P C Ltd. Sesa Goa Ltd. returns. Additionally, MA(2) is also significant for D L F Ltd. under this study period.

In 2nd sub period, AR(1) is significant for Infosys Ltd. and H D F C Bank Ltd. returns, where as AR(2) and AR(3) is significant for Nifty returns. On the other hand MA(1) is significant for State Bank Of India, Infosys Ltd., H D F C Bank Ltd., Axis Bank Ltd., D L F Ltd., Bharat Heavy Electricals Ltd., Hindalco Industries Ltd., N T P C Ltd. and Sesa Goa Ltd.

In 3rd sub period, AR(1) is significant for Nifty, Infosys Ltd., H D F C Bank Ltd., Hindalco Industries Ltd. and Sesa Goa Ltd. AR(2) is significant for I C I C I Bank Ltd., H D F C Bank Ltd. and Axis Bank Ltd. AR(3) is significant for Axis Bank Ltd. and AR(17) is significant for D L F Ltd. On the other hand, MA(1) is significant for State Bank Of India, H D F C Bank Ltd., Bharat Heavy Electricals Ltd., N T P C Ltd. and Sesa Goa Ltd. MA(2) is significant for I C I C I Bank Ltd only. All AR and MA terms are significant at 1% or 5% significance level.

Various studies such as Mobarek & Keasey (2000) Abrosimova et al. (2002) Rahman & Hossain (2006) Mollah (2007) Asiri (2008) Irfan et al.(2010) applied ARMA model in a variety of financial markets over diverse periods. All of these studies observed various significant AR and MA terms and claimed various financial markets to be weak form inefficient. Corroborating the results of these earlier studies, findings of this study also found Indian markets to be weak form inefficient. In order to re-confirm and interpret dependency in return series of sample understudy, further investigation is required. This interdependence is further investigated by GARCH(1,1) model.

**Table 6: Average (ARMA) terms in return series**

| | 1st January 2009-31st December 2009 | | | 1st January 2010-17th October 2010 | | | 18th October 2010-31st March 2011 | | |
|---|---|---|---|---|---|---|---|---|---|
| | AR terms | MA terms | | AR terms | | MA terms | AR terms | | MA terms |
| | AR(1) | | | AR(2) | AR(4) | | AR(1) | | |
| | 0.016046 | | | -0.0177 | 0.0247 | | -0.04694 | | |
| Nifty | (0.039)** | | | (0.0271)** | (0.0021)* | | (0.000)* | | |
| | AR(1) | | | | | MA(1) | AR(2) | | MA(2) |
| | -0.03794 | | | | | -0.07005 | 0.563832 | | -0.54272 |
| I C I C I Bank Ltd. | (0.000)* | | | | | (0.000)* | (0.002)* | | (0.003)* |
| | | MA(1) | | | | MA(1) | | | MA(1) |
| | | -0.05217 | | | | -0.06661 | | | -0.10123 |
| State Bank Of India | | (0.000)* | | | | (0.000)* | | | (0.000)* |
| | | MA(1) | | AR(1) | | MA(1) | AR(1) | | |
| | | -0.10332 | | 0.4345 | | -0.5046 | -0.02355 | | |
| Infosys Ltd. | | (0.000)* | | (0.000)* | | (0.000)* | (0.029)** | | |
| | AR(1) | | | AR(1) | | MA(1) | AR(1) | AR(2) | MA(1) |
| | -0.06513 | | | 0.11875 | | -0.2605 | 0.422996 | 0.052032 | -0.46811 |
| H D F C Bank Ltd. | (0.000)* | | | (0.027)** | | (0.000)* | (0.043)** | (0.000)* | (0.025)** |
| | | MA(1) | | | | MA(1) | AR(2) | AR(3) | |
| | | -0.0851 | | | | -0.12759 | 0.0297 | 0.0197 | |
| Axis Bank Ltd. | | (0.000)* | | | | (0.000)* | (0.006)* | (0.068)*** | |
| | | MA(1) | MA(2) | | | MA(1) | AR(17) | | |
| | | -0.056 | -0.01605 | | | -0.04469 | -0.02247 | | |
| D L F Ltd. | | (0.000)* | (0.040)** | | | (0.000)* | (0.038)** | | |
| | AR(1) | MA(1) | | | | MA(1) | | | MA(1) |
| | 0.334 | -0.383 | | | | -0.1097 | | | -0.0348 |
| Bharat Heavy Electricals Ltd. | (0.009)* | (0.002)* | | | | (0.000)* | | | (0.001)* |
| | | MA(1) | | | | MA(1) | AR(1) | | |
| | | -0.0603 | | | | -0.1005 | -0.0241 | | |
| Hindalco Industries Ltd. | | (0.001)* | | | | (0.000)* | (0.025)** | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | MA(1) | | MA(1) | | | MA(1) |
| | -0.1775 | | -0.2036 | | | -0.0557 |
| N T P C Ltd. | (0.000)* | | (0.000)* | | | (0.000)* |
| | MA(1) | | MA(1) | | AR(1) | MA(1) |
| | -0.1124 | | -0.0578 | | -0.8218 | 0.8014 |
| Sesa Goa Ltd. | (0.000)* | | (0.000)* | | (0.000)* | (0.000)* |

