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Validating Black-Scholes Model in Pricing Indian Stock Call Options

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Abstract

Derivatives' trading was introduced in India during 2001, and the trade value of derivatives is almost three times that of cash market trade values. However, only about 20 percent of the options offered by the National Stock Exchange (NSE) are traded on an active basis. This is perhaps due to the lack of investor education about options and its pricing methodology. It is hoped that research on option pricing in India will enable investors to understand the mechanism of option pricing and its use as a tool to hedge risks. This empirical paper uses more than 95,000 call options to test the validity of the Black-Scholes (BS) model in pricing Indian Stock Options. The results show the robustness of the Black-Scholes model in pricing stock options in India and that pricing is further improved by incorporating implied volatility into the model.

JEL classification numbers: D4, R32
Keywords: Option pricing, pricing call options in India, Black-Scholes model

1 Introduction

Derivatives' trading was introduced in India during 2001, and the trade value of derivatives is almost three times that of cash market trade values. However, only about 20 percent of the options offered by the National Stock Exchange (NSE) are traded on an active basis. This is perhaps due to the lack of investor education about options and its pricing methodology. It is hoped that research on option pricing in India will enable investors to understand the mechanism of option pricing and its use as a tool to hedge risks. This empirical paper uses more than 95,000 call options to test the validity of the Black-Scholes (BS) model in pricing Indian Stock Options. The results show the robustness of the Black-Scholes model in pricing stock options in India and that pricing is further improved by incorporating implied volatility into the model.

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2 Literature Review

As can be expected, extant literature on option pricing in India is scant due to thin trading and gaps in option pricing data. Also, the option pricing data has to be hand gathered for analysis and research. Kakati (2006) studied the Black-Scholes (BS) model in pricing option contracts for ten Indian stocks. The study found that the BS model mispriced the option contracts considerably and underpriced the options in many cases. However, the study was limited in scope and thereby one cannot draw generalized conclusions from the study. Khan, Gupta, and Siraj (2013) found improvement in pricing of NSE derivatives by using alternative proxies for the risk free rate in the BS model. Panduranga (2013) found the BS model effective in pricing Cement stock options in India. However, there has been no large scale study on the pricing of Indian stock options and it is expected that the current large scale study, both in terms of sample size and time period under consideration, will be a valuable addition to the option literature on Indian option markets.

3 Sample Selection

This study focuses on pricing of call options. Data are taken from National Stock Exchange (NSE) for the time period1/1/2002 –10/31/2007. According to NSE data, 52 companies traded in the derivative segment in 2003, 116 companies traded in 2005,and 223 companies traded in this segment in 2007. The stock call options related to these companies for the aforementioned time period were considered. A random sample of 28 companies was selected for the time period under consideration. The selected sample represents a wide spectrum of important industries such as Automobiles, Banks, Cement, Engineering, Information Technology, Petroleum, Pharmaceuticals, Telecom, Textile, and Steel. The selected 28 sample companies are listed in Table 1 below.

Table 1: Sample Call Option Data

S. No. 1	Company 2	From 3	To 4	Offered 5	Traded 6	Non-Dividend Paying 7
1	Tata Steel	1/1/2002	10/31/07	59,912	18,462	16,100
2	Reliance Ind.	1/1/2002	10/31/07	53,118	16,271	14,145
3	Infosys Technologies	1/31/2003	10/31/07	60,653	18,046	12,559
4	ACC	1/1/2002	10/31/07	56,006	11,577	9,334
5	MTNL	1/1/2002	10/31/07	49,049	13,085	9,298
6	Satyam	1/1/2002	10/31/07	53,376	16,122	8,673
7	HUL	1/1/2002	10/31/07	49,742	12,444	7,776
8	Ranbaxy Laboratories Ltd.	1/1/2002	10/31/07	57,502	9,975	7,481
9	ITC	1/1/2002	10/31/07	50,349	8,864	7,264
10	M & M	1/1/2002	10/31/07	56,020	8,739	7,232
11	Ambuja Cements	1/1/2002	10/31/07	47,152	7,643	6,793
12	ICICI	1/31/03	10/31/07	47,754	7,989	6,475
13	ONGC	1/31/03	10/31/07	48,223	9,567	5,978
14	SCI	1/31/03	10/31/07	45,178	6,962	5,574
15	BPCL	1/1/2002	10/31/07	53,954	7,780	5,347
16	Cipla	1/1/2002	10/31/07	56,632	5,665	4,833
17	Dr. Reddy'S	1/1/2002	10/31/07	55,490	5,805	4,721
18	Bank Of India	8/29/03	10/31/07	40,364	6,203	4,660
19	Andhra Bank	8/29/03	10/31/07	33,559	5,896	4,518
20	Wipro Ltd.	1/31/03	10/31/07	47,780	6,417	4,505
21	Syndicate Bank	9/26/03	10/31/07	32,941	5,759	4,389
22	UBI	8/29/03	10/31/07	36,327	5,166	4,122
23	BHEL	1/1/2002	10/31/07	65,471	6,051	4,083
24	PNB	8/29/03	10/31/07	49,229	4,661	3,870
25	Bank Of Baroda	8/29/03	10/31/07	49,764	4,457	3,589
26	Canara Bank	8/29/03	10/31/07	46,500	4,676	3,262
27	Bajaj Auto	1/1/2002	10/31/07	63,292	2,331	1,790
28	Grasim	1/1/2002	10/31/07	64,195	2,086	1,761
Total				**1,429,537**	**238,705**	**180,139**

