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Whether high frequency intraday data behave randomly: Evidence from NIFTY 50

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Abstract. *Keeping in mind the notion of random walk and market efficiency, the present study gives importance on the sense of the above issues by considering high frequency logarithmic intraday time series data of the popular Indian stock market index NIFTY 50 during the global Covid-19 pandemic. Thus, to realize the above notion deeply, the study uses parametric and non-parametric statistical approaches. The study reports that the null hypothesis of random walk is rejected based on various measures and the NIFTY 50 is inefficient in its weak form during the pandemic period. However, there is a little hope also because runs test accepts the null hypothesis that means NIFTY 50 follows random walk and informationally efficient in its weak form during the global pandemic. It may also be opined that testing of random walk and market efficiency largely depends on methodological innovation.*

Keywords: NIFTY 50, India, Covid, RWH, EMH.

JEL Classification: G00, G01, G02.

1. Introduction

Random walk and market efficiency are the most important topics of research in finance. A lot of studies are conducted on this area by the researchers around the globe. Generally, there are two sets of opinions that theoretically and empirically support the RWH (see Fama, 1965a, 1965b) under the efficient market hypothesis (EMH) and the second one is uncertainty regarding RWH (Lo and Mackinlay, 1988 etc.). An efficient market always discloses all the information on the stock prices and thus making of abnormal profit is impossible to the investors. But, dissemination of improper information on stock prices may generate manipulation and irrationality. According to Fama (1970, 1991), the market efficiency is divided into three forms particularly weak form, semi-strong form and strong form. Thus, the market is said to be efficient when the stock prices reflect all the information where insider information is of no use. RWH assumes that stock price movement don't follow any pattern and therefore it is tricky to guess the upcoming price movement based on past movement. Thus, market efficiency can be judged by observing the random walk pattern of the stock prices. It is observed that stock markets are badly affected during the Covid-19 pandemic around the globe. With this notion in mind, the present study tries to examine the random walk and market efficiency of the Indian stock market during the pandemic period.

After brief introduction in section1, the literature survey is given in section II. Section III describes about data and study period. Section IV deals with methodological aspect. Section V explains about analysis of result and finally, section VI ends with conclusion and recommendation.