* 1% significance level ** 5% significance level *** 10% significance level

**Test For Volatility Clustering Using Garch (1,1).**

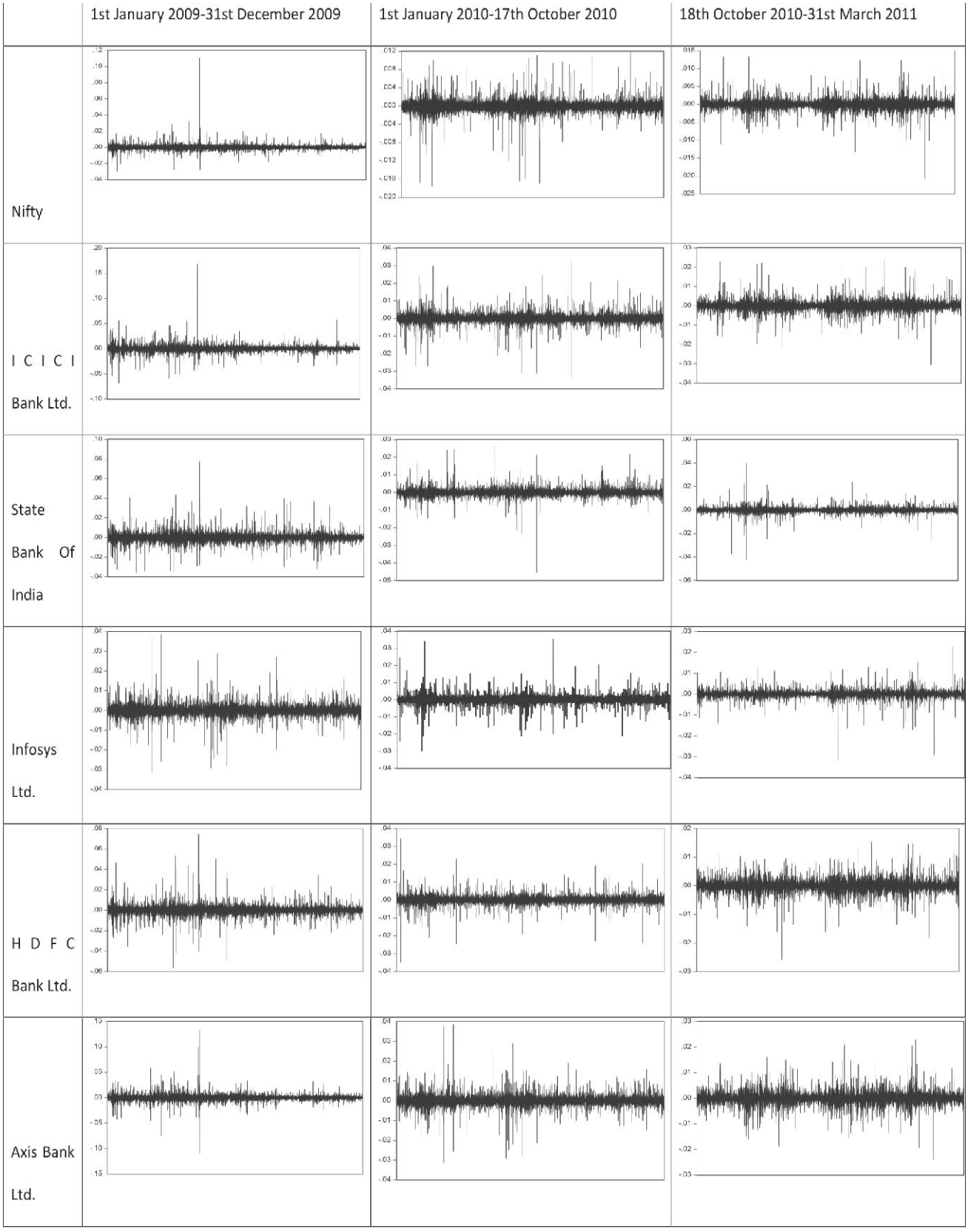
Another important requirement of time series data is that error terms of this developed autoregressive moving average model for stock returns should exhibit constant variance. If error terms does not exhibit constant variance, they are said to be heteroscedastic. Table 7 depicts the test for Heteroskedasticity :ARCH effects.