Source: Column 1 to 6 from www.nseindia.com

The initial data size for the sample companies were 1,429,537 call options. Options that were not traded, related to dividend paying stocks, and those with those with risk-less Arbitrage Opportunities were eliminated from the sample. Box-plot analysis was done to find outliers in the sample and they were eliminated. Some of the options for which implied volatility could not be found were also eliminated. This led to the final sample size of 95,956 call options. To estimate the volatility of returns of the stock prices, stock prices of the 28 sample companies were downloaded at least from 120 days prior to the first date of the option data. For the 28 sample companies almost 48,000 stock price data were collected.

The BS model is designed for European type options that can be exercised only on the expiration date. But, Indian stock options are of the American type and can be exercised any time on or prior to the expiration date. However, if we eliminate all arbitrage opportunities for American type options, one will not exercise the options early and hence they can be treated like European type options. In view of the above, all risk-free arbitrage opportunities were eliminated from the sample to make use of the BS model for pricing call options.

4 Methodology

4.1 Black-Scholes Model

The Black-Scholes call option pricing model used in our study is given as:

$$C_o = S_0 N(d_1) - X e^{-rT} N(d_2)$$

where:

$$d_1 = \frac{\ln(S_0 / X) + (r + \sigma^2/2)T}{\sigma \sqrt{T}}$$

$$d_2 = \frac{\ln(S_0 / X) + (r - \sigma^2/2)T}{\sigma \sqrt{T}}$$

and the variables are defined as:

C_0 = Current call option value
S_0 = Current stock price
N(d) = The probability that a random draw from a standard normal distribution will be less than d. This equals the area under the normal curve up to d.
X = Exercise price / Strike Price
e = 2.71828(base of natural log function)
r = Risk free interest rate (the annualized continuously compounded rate on a safe asset with the same maturity as the expiration of the option).
T = Time to maturity of option in years
ln = Natural Logarithm function.
σ = Standard deviation of the annualized continuously compounded rate of return of the stock.

The assumptions of the model are:

1. The distribution of asset price follows the lognormal random walk.
2. The underlying asset pays no dividends during the life of the option.
3. There are no arbitrage possibilities.
4. Transactions cost and taxes are zero.
5. The risk-free interest rate and the asset return volatility are constant over the life of the option.
6. There are no penalties for short sales of stock.
7. The market operates continuously and the share prices follow a *continuous Ito process.*

4.2 Moneyness Measure

Moneyness is a basic term describing whether an investor would make money if the option is exercised at the current time. There are three different outcomes for the moneyness measure: in, out, or at the money. In-the-money (ITM) means one would make a profit at this moment, out-of-the-money (OTM) means one would lose a portion of his initial investment if he exercises the option right now, and at-the-money (ATM) means one would break even. In our paper, the moneyness measure is calculated as S_0 / X where S is the spot price and the X is the strike price.

5 Results

5.1 Mean Absolute Errors

The options are classified on the basis of various outcomes of moneyness measure and the option prices are calculated using BS model. The actual markets prices of call options taken from the NSE website are then compared with the respective predicted prices by the BS model and the Mean Absolute Errors thus calculated are summarized and shown in the Table 2 below.

It may be observed from the table that the Mean Absolute Errors are as high as 0.53 for the deep out-of-the-money options having moneyness between 0.80-0.92. Then it starts to decrease at a faster rate. For moneyness between of 0.93-0.95, it decreases by about 17% to 0.43, and for the next classification of 0.96-0.98, it further falls by 23% to 0.33. Then, Mean Absolute Errors reduce by 24%, 32%, 23% and 7% for next four moneyness classifications. At the end, it is almost flat.