2. Literature review

The efficient market hypothesis is associated with the random walk behaviour. Bachelier introduces the concept of random walk in 1990. Fama in 1991 describes about three forms of market efficiency specifically weak, semi-strong and strong forms. In 1973 Conrad and Juttner claim that random walk hypothesis is inappropriate to explain the behaviour of price changes. On the other hand, Shiller and Perron (1985) walk in a different path and try to investigate an assertion about power functions of a statistical test about random walk hypothesis. Random walk model says about prices of speculative assets which uses many observations. Sometimes data may arise with a short period of time with many observations then power of a test may be very high. To evaluate this, power functions for an important class of alternatives is tabulated with fixed span of data and the number of observations is varied by changing the frequency of observations. They observe that for *t* test and normalized beta test for short spans there is absence of much power but it rises in intermediate spans with the increase of observations. So over a substantial range, power depends on span of the data than the number of observations. They also opine that it is wrong to presume that power of tests of random walk hypothesis is high just because of many observations. There are lot of studies where models of economic fluctuations are examined in a context where economic growth is either assumed away or triggered by independent factors. In 1987, Ching considers an approach that the nature of aggregate fluctuations cannot be abstracted from the process of economic development. He assumes that business cycle can be better understood by considering growth dynamics. He tries to develop an economic model where population is endogenously determined rather than exogenously specified and the novelty of this model is that diminishing returns to factors of production don't constrain the growth of the economy. The model forecasts that aggregate capital shocks, output, consumption and labour follow random walk with drift and the temporary real shocks which occur at a particular point in time is shifted permanently into the future and shift the entire equilibrium path and this process is not trend stationary and doesn't process stationary distributions. He opines that random walk process identifies the specific form of non-stationarity as suggested by Nelson and Plosser (1982). Although, Frennberg and Hansson (1993) argue that stock price doesn't follow random walk. However, Cooper's (1982) study supports in favour of random walk and efficient market hypothesis (See Sharma and Kennedy 1977). Similarly, Panas (1990) observes stock market is efficient in its strong form. Chan, Gup and Pan (1992) observe that the stock prices in the Asian markets as well as USA are efficient at their weak forms. Similar evidences are observed by Dickinson and Muragu (1994) at Nairobi stock market. Barnes (1986) shows that there is a high degree of efficiency in Kuala Lumpur market. Correspondingly, Groenewold and Kang (1993) observe semi strong form of market efficiency in Australian market. On the other hand, evidence of inefficient market efficiency is observed in the Kuwait market (Butler and Malaikah, 1992), Nairobi market (see Barnes, 1986), Istanbul stock market (Zychowicz et. al., 1995) and the Sri Lanka stock market (Abeysekera, 2001). Gradojevic, Djakovic and Andjelic (2010) investigate the soundness of the RWH by employing Lo and MacKinlay's (1988) VR test. Their study doesn't support RWH. But, Gu's (2004) study shows evidence of weak form of market efficiency in NASDAQ composite index. Dragotă et al. (2009) tries to examine the information efficiency of the Romanian capital market by considering two issues namely (i) can the capital market provides return to the normal mechanisms which make them work after a long silence and (ii) how long is it going to take the capital markets to return to the mechanism of the market economy? Thus, they consider daily data for those securities which are traded on Bursa stock exchange and applied various statistical tests like Cowles-Jones test, runs test and multiple variance ratio test. The study reports that the daily and weekly returns don't follow normality and there are evidences of information asymmetry in the Romanian capital markets. They also report that there is a very limited evidence of random walk based on runs test but this evidence is rejected by sequences and reversals ratio. Finally, they opine that Romanian capital market follows random walk and efficient in its weak form after long silence. Similarly, Ikram and Mehtab (2011) seek to examine the market efficiency of Indian equity market by considering daily closing time series data over a period from 2000 to 2010. Thus, they apply non parametric runs test and observe that the Indian equity markets don't follow random walk and inefficient at their weak forms. It is assumed that asset prices incorporate all available information instantaneously and behave accordingly where there is no place of abnormal gains. Thus taking this notion in mind, Oprean (2012) tries to examine the market efficiency by considering the emerging capital markets over a long period of time. Therefore, the study considers various statistical and econometrical tools and techniques to examine the pricing behaviour under random walk framework. The study reports mixed results about random walk and market efficiency in emerging capital markets. Similarly, in 2014, Yadirichukwu tries to examine the weak form of market efficiency in Nigerian stock market indices over a period from 1984 to 2012 by considering monthly time series data. Their study reports evidence regarding presence of random walk with absence of market efficiency in Nigerian stock market when annual data is