## Table 7: Heteroskedasticity Test: ARCH test

| | 1st January 2009-31st December 2009 | | 1st January 2010-17th October 2010 | | 18th October 2010-31st March 2011 | |
|---|---|---|---|---|---|---|
| | F-statistics | p-value | F-statistics | p-value | F-statistics | p-value |
| Nifty | 46.65296 | 0.000* | 100.7077 | 0.000* | 48.47189 | 0.000* |
| I C I C I Bank Ltd. | 62.00874 | 0.000* | 727.4613 | 0.000* | 58.13098 | 0.000* |
| State Bank Of India | 1833.424 | 0.000* | 374.0223 | 0.000* | 764.8163 | 0.000* |
| Infosys Ltd. | 1511.131 | 0.000* | 815.8887 | 0.000* | 387.002 | 0.000* |
| H D F C Bank Ltd. | 1635.375 | 0.000* | 2555.182 | 0.000* | 62.5085 | 0.000* |
| Axis Bank Ltd. | 3347.442 | 0.000* | 1299.572 | 0.000* | 195.6403 | 0.000* |
| D L F Ltd. | 167.9396 | 0.000* | 462.859 | 0.000* | 110.1322 | 0.000* |
| Bharat Heavy Electricals Ltd. | 642.7608 | 0.000* | 1089.268 | 0.000* | 91.41244 | 0.000* |
| Hindalco Industries Ltd. | 1099.581 | 0.000* | 2138.143 | 0.000* | 61.07063 | 0.000* |
| N T P C Ltd. | 46.42308 | 0.000* | 1342.532 | 0.000* | 128.5512 | 0.000* |
| Sesa Goa | 1320.322 | 0.000* | 176.5055 | 0.000* | 220.033 | 0.000* |

