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MODELING NIFTY VOLATILITY USING GARCH

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ABSTRACT

Statistical volatility of an asset during a period is defined as the variance of asset returns over that period. Unlike price of an asset, volatility is not directly observable. Moreover the volatility of an equity or an index can vary with time. Consequently modeling volatility of an equity or an index is a challenging problem. Accurate assessment of volatility of an index or an equity is important for option pricing and portfolio management. In this paper we measure the volatility of S&P CNX NIFTY, the leading Indian benchmark Index, during the period 1st April 2001 to 31st March 2011. Robert Engle introduced the idea of modeling time varying volatility by introducing the concept autoregressive conditional heteroscadasticity (ARCH). An advanced version of this model is the generalized ARCH or GARCH model. We use GARCH model to estimate the volatility in the daily NIFTY returns during the last ten financial years, during which the Indian and global equity markets witnessed great fluctuations. The fitted GARCH model reveals that during the last ten financial years the most volatile period seems to be from 1st week of June 2006 to 1st week of November 2008. Volatility in NIFTY daily returns seems to have increased drastically since June 2006.

KEYWORDS

NIFTY volatility estimation, GARCH, Time varying volatility, autocorrelation function.

INTRODUCTION

Measuring volatility of asset returns is an important problem in finance. For instance, option-pricing formulae express prices of options and other derivative instruments in terms of volatility of the underlying asset. In Portfolio-choice theory, optimal portfolios are derived as functions of variances and covariances of asset returns. Financial economists have long since known that volatility in returns tends to cluster (i.e. a high price movements are likely to be followed by high price movements) and that in any share or commodity market there are highly volatile as well as passive phases. Even though the time varying nature of volatility of financial assets was known to many researchers, but until 1980s researchers used models in which volatility was assumed constant over time. For example, Mandelbrot (1963), Mandelbrot and Taylor (1967) used so-called stable Paretian models to characterize the return distributions.

Engle (1982) introduced the assumption that the conditional variance of the residual component in a time series model is time-varying. In simple terms, Engle assumed that a large error is likely to be followed by another large error and a small error by a small error. This revolutionary concept made it possible to explain systematic features in the movements of variance over time. Economists believe that volatility of an index can be explained by the weak form of efficient market hypothesis. A stock market index is said to be weak form efficient (see Sharma and Chander (2011)) if it is not possible to forecast future returns by studying past returns. To be precise efficient market hypothesis assumes that the successive daily returns of a market index are stationary (exhibiting constant mean) and are not correlated.

Let $R_t = Log(P_t/P_{t-1})$, where P_{t-1}, P_t denote the price of a market index at times $t-1$ and t. Then efficient market hypothesis implies that $\{R_t\}$ is a white noise process, exhibiting no auto-correlation. However it is well known that returns on any equity or index tend to have periods of high volatility clustered together.

Using Engle's idea of capturing time varying volatility, an appropriate model for R_t seems to be

$$R_t = \mu + y_t, \text{ where } y_t = \sigma_t z_t \text{ and } \sigma_t^2 = \alpha_0 + \sum_{i=1}^{m} \alpha_i y_{t-i}^2$$

$\{z_t\}$ is a sequence of pure white noise or independent and identically distributed random variables with mean zero and variance 1. The coefficients $\alpha_i, i = 0,1,2,\ldots$ are non negative. σ_t^2 represents the volatility at time t. This model is known as the ARCH (m) model (see Rajan (2011)). Since volatility is persistent in financial markets, it is observed that an appropriate value of "m" can be very large. This increases the computational cost involved in estimation of the model parameters.

To overcome this difficulty a generalization of the ARCH model was proposed (see Bollerslev (1986)) which is defined as follows

$$R_t = \mu + y_t, \text{ where } y_t = \sigma_t z_t \text{ and } \sigma_t^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_i y_{t-i}^2 + \sum_{i=1}^{q} b_i \sigma_{t-i}^2.$$

The above model is known as generalized ARCH or GARCH (p,q) model.

The last ten financial years, *viz* from 1st April 2001 to 31st March 2011, has been very eventful and volatile for Indian equity market. During this period the national stock exchange (NSE) in India have taken a number of steps to improve the share market microstructure in India. As a result the NSE has gradually evolved into an efficient market (see Dutta (2011)). Dutta (2011) observed that the S&P CNX NIFTY daily returns, during the last ten financial years, exhibit time varying volatility. Consequently GARCH seems to be a suitable model for modeling the volatility in NIFTY daily returns.

OBJECTIVE

In this paper we fit the above mentioned GARCH model to estimate and visualize the volatility in daily returns of S&P CNX NIFTY index, during 1st April 2001 to 31st March 2011. We analyze how the volatility in NIFTY daily returns have changed over the last ten financial years.