considered. The evidence is quite opposite when monthly data is considered with presence of market efficiency with absence of random walk. In 2015, Hodrea conducts a new study with a motto to examine the association between market efficiency and market liquidity of an emerging market like Romanian capital market. The author explains that liquidity of the market is closely associated with market efficiency based on the views of various studies. So, to establish the above relationship the study considers 13 companies which are traded in Bucharest stock exchange with daily intraday data and then the observations are arranged in a panel data framework. The study reports that there is a significant association between market efficiency and liquidity with presence of random walk. The study also claims that market liquidity plays a positive role to make the Romanian financial market efficient. Similarly, in 2015, Titan seeks to examine few previous studies which are conducted to examine efficient market hypothesis. It is accepted that market efficiency is a central problem in finance literature. He claims that various studies are conducted to realize the concept of efficient capital markets. There are many theoretical as well as empirical studies which focus on this problem. There are many arguments also. Some studies reject efficient market hypothesis and many studies accept this. There are few studies that support RWH and many of them reject it. In the same fashion, Kalsie et al. (2015) seeks to examine the weak form of market efficiency of NIFTY and six major sectoral indices over a period from 2001 to 2011 by considering daily data. They observe that NIFTY and its allied six sectoral indices are not efficient at their weak forms. In 2018, Gramatovici et al., tries to examine random walk hypothesis of two market indices of Bucharest stock market namely BET and BET plus by considering daily data with short time span. The study applies ARCH test, Naïve Bayes Classifier algorithm, K Nearest Neighbors algorithm, Monte Carlo simulation method, ARIMA modelling and support vector machine. The study reports that the markets follow random walk and efficient at their weak forms. Abkah et al., in 2018, tries to re-examine the weak form of market efficiency by considering 5 African stock markets particularly South Africa, Nigeria, Egypt, Ghana and Mauritius by taking into account weekly data over a period from 2000 to 2013. The study uses Fourier unit root test and augmented regression model to examine the stated objective. They report that three stock markets follow random walk and efficient at their weak forms based on non-linear Fourier unit root test and also opine that stock market efficiency depends on methodological application. Similarly, in 2020, Dias et al., tries to examine the weak form of market efficiency of BEL20 CAC40, DAX30, Dow Jones, FTSE Athex 20, IBEX3, ISEQ, PSI20 and SSE indices which are considered from various countries during the Covid-19 pandemic. Here, the study applies panel unit root test, structural break test and variance ratio test to fulfil the stated objectives. The study reports a mixed result about EMH and almost all the indices don't follow random walk and the prices don't reflect the available information in stock prices. Again in 2020, Dias et al., seeks to establish weak form of market efficiency by considering various stock markets around the glove during the pandemic time by considering daily time series data. They observe that the market indices don't follow random walk and the indices are inefficient at their weak forms and the information doesn't reflect in stock prices and there is a strong possibility to earn abnormal profit. In 2020, Cepai tries to examine the stock market reaction during Covid-19 news by taking into consideration the most effected nations particularly USA, UK, Germany, France, Spain and Italy over a period from 3rd February 2020 to 17th April 2020. Therefore, the study considers six indices of those countries by considering daily time series data. Here, the study uses panel quantile regression framework which is recognised as more powerful tool for controlling extreme values throughout the asset distributions (Plooly, 2019). The study reports presence of asymmetric dependencies with various types of data related to Covid-19 of all the countries. In 2021, Evangelos tries to examine the efficient market hypothesis of US stock market particularly S&P 500 index by using daily time series data during the Covid-19 pandemic. The study reports that the US stock market doesn't react randomly and the market is not informationally efficient during the study period of the Covid-19 pandemic. Pillai et al. in 2021 also tries to examine the nature of market efficiency of the Indian stock market particularly NIFTY 50 during the pandemic time. In this study they seek to examine the behaviour of NIFTY 50 after the announcement of Covid-19 as a public health emergency of international concern and the announcement of lock down in India. The study uses event study approach to determine the efficiency. The study reports that the market is inefficient during this pandemic period and there is a lot of opportunity to make abnormal profits. They also observe that various sectors are affected by the information circulating in the market. In 2021, Budiharto tries to examine stock market forecasting by proposing a data science model by considering Indonesian stock exchange. The data science model is based on statistics and performed on R language and long short term memory (LSTM). The study reports that during Covid-19 pandemic, the composite stock price index is decreased by 28% and most affected industries are cigarette producers and banking sectors. The study also shows that EPOCH method is the best method for stock market prediction and its offers 94.59% accuracy based on data.