* 1% significance level

**Figure 1: Plot of Returns residual from ARMA Model.**



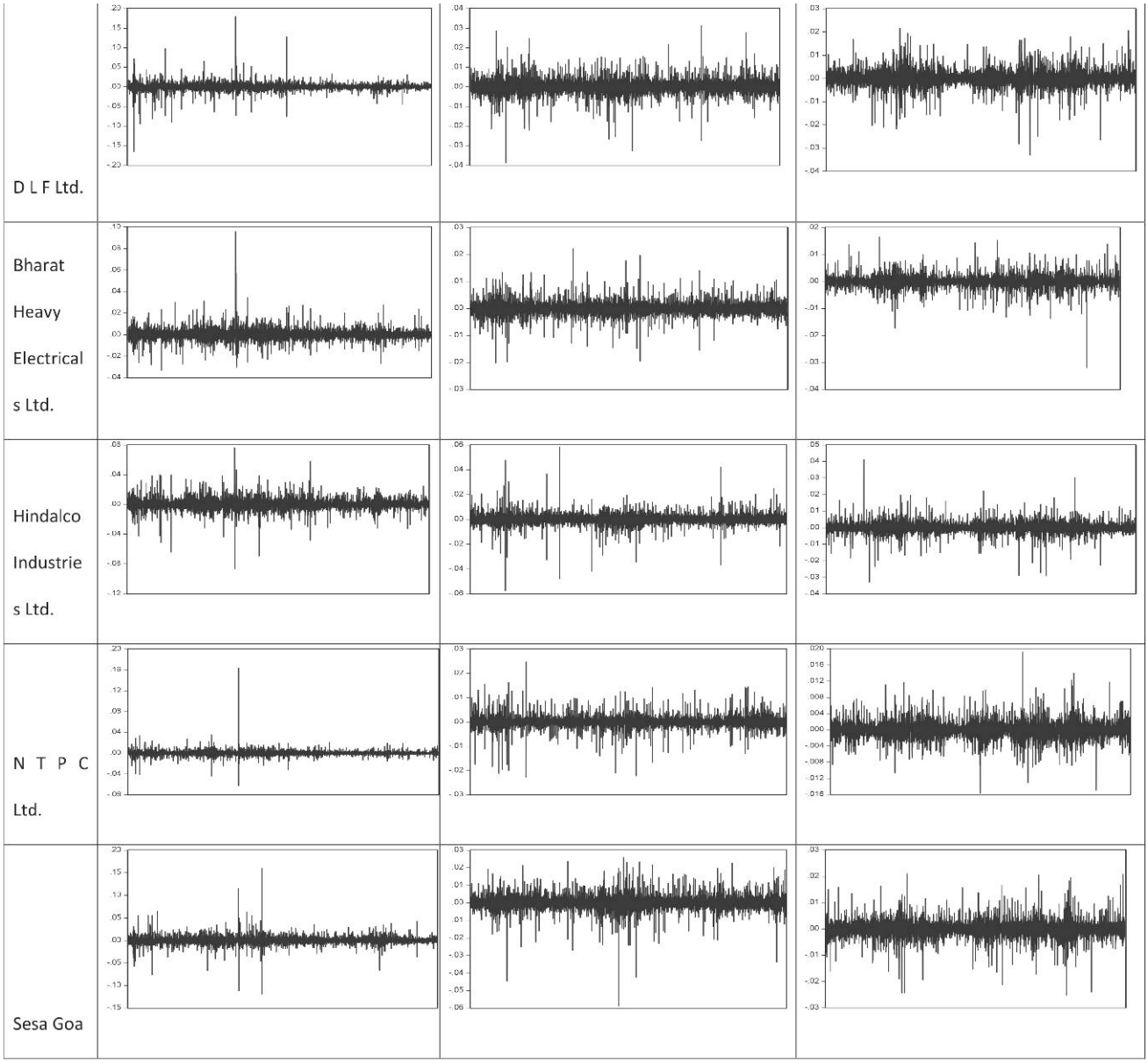



**Table 8: Variance Equation of GARCH(1,1)**

| | 1st January 2009-31st December 2009 | | | 1st January 2010-17th October 2010 | | | 18th October 2010-31st March 2011 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Constant | ARCH(1) | GARCH(1) | Constant | ARCH(1) | GARCH(1) | Constant | ARCH(1) | GARCH(1) |
| Nifty | 2.10E-07 | 0.20 | 0.79 | 7.51E-08 | 0.25 | 0.73 | 1.26E-07 | 0.15 | 0.80 |
| p-value | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |
| I C I C I Bank Ltd. | 3.43E-07 | 0.13 | 0.86 | 8.63E-07 | 0.25 | 0.59 | 6.01E-07 | 0.19 | 0.74 |
| p-value | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |
| State Bank Of India | 2.01E-06 | 0.37 | 0.54 | 4.31E-07 | 0.29 | 0.61 | 3.78E-07 | 0.15 | 0.79 |
| p-value | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |
| Infosys Ltd. | 9.20E-07 | 0.35 | 0.64 | 3.25E-07 | 0.45 | 0.57 | 6.99E-07 | 0.22 | 0.59 |
| p-value | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |
| H D F C Bank Ltd. | 2.59E-06 | 0.48 | 0.41 | 6.82E-07 | 0.41 | 0.46 | 3.96E-07 | 0.17 | 0.75 |
| p-value | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |
| Axis Bank Ltd. | 7.06E-07 | 0.19 | 0.80 | 6.09E-07 | 0.27 | 0.64 | 5.17E-07 | 0.19 | 0.73 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| p-value | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |
| D L F Ltd. | 1.20E-06 | 0.16 | 0.82 | 1.45E-06 | 0.17 | 0.66 | 8.60E-07 | 0.12 | 0.78 |
| p-value | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |
| Bharat Heavy Electricals Ltd. | 5.76E-07 | 0.22 | 0.77 | 5.23E-07 | 0.26 | 0.56 | 5.23E-07 | 0.27 | 0.63 |
| p-value | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |
| Hindalco Industries Ltd. | 3.34E-06 | 0.31 | 0.60 | 1.64E-06 | 0.24 | 0.60 | 6.58E-07 | 0.18 | 0.76 |
| p-value | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |
| N T P C Ltd. | 1.07E-06 | 0.59 | 0.40 | 4.16E-07 | 0.50 | 0.47 | 3.60E-07 | 0.18 | 0.71 |
| p-value | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |
| Sesa Goa | 7.57E-06 | 0.72 | 0.27 | 9.32E-07 | 0.23 | 0.69 | 1.10E-06 | 0.17 | 0.69 |
| p-value | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |

* 1% significance level, **Source:** Author's calculations.

Table 7 represents the nature of residuals of ARMA model, for which null hypothesis is that residuals are homoscedastic. It is clearly evident from the table that residuals are heteroscedastic at 1% level of significance. Heteroscedastic nature of residual is again observed in plot of return residuals from ARMA model in figure 1. From this plot it is clearly evident that the period of high volatility is followed by the period of high volatility and the period of low volatility is followed by the period of low volatility, this suggests that the residuals are conditionally heteroscedastic, can be represented by ARCH and GARCH model.