LITERATURE REVIEW

Modeling volatility of Indian equity markets has been an area of active research. For instance, Rajan (2011) has used GARCH model to capture the irregular time varying movement in SENSEX, the leading Index in Bombay stock exchange in India, during 1st July 1996 to 3rd July 2009.

Dutta (2011) have estimated the volatility of S&P CNX NIFTY index for the last ten financial years by measuring the variance of the daily index returns within each financial years. The author observed that the volatility varied from one financial year to another. This observation in fact justifies the use of heteroscedastic models such as ARCH or GARCH to capture the time varying volatility in Indian share market.

Kaur (2004) studied the extent and pattern of stock return volatility in Indian equity market during 1999 to 2000. The author observed that April was the most volatile month followed by March and February.
Rao (1997) has observed that budget increased the volatility of stock prices.
S&P CNX NIFTY in one of the leading stock market indices in India. It represents 22 sectors in Indian economy. We have not come across any recent study on estimating volatility of S&P CNX NIFTY covering the last ten financial years, from 1st April 2001 to 31st March 2011. This paper is attempt in this direction.

DATA

Daily return of S&P CNX NIFTY index is defined as $R_t = Log(P_t/P_{t-1})$, where P_{t-1}, P_t denote the closing price of S&P CNX NIFTY index in two consecutive trading days. We have collected data on closing values of S&P CNX NIFTY Index from NSE website, viz. www.nseindia.com, and computed the values of daily NIFTY returns for the period 1st April 2001 to 31st March 2011.

METHODOLOGY

The data analysis is performed in three stages which are described below.

i. *1st Step. Model Detection:* GARCH models assume that the present variance σ_t^2 be a linear combination of the squares of the previous innovations. For instance, $\sigma_t^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_i y_{t-i}^2 + \sum_{i=1}^{q} b_i \sigma_{t-i}^2$. So our first step is to check whether this assumption is acceptable for the data under study.
The square of the daily NIFTY returns represent the variance of the daily returns (see Ranjan (2011)). Existence of autocorrelation among the squared returns provide evidence in favor of the hypothesis that the present volatility can be estimated in terms of the past volatility. Therefore, existence of autocorrelation in squared returns will justify the GARCH modeling of the NIFTY volatility.
An autocorrelation coefficient of lag k, measures the extent of correlation among the observations separated by time lag k in a time series. Given a time series $\{X_t\}_{t=1,2,\ldots,}$ the autocorrelation coefficient of lag k, denoted by ρ_k, is defined as

$$\rho_k = \sum_{t=1}^{n-k}(X_t - \bar{X})(X_{t+k} - \bar{X}) / \sum_{t=1}^{n}(X_t - \bar{X})^2$$, where

$\bar{X}$ is the mean of the n observations $X_1, \ldots\ldots, X_n$. In this paper $X_t = R_t^2$, where R_t is the NIFTY return for the tth day, and n is the number of trading days in the period under study.

The plot of ρ_k against k is called the autocorrelation (acf) function plot. We use "acf" command in R software to produce the acf function plot (see *www.r-project.org*). If the calculated value of $\rho_k,\ k = 0,1,2,\ldots,$ lie outside the confidence limits (the blue lines in Figure 1), then we *reject* the hypothesis of no autocorrelation in daily squared returns. In that case we can estimate the volatility by fitting GARCH model.
ii. *2nd Step. Fitting GARCH model.* If the lower order autocorrelations are significant and the autocorrelations decrease rapidly as lag is increased (see Figure 1), then the squared returns seem to follow a 1st order auto-regression process. In that case, we fit a simple GARCH (1,1) model which is defined below.

$$R_t = \mu + y_t, \text{ where } y_t = \sigma_t z_t \text{ and } \sigma_t^2 = \alpha_0 + \alpha_1 y_{t-1}^2 + b_1 \sigma_{t-1}^2 \quad (1)$$

The parameters μ, α_0, α_1 and b_1 are estimated by maximum likelihood method using the package fGarch in free software R for statistical computing (see *www.r-project.org*). The parameter estimates are tabulated in Table 1.