Accordingly, random walk and market efficiency obtain serious attention to the researchers. As discussed above that lot of studies are conducted to test randomness and market efficiency of stock prices around the globe by using various tools and techniques but till now there also exist a plenty of conflicts. This study tries to examine the same issue during the time of Covid-19 global pandemic by considering high frequency intraday data and the number of observation is very high and it is assumed that this study surely adds value to the existing domain of knowledge.

3. Data and study period

The present study is based on the perspective of recent Covid-19 pandemic. Therefore, NIFTY 50 which is considered as the popular stock market index in India and well recognised in the world is considered because many researchers use this index for their studies around the globe. Here, intraday data is collected per minute. Finally, 93529 observations are obtained per minute over a period from 1st April 2020 to 31st March 2021 in 249 trading days during Covid-19 pandemic. It is well known that Indian market is opened for trading at 9.15 a.m. and ended at 3.30 p.m. every day in general. So, during this time interval the data is collected per minute through a computer system in every trading day and crossed checked with the intraday technical chart of NSE every day. Here, the time series observation is very large not ever been used by the researchers in recent time and this study surely add value to the existing literature.

4. Methodology

Generally, logarithm time series is more realistic than normal time series because it provides various statistical characteristics that make the analysis simple. Generally, NIFTY 50 contains large value and after log conversion it becomes small and easy to manage and therefore, stationarity features are appropriately visible which is impossible in normal time series. The NSE prices series are converted in logarithm form by using the following mathematical formula:

$$R_{NSE,t} = Ln(\frac{NSE_t}{NSE_{t-1}}) \tag{1}$$

where:
$R_{NSE,t}$ is the per minute logarithm return of NIFTY 50 at time t,
NSE_t is the current per minute index price and
NSE_{t-1} denotes per minute index price of the previous respectively.

The study begins with the following regression equation with drift parameter:

$$LnR_{NSE,t} = LnR_{NSE,t-1} + \alpha + e_t \tag{2}$$

where:
$LnR_{NSE,t}$ denotes logarithmic return of the current minute and $LnR_{BSE,t-1}$ is the logarithmic return of the immediately previous minute respectively,
α indicates subjective drift parameter,
e_t denotes regression error with usual assumptions $E(e_t) = 0$, $E(e_t e_{t-i}) = \sigma_t^2$ for i = 0 and $E(e_t e_{t-i}) = 0$ for $i \neq 0$.

Commonly, the error term captures the differences of index price i.e. $(LnR_{NSE,t} - LnR_{NSE,t-1})$ which is unpredictable white noise.

The following expression is applied to test random walk of NIFTY 50:

$$\Delta LnR_{NSE,t} = (LnR_{NSE,t} - lnR_{NSE,t-1}) = \alpha + e_t \tag{3}$$

Random walk model supports that $LnR_{NSE,t}$ is I(1) ($\Rightarrow \Delta LnR_{NSE,t} \sim I(0)$), α is different from 0 insignificantly and e_t is independently identically distributed.

A lot of statistical test is available to test random walk and market efficiency. The study considers both parametric and non-parametric techniques. Here, serial correlation test like Q statistic and Breusch-Godfrey LM test is applied under parametric approach and runs test is used for examining serial dependence of high frequency time series data under non-parametric framework. Along with these, the study applies ADF and PP unit root tests to explore randomness of the time series data. At last, variance ratio test is used for examining randomness under the assumptions of homoskedasticity and heteroskedasticity conditions.

A. Parametric approach

(i) Serial correlation test

This test is applied to check the relation between the current logarithmic return and immediately the previous. It helps to measure whether the serial correlation (ρ_k) of the successive logarithm return is significantly diverse from 0 and if the association between the present and immediately previous periods is significantly positive then it may be said that the time series follows certain trends meaning that non-randomness. Here, equation 3 is used to examine the serial correlation between the two periods (current and previous) by taking into consideration the high frequency time series data and Ljung and Box's (1978) portmanteau Q-statistic is applied to test the significance of the autocorrelation (null: absence of autocorrelation) that can be shown below:

$$QLB = n(n+2)\sum_{k-1}^{m}\left(\frac{\hat{\rho}_k^2}{n-k}\right) \tag{4}$$

where:
n denotes number of observation.
m is the lag length and the test follows Chi square (χ^2) distribution.

The second parametric approach is applied to check the autocorrelation is Breusch-Godfrey LM test. The test is conducted by taking into account the disturbances of a regression equation. Here, the relationship between disturbances (e_t) and its lagged values at the same time period is tested and this test is extensively applied for testing autocorrelation of the lags up to n^{th} order and this can be shown as below:

$$e_t = \rho_1 e_{t-1} + \rho_2 e_{t-2} + \rho_3 e_{t-3} + \dots\dots\dots + \rho_n e_{t-n} + \omega_t \tag{5}$$

where:
n ≈ N(0, $\sigma^2\omega$)

Here, the coefficients are the autocorrelation coefficients which are to be estimated. It is assumed that if the autocorrelation function dies out at a geometric rate and the partial autocorrelations become zero after one lag then application of first order autoregressive (AR) function is suitable. Otherwise, first-order moving average model is appropriate when autocorrelations become zero after one lag and the partial autocorrelations come down as a geometric rate.