Hence, GARCH (1,1) is employed to study the nature of the return residuals. From GARCH model volatility clustering can be observed. Variance equation depicts the nature of volatility or conditional variance of the return series. This variance equation of GARCH(1,1) have two terms: ARCH and GARCH. The sum of the coefficients ($\alpha 1+ \beta$) of these terms depicts high persistence in volatility clustering, if the value is very close to one. High persistent volatility clustering represent the inefficiency of a stock market (Hameed et al., 2006). Table 8 shows that sum of ARCH and GARCH coefficient are very close to 1 for complete sample under study. Thus, suggesting a high persistence of volatility clusters over the sample period in the market. Similar volatility clustering was observed in Indian stock market by Abrosimova et al. (2002) using the daily data.

## Conclusion

Financial market efficiency is an important issue for investors, researchers, analysts and regulators of emerging market like India. Evidence of weak-form inefficiency is an imperative signal of predictability, thus making traders to earn supernormal profits. Earlier studies investigating the weak form efficiency have used the daily data, however, re-testing the weak form of efficiency using high frequency data is required to capture the intraday predictability characteristics of the stock market. Additionally, problem associated with the daily data is that it is an average of last 30 minutes of the trade, consequently, it is not suitable to bring out the dynamics of complete trading session. Hence, this study tries to re-examine the weak form efficiency using high frequency data. Various statistical techniques are employed such as ARMA model and GARCH (1,1) for the return series. ARMA model confirms significant serial dependence in the 5-minute interval return series. GARCH (1,1) model symbolize high persistence in volatility clustering for the three sub-periods. The outcome of these statistical models present evidence for the nonexistence of the weak-form efficiency.

The results of this study do not hold up the validity of weak form efficiency for stock market returns for Nifty 50 and top 10 frequently traded stocks. Therefore, this gives an opportunity to traders to forecast future prices and earn abnormal profits. Hence, this study re-confirms the testable implications for traders and investors, so that they can exploit predictability of stock using the intra-daily data. On the other hand, this study also have an implications for the market regulators who have been introducing major structural changes in the stock market to improve liquidity, lessen volatility and improve efficiency. Results of the study shows that advancement of trading hours and introduction of pre-opening session have not improved weak form inefficiency. Hence, market regulators need to take some more stringent steps to improve the same.

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