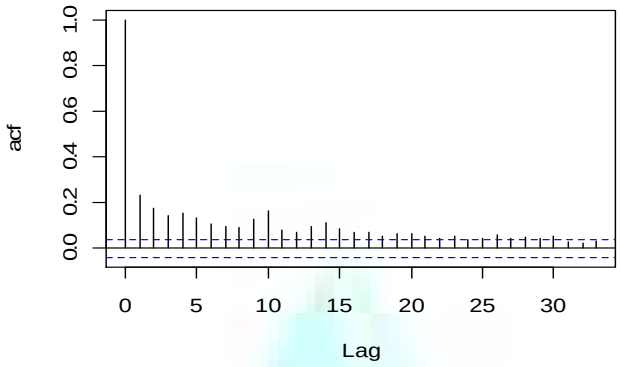
iii. *3rd Step. Verifying the adequacy of the fitted model.* Let $\hat{\mu}, \hat{\alpha_0}, \hat{\alpha_1}$ and $\hat{b_1}$ be the maximum likelihood estimates of the model parameters. The standardized residual, at time t, is defined as $\hat{z}_t = (R_t - \hat{\mu}) / \hat{\sigma}_t$ where $\hat{\sigma}_t^2 = \hat{\alpha_0} + \hat{\alpha_1} y_{t-1}^2 + \hat{b_1} \sigma_{t-1}^2$. Note that $\hat{z}_t$ is an approximation of the residual z_t.

The GARCH model assumes that the residual $\{z_t\}$ are white noise. Therefore if our fitted model is appropriate, then there should be no autocorrelation left in the squared standardized residuals $\{\hat{z}_t^2\}$. The final step is to verify whether there exists any autocorrelation among the squared standardized residuals $\{\hat{z}_t^2\}$. In Figure 2 we plot the acf function for the $\{\hat{z}_t^2\}$ values.

If there is no significant autocorrelation in $\{\hat{z}_t^2\}$ terms (i.e. autocorrelation coefficients lie within confidence limits), we conclude that the fitted GARCH (1,1) model is appropriate. In that case $\hat{\sigma}_t^2 = \hat{\alpha_0} + \hat{\alpha_1} y_{t-1}^2 + \hat{b_1} \sigma_{t-1}^2$ provide reliable estimate of the daily NIFTY volatility. In Figure 3, we visualize the NIFTY volatility by plotting $\hat{\sigma}_t^2$ against t.

Data Analysis and Findings: In Figure 1 we plot the autocorrelation function of the daily NIFTY returns from 1st April 2001 to 31st March 2011.

Fig1: acf of squared NIFTY returns 2001-2011



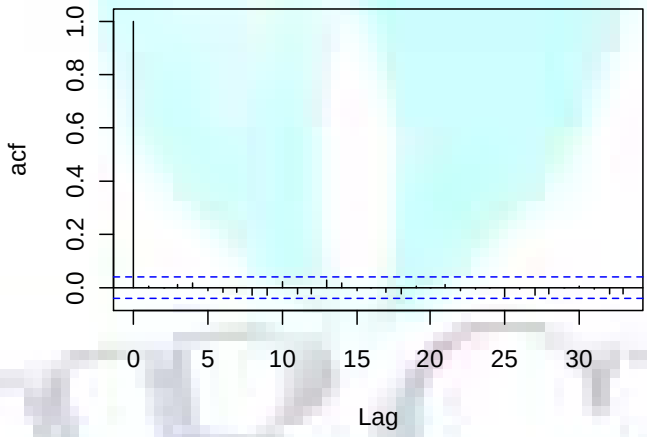
From Figure 1 we see that there exists strong autocorrelation between the squared daily returns of the NIFTY index for the period under study. This motivates the GARCH model. We fit a simple GARCH (1,1) model, see equation (1), to the NIFTY daily return data.
The four parameters are estimated by maximum likelihood method using fGarch package in R. The values of the maximum likelihood estimates $\hat{\mu}, \hat{\alpha_0}, \hat{\alpha_1}$ and $\hat{b_1}$ are given in Table 1.

TABLE 1: MAXIMUM LIKELIHOOD ESTIMATES AND P-VALUE OF THE TEST OF SIGNIFICANCE FOR THE PARAMETERS

Parameters	Estimates	p-value
μ	0.056	0
α_0	0.014	0
α_1	0.150	0
b_1	0.827	0

The p-values, in the third column of Table 1, are p-values of the tests of hypotheses that the model parameters are zero. The zero p-values indicate that effect off all the parameters is important, and none of them can be assumed to be zero.

Fig 2: acf plot of squared residuals in GARCH



Substituting the values of the parameter estimates $\hat{\mu}, \hat{\alpha_0}, \hat{\alpha_1}$ and $\hat{b_1}$ in equation (1) we get the fitted GARCH (1, 1) model. In this model the estimated volatility at time t is given by