The autocorrelation of a series of H at lag M can be estimated as below:

$$\Psi_m = \frac{\sum_{t=m+1}^{T}(h_t - \bar{h})(h_{t-1} - \bar{h})}{\sum_{t=1}^{T}(h_t - \bar{h})^2} \tag{6}$$

$\bar{h}$ denotes sample average and the correlation coefficient for values of the series m periods apart. If Ψ_1 is non-zero that indicates that the series is serially correlated with order one if Ψ_m dies out more or less geometrically with increasing m lag then the series follows a low order AR process. On the other hand, if Ψ_1 comes to 0 after a few lags then the series follows a low order MA process. Now, if the autocorrelation pattern is one which can be captured by an auto regressive function of order less that m then the partial auto correlation at lag m will be close to 0. Thus, the partial auto correlation at lag m can be recursively shown as under:

$$\Pi_m = \frac{\Psi_m^{\Psi_1} - \sum_{j=1}^{m-1} \Pi_{m-1}, j^{\Psi_{m-j}}}{1 - \sum_{j=1}^{m-1} \Pi_m, j^{\Psi_{m-j}}} \qquad (7)$$

M = 1 for M > 1; where Ψ_m is the estimated auto correlation at lag m and $\Pi_{m,j} = \Pi_{m-1,} j - \Pi_m, \Pi_{m-1,} m - j$ which can be tested by using Q statistics for checking white noise as already shown in equation 5.

B. Non-parametric approach

(i) Runs test

The runs test is a nonparametric statistical approach that allows identifying the independences of successive changes of logarithmic rate of return. It is a sequence of successive alteration of logarithmic rate of returns with positive or negative sign (+ or -) and a state of affairs when the change is zero. The return is categorized based on its position in respect of average return. The expected runs are the change in returns required if the data is generated by a random process. If the actual runs are close to expected number of runs then it is assumed that returns are generated by random process. The expected number of runs is distributed as normal with the subsequent mean as under:

$$e = \frac{S(S+1) - \sum_{i=1}^{3} s_i^2}{S} \qquad (8)$$

The standard deviation can be written as below:

$$\sigma_e = \left[\frac{\sum_{i=1}^{3} \left[\sum_{i=1}^{3} s_i^2 + S(S+1) \right] - 2S\left(\sum_{i=1}^{3} s_i^3 - S^2 \right)}{S^2(S-1)} \right]^{\frac{1}{2}} \qquad (9)$$

Where s_i is the number of runs of each category of i. The study uses Z statistic to conduct runs test that can be written as below:

$$z = \frac{N - p \pm 0.5}{\sigma p} \sim \text{S}(0,1) \tag{10}$$

N denotes actual number of runs. If the actual number of rums higher (lower) than the expected runs then positive (negative) Z values can be obtained that means positive Z values associated with negative serial correlation and vice-versa.

(ii) Unit root test

Modelling of time series data for economic relationship encounters non-stationarity and thus OLS technique may produce spurious results and therefore, testing of non-stationarity is an important task before moving on. Here, the study applies Augmented Dickey-Fuller (1979, 1981) test and Phillips-Peron (1988) test to examine non-stationarity of high frequency time series logarithm data. Here, unit root test is used to examine the market efficiency because it demands randomness (non-stationary) in the stock prices. Thus, two regression equations are applied:

$$\Delta \ln R_{NSE,t} = \alpha_0 + \beta_{i,t-1} \sum_{i=1}^{q} \Delta \ln R_{NSE,t-1} + e_t \tag{11}$$

$$\Delta \ln R_{NSE,t} = \alpha_0 + \alpha_{1t} + \beta_0 \ln R_{NSE,t-1} + \lambda_i \sum_{i=1}^{q} \Delta \ln R_{NSE,t-1} + e_t \tag{12}$$

Here, equation 13 includes both an intercept and trend terms where, equation 12 includes only an intercept term. *q* is the number of lagged lengths which can be determined by using AIC and *e* is the white noise.