Table 2: Mean Absolute Errors of Options with Various Moneyness Measures

Moneyness S_o / X	No. Of data	Total Observed Price	Total Absolute Error	Mean Absolute Error
< 0.83	187	4,130	1,635	0.40
0.84-0.86	370	7,265	3,720	0.51
0.87-0.89	1,005	17,501	9,349	0.53
0.90-0.92	3,163	54,356	28,077	0.52
0.93-0.95	8,671	155,569	66,442	0.43
0.96-0.98	17,112	383,157	127,623	0.33
0.99-1.01	21,984	624,996	154,049	0.25
1.02-1.04	17,643	660,766	114,602	0.17
1.05-1.07	11,191	542,341	70,111	0.13
1.08-1.10	6,550	378,344	45,151	0.12
1.11-1.13	3,854	251,920	26,870	0.11
1.14-1.16	2,328	164,207	16,709	0.10
1.17-1.19	1,383	101,157	11,043	0.11
> 1.20	515	62,963	7,688	0.12

The time to expiration was then divided into three categories; life less than or equal to 30 days, life between 31 days to 60 days, and life greater than 61 days. The respective mean absolute errors for the three categories are given below in Table 3. Around 78.01% of options had life less than or equal to 30 days, options with life between 31 days to 60 days were 21.77 %, and options with life more than 61 days were 0.22%.

Table 3: Mean Absolute Errors for Various Lives of Options

Moneyness S_o / X	All Data	≤ 30 Days	31 - 60 Days	> 61 Days
0.84 -0.86	0.51	0.61	0.44	0.54
0.87 -0.89	0.53	0.63	0.43	0.28
0.90 -0.92	0.52	0.58	0.44	0.76
0.93 -0.95	0.43	0.46	0.38	0.42
0.96 -0.98	0.33	0.35	0.30	0.47
0.99 -1.01	0.25	0.25	0.24	0.28
1.02 -1.04	0.17	0.17	0.20	0.18
1.05 -1.07	0.13	0.12	0.16	0.11
1.08 -1.10	0.12	0.12	0.13	0.10
1.11 -1.13	0.11	0.10	0.13	0.06
1.14 -1.16	0.10	0.10	0.10	0.18
1.17 -1.19	0.11	0.11	0.12	Nil

5.2 Residual Analysis

Residuals are calculated as the differences between the observed call option prices and the prices predicted by BS model. Residual analysis is an important tool to test for model adequacy and to identify any model specification errors; such as omission of an important variable, or incorrect functional form etc. The distribution of residuals is exhibited in the Figure 1 below.

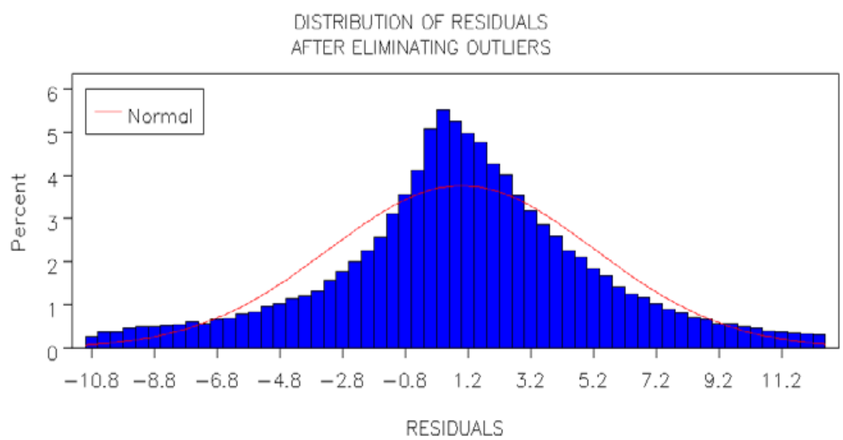


Figure 1: Residual Analysis

As can be seen above, the distribution of the residuals is almost normal but exactly not normal. This is further confirmed from the statistics in Table 4 and 5 below. This indicates that the model may be mis-specified and present opportunities for improvement.