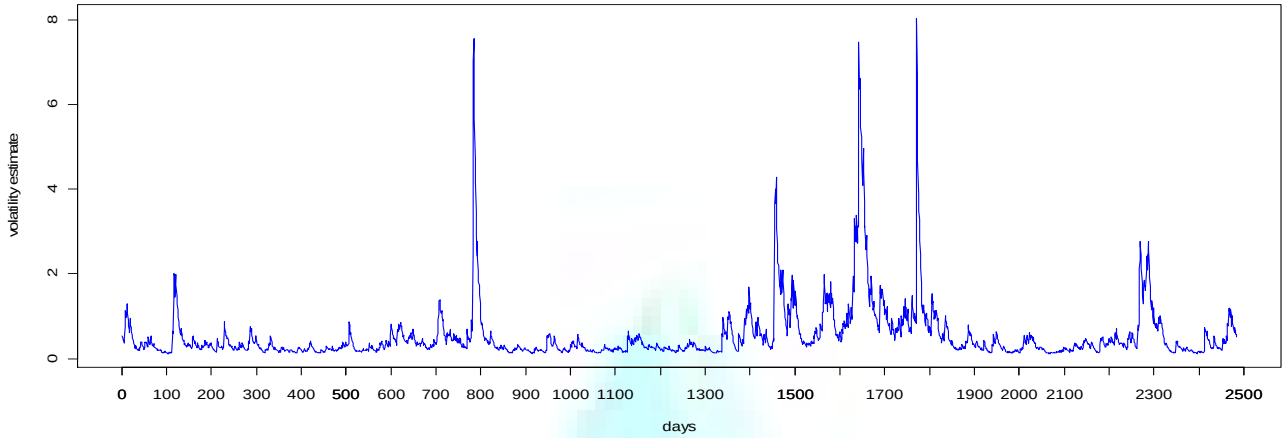
$$\hat{\sigma_t}^2 = \hat{\alpha_0} + \hat{\alpha_1}\, y_{t-1}^2 + \hat{b_1}\, \sigma_{t-1}^2 = 0.014 + 0.150 y_{t-1}^2 + 0.827\, \sigma_{t-1}^2 \quad (2)$$

The standardized residual at time t equals, $\hat{z_t} = (R_t - \hat{\mu})/\hat{\sigma_t}$. If the estimated volatility $\hat{\sigma_t}^2$ in equation (2), is successful in capturing the true volatility present in the data then there should be no autocorrelation left in the squared standardized residuals.

In Figure 2 we plot the autocorrelation function of the squared standardized residuals $\{\hat{z_t}^2\}$ in the fitted GARCH (1,1) model. From Figure 2, we see that there is no significant autocorrelation in the squared standardized residuals. This indicates that $\hat{\sigma_t}^2$, in equation (2), successful in capturing the volatility present in the data.

Finally in Figure 3 we plot the volatility estimate $\hat{\sigma_t}^2$ values to visualize how volatility has changed during period under study.

Fig 3: Estimated daily NIFTY volatility during 2001-2011



There are 2487 trading days during the period from 1st April 2001 to 31st March 2011. These days are numbered 1 to 2487 and are plotted along the x-axis in Figure 3. The corresponding volatility estimates are plotted along the y-axis in Figure 3.

FINDINGS

The main observations are as follows.

1. From Figure 3 we can see that there are six prominent peaks, which indicate that there were sharp increases in NIFTY volatility on six occasions during the last ten financial years.
2. The first prominent peak occurred between 100 to 150 days, i.e. during last week of August 2001 to 2nd week of October 2001. Another sharp increase in volatility is observed near 800 days, that is in June 2004.
3. During the last ten financial years the most volatile period seems to be from 1300 to 1900 days, i.e. from 1st week of June 2006 to 1st week of November 2008. Within this period there are three high peaks, indicating rapid increase in volatility. One peak occurred during 1450 to 1500 days, i.e. during January to March 2007. The next two peaks occurred during 1600 to 1800 days i.e. from 2nd week of August 2007 to 2nd week of June 2008. During this period the NIFTY moved from 4400 to above 6200 in 1st week of January 2008, and then again back to 4040 during June 2008.
4. A sharp increase in volatility is again observed during 2300 days i.e. July 2010.
5. The volatility in NIFTY daily returns seems to have increased quite drastically since June 2006. For instance, before June 2006 there were only two occasions when volatility increased sharply. In contrast the volatility has increased sharply four times after June 2006.

Moreover for a substantial period viz. 850 to 1300 days i.e. August 2004 to June 2006, the NIFTY daily returns were less volatile. However after June 2006, NIFTY daily returns have been highly volatile for almost two years till January 2008.

CONCLUSION

We see that the plot of the volatility estimates using GARCH (1,1) model is a powerful tool to visualize the changes in volatility in NSE over the last ten financial years. The volatility in Indian equity market, especially in NSE, seems to have increased quite drastically during the last four financial years. The reason for this increase in volatility seems to be the in and out flow of large institutional investments in Indian equity markets, depending global economic scenario and some domestic factors such as GDP growth, RBI interest rate policies, inflation rate etc. Considering the present economic uncertainly in Europe and high inflation rate in India, the Indian equity market may witness more volatile days ahead.

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