(iii) Lo and MacKinlay Variance Ratio test

Lo and MacKinlay's (1988) variance ratio test statistic is obtained from the assumption of linear relations in observations interval regarding the variance of increments. If the logarithmic time series rate of return follows random walk then the q^{th} differenced variable is q times higher than the first-differenced variable and if the logarithmic rate of return series is divided into equally spaced distance and characterised by random walk then the q^{th} variance of ($\ln R_{NSE,t} - \ln R_{NSE,t-q}$) is equal to the variance of ($\ln R_{NSE,t} - \ln R_{NSE,t-1}$): $Var(\ln R_{NSE,t} - \ln R_{NSE,t-q}) = q Var(\ln R_{NSE,t} - \ln R_{NSE,t-1})$

Where, q is the positive integer and the variance ratio may be written as follows:

$$VR(q) = \frac{\frac{1}{q} Var(\ln R_{NSE,t} - \ln R_{NSE,t-q})}{Var(\ln R_{NSE,t} - \ln R_{NSE,t-1})} = \frac{\sigma^2(q)}{\sigma^2(1)} \tag{13}$$

Here, H_0 is $VR(q) = 1$

Lo and Mackinlay's (1988) unbiased estimates of $\sigma^2(1)$ and $\sigma^2(q)$ for a sample size of nq + 1 observations ($R_0, R_1, \ldots, R_{nq}$) may be expressed as follows:

$$\hat{\sigma}^2(1) = \frac{\sum_{k=1}^{nq}(R_k - R_{k-1} - \hat{\mu})^2}{nq - 1} \tag{14}$$

and

$$\hat{\sigma}^2(q) = \frac{\sum_{k=q}^{nq}(R_k - R_{k-q} - q\hat{\mu})^2}{v} \tag{15}$$

where:

$\hat{\mu} = \text{sample mean of } (R_t - R_{t-1})$

Mackinley (1988) talks about two test statistics which are Z(q) and Z*(q) under the null hypothesis of homoskedasticity and heteroskedastic increments random walk. If the null hypothesis is accepted then the associated test statistic follows asymptotic standard normal distribution. Under the null hypothesis of homoskedastic increments with a sample size of nq + 1 observations ($R_0, R_1, \ldots, R_{nq}$), the standard normal test statistic Z(q) may be written as follows:

$$Z(q) = \frac{V\hat{R}(q) - 1}{\hat{\sigma}_0(q)} \tag{16}$$

where:

$$\hat{\sigma}_0(q) = \left[\frac{2(2q-1)(q-1)}{3q(nq)}\right]^{\frac{1}{2}} \tag{17}$$

Whereas, the random walk test statistic of heteroskedastic increments Z*(q) may be expressed as follows:

$$Z^*(q) = \frac{V\hat{R}(q) - 1}{\hat{\sigma}_e(q)} \tag{18}$$

where:

$$\hat{\sigma}_e(q) = \left[4\sum_{k=1}^{q-1}(1 - \frac{k}{q})^2 \hat{\delta}_k\right]^{\frac{1}{2}} \tag{19}$$

and

$$\hat{\delta}_k = \frac{\sum_{j=(k+1)}^{nq} (R_j - R_{j-1} - \hat{\mu})^2 (R_{j-k} - R_{j-k-1} - \hat{\mu})^2}{\left[\sum_{j=1}^{nq} (R_j - R_{j-1} - \hat{\mu})^2 \right]} \tag{20}$$

(iv) Multiple Variance Ratio (MVR) Test

Chow and Denning develops the multiple variance ratio test in 1993 that captures auto-correlation and heteroscedasticity in time series data. This corresponds to the test $E(e_t e_{t-i})$ = 0 and $\sigma^2(e_t e_{t-i})$ is constant or e_t ~ i.i.d. Lo and Mackinlay's (1988) procedure is designed to test individual variance ratio for a specific aggregation interval (q) whereas the condition of RWH is VR(q) = 1 for all q. But, multiple variance ratio (MVR) test helps to compare multiple variance ratio estimates with the unity. The condition of null hypothesis for a single variance ratio test is VR(q) = 1 and for multiple variance ratio test is $M_r(q)$ = VR(q) – 1 = 0 and further the set of m variance ratio tests is {Mr(q_i) / i = 1, 2,..., m}. Under RWH, multiple and alternative hypotheses are as under:
H_{0i}: $M_r(q_i) = 0$ for i = 1, 2,..., m.
H_{1i}: $M_r(q_i) \neq 0$ for any i = 1, 2,..., m.

The null of random walk is rejected when any one or more of H_{0i} is rejected. The homoscedastic test statistic in Chow-Denning may be expressed as under:

$$CD_1 = \sqrt{T\,Max} \,/ 1 \leq i \leq Z(q_i) / \tag{21}$$

Chow-Denning test follows standardized maximum modulus (SMM(α, m, T)) distribution with m parameters with T degrees of freedom. Similarly, heteroscedastic robust statistic of Chow-Denning may be expressed as under:

$$CD_2 = \sqrt{T\,Max} \,/ 1 \leq i \leq Z^*(q_i) / \tag{22}$$

The RWH is rejected if the value of standardized test statistic CD_1/CD_2 is greater than the SMM critical value at chosen level of significance.

5. Result and analysis

The descriptive statistics of high frequency per minute logarithmic return series of NIFTY 50 index is presented in Table 1. It is observed that NIFTY 50 index provides positive return to the investors during Covid-19 pandemic study period. However, the risk exposure of NIFTY 50 is slightly higher during pandemic time. The skewness is found to be negative that means data are skewed right (platykurtic) as compared to the left one and positive kurtosis denotes logarithmic return distribution of the index has flatter tails than a normal distribution. Furthermore, the computed JB statistic of the high frequency logarithmic return distribution of NIFTY 50 is very large and the probability of obtaining such statistic under the normality assumption is approximately significantly zero that means rejection of null hypothesis (H_0: Normally distributed) and opined that that the high frequency logarithmic return series of NIFTY 50 is not normally distributed.

Table 1. *Descriptive statistics*

Index	OB	Mean	Max.	Min.	Standard Deviation	Skew.	Kurtosis	J-B	P-Value
LnNSE	93038	0.000005	0.0410	-0.0375	0.0007	4.0451	544.5439	1140000000	0.000*

*Significant at 5% level.
Source: Authors' own calculation.

Table 2 presents the auto correlation and partial auto correlation functions of the high frequency logarithmic return series of NIFTY 50 along with Q statistic and B-G serial correlation LM statistic. It is observed that the Q statistics of high frequency logarithmic return series of NIFTY 50 is statistically significant that supports to reject the null hypothesis (H_0: weak-form of market efficiency) and also implies significant association between current period and its immediately preceding period which confirms about presence of serial dependence in NIFTY 50 returns during Covid-19 period which also claims about absence of weak form of market efficiency.

In the same light it is observed that the probability value of the χ^2 statistic (=Obs*R^2) is 0.000 which is statistically significant and thus reject the null hypothesis and also confirms about presence of serial correlation. Therefore, it may be opined that the NIFTY 50 index with high frequency time series data doesn't support random walk behaviour.

Table 2. *Test of Serial Independence*

Index	Lags	AC	PAC	Q Statistic	Prob.	B-G Serial Correlation LM Test			
						F-stat.	Prob.	Obs*R^2	Prob.
LnNSE	1	-0.022	-0.022	44.716	0.000*	37.6041	0.0000*	75.1507	0.0000*
	2	-0.022	-0.022	88.485	0.000*				
	3	-0.007	-0.008	93.279	0.000*				
	4	-0.002	-0.003	93.808	0.000*				
	5	0.011	-0.010	104.57	0.000*				
	6	0.016	0.016	127.16	0.000*				
	7	-0.012	-0.011	140.53	0.000*				
	8	-0.005	-0.004	142.48	0.000*				
	9	-0.012	-0.012	154.96	0.000*				
	10	-0.000	-0.001	154.97	0.000*				

*Significant at 5% level.
Source: Authors' own calculation.

Runs test is a non-parametric statistical test which is conducted to check the independency of consecutive price changes of a time series or in other words a test of randomness for the sequence of returns. It is opined that time series is not normally distributed and thus there is a possibility of structural breaks (outliers) in the time series returns which may influence the test results. So, keeping in mind such issues, the runs test is conducted by using mean and median as a base. However, considering median can provide better result in the presence of structural break in the series. The outcome of runs test is presented in table 3 and 4. It is found that the computed z statistic is negative and insignificant which is also lower than the critical value at 5% significance level (1.96) in absolute term in both the cases and thus the null hypothesis is accepted. Hence, it may be opined that the stock price movement with high frequency data in the pandemic period is random in nature and the past movement is affected by the previous movement. Therefore, it may be said that the NIFTY 50 index during the sample pandemic period with high frequency data follows random walk and the index is efficient in its weak form.

Table 3. *Runs test (Mean as base)*

Var.	Test Value	Case<test value	Case>=test value	Total Cases	Number of runs	z-statistic	p-value
LnNSE	0.00000578	46900	46138	93038	46430	-0.570	0.569

Source: Authors' own calculation.

Table 4. *Runs test (Median as base)*

Var.	Test Value	Case<test value	Case>=test value	Total Cases	Number of runs	z-statistic	p-value
LnNSE	0.00000	46513	46525	93038	46402	-0.774	0.439

Source: Authors' own calculation.

Unit root testing is one of the important tests for examining market efficiency. Table 5 presents the result of unit root test. It is found that the test statistic based on two measures is negative and statistically significant at level form that means rejection of null hypothesis. Thus, it may be claimed that logarithmic return of the high frequency time series of NIFTY 50 is stationary and against random walk behaviour during the pandemic time and therefore it may be opined that NIFTY 50 is inefficient at its weak form.

Table 5. *Unit Root Tests*

Index	ADF Test		PP Test	
	Level		Level	
	t-stat.	Prob.	t-stat.	Prob.
lnNSE	-223.0731	0.0001*	-312.0410	0.0001*

*Significant at 5% level.
Source: Authors' own calculation.

The absolute value of z(q) and z*(q) statistics is examined (homoskedastic and heteroskedastic increments random walk) based on the outcome of MacKinlay's variance ratio test. It is observed from the table (Table 6) that the absolute values of homoskedactic-consistent statistics [z(q)] as well as heteroskedasticity-consistent statistics [z*(q)] under the various sampling intervals [z(2), z(4), z(8) and z(16)] are higher than the critical value (2.49) at 5% level of significance in high frequency logarithmic return series of NIFTY 50 that confirms about rejection of null hypothesis of random walk and thus, it may be opined that NIFTY 50 index is inefficient at its weak forms.

Similarly, the maximum homoskedastic and heteroskedastic robust test statistics proposed by Chow and Denning are also reported in the same table. It is observed that Chow-Denning MVR test statistics are higher than the critical value (2.49) at 5% level of significance that indicates rejection of null hypothesis of random walk and thus it may be opined that NIFTY 50 index is inefficient at its weak form during the pandemic period.

Table 6. *Variance Ratio Test*

Index	Lo-Mackinlay VR Test				Prob.	Chow-Denning MVR Test	
	q	VR(q)	Z(q)	Z*(q)		Homoskedastic Statistic	Heteroskedastic Statistic
lnNSE	2	0.499824	-152.5634	-11.76347	0.0000	152.5634 (0.0000)	11.76347 (0.0000)
	4	0.245196	-123.0632	-11.72670	0.0000		
	8	0.122868	-90.44590	-11.54911	0.0000		
	16	0.060686	-65.09049	-11.34220	0.0000		

*Significant at 5% level.
Source: Authors' own calculation.

6. Conclusion and recommendation

The present study tries to examine the RWH and market efficiency of the high frequency intraday time series logarithmic return data of the well-known stock market index NIFTY 50 in India during the period of Covid-19 pandemic. The logarithmic return series of NIFTY 50 is not normally distributed and return series doesn't support random walk theory and thus inefficient in its weak form during the pandemic period based on parametric as well as non-parametric test approaches. However, the return series of NIFTY 50 index supports random walk behaviour during this pandemic period and the market is also efficient in its weak form based on runs test. Finally, it may be recommended that this study is helpful to the financial planners, policy makers and the investors who can get advantage from the evidences when they plan for stock market trading and market forecasting during pandemic period. The researchers may also conduct further study by taking into consideration of others financial markets those are affected a lot during this pandemic period by considering high frequency time series data.

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