Table 4: Comparison of Mean-based Statistics

Statistics	Full Data	Without outliers
Mean	-0.071	1
Median	0.87	0.99
Mode	0.53	0.47
Standard Deviation	16.915	4.25
Skewness	-2.74	-0.11
Kurtosis	193.77	0.42
Pearson's Skewness	-0.1668	0.007

Table 5: Comparison of Order-based Statistics

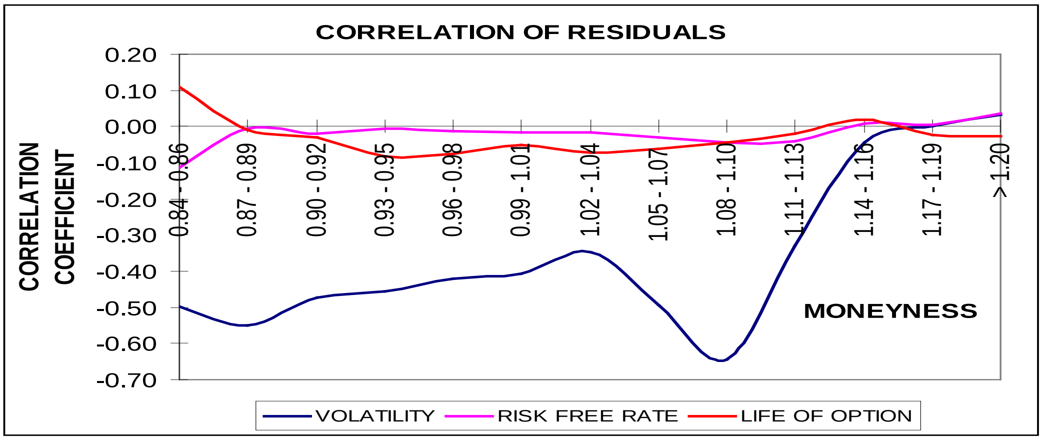
Statistics	Full Data	Without outliers
Q1	-2.08	-1.19
Median	0.87	0.99
Q3	3.79	3.43
Bowley's Skewness	-0.005	0.056

In order to improve the robustness of the model, a correlation matrix with the coefficients of correlation of the variables with the residuals was constructed in Table 6 below.

Table 6: Coefficient of Correlation of Residuals with Variables

MONEYNESS S_0 / X	COEFFICIENT OF CORRELATION		
	Volatility	Life of Option	Risk - free - interest rate
0.84 - 0.86	-0.497	0.111	-0.113
0.87 - 0.89	-0.550	-0.009	-0.004
0.90 - 0.92	-0.474	-0.031	-0.019
0.93 - 0.95	-0.455	-0.084	-0.005
0.96 - 0.98	-0.420	-0.075	-0.012
0.99 - 1.01	-0.408	-0.051	-0.017
1.02 - 1.04	-0.347	-0.073	-0.016
1.05 - 1.07	-0.493	-0.063	-0.031
1.08 - 1.10	-0.643	-0.046	-0.044
1.11 - 1.13	-0.330	-0.019	-0.042
1.14 - 1.16	-0.045	0.020	0.009
1.17 - 1.19	-0.001	-0.024	0.006
> 1.20	0.034	-0.027	0.034

Figure 2: Correlation of Residuals with the Variables and Parameters



The above table and figure clearly indicate that the residuals are more correlated with volatility than any other variable. Hence, the misspecification of the model may be a function of volatility and not in others.

5.3 Results Incorporating Mean Implied Volatility

There have been many attempts to improve the BS model, especially, on the volatility front such as the Jump - Diffusion / Pure Jump models of Bates (1991), Madan and Chang (1996), and Merton (1976); the Constant Elasticity of Variance model of Cox and Ross (1976); the Markovian models of Rubinstein (1994); the Stochastic Volatility models of Heston (1993), Hull and White (1987a), Melino and Turnbull (1990, 1995), Scott (1987), Stein and Stein (1991), and Wiggins (1987); the Stochastic Volatility and StochasticInterest rate models of Amin and Ng (1993), Baily and Stulz (1989), Bakshi and Chen (1997a,b), and Scott (1997). However, none of these models were effective. Bjorn Eraker (2004) compared the Stochastic Volatility (SV) model,Stochastic Volatility with Jump (SVJ) model, Stochastic Volatility with Correlated Jumps (SVCJ) model, and Stochastic Volatility with State-dependent Correlated Jumps (SVSCJ) model with BS model. He concluded that there were no significant improvements in the errors by the new models. Also none of the above models were parsimonious when compared to the BS model. Hence,we decided to use just the BS model and attempt to improve its predictive ability. We replaced historical volatility with Mean Implied Volatility (MIV).

Implied volatility may be defined as the volatility for which the BS model price and the actual market price of the option are equal while all the other four variables are kept constant. In other words, implied volatility is the volatility calculated using the actual call option price and other variablessuch as Risk-free-interest rate, Stock Price, Strike Price and life of the option in the BS formula. Implied volatility is calculated using a trial and error approach.One has to apply an approximate value for volatility, keeping other variables constant, and then calculate the theoretical call option price using BS formula. Then, compare the same with the corresponding actual observed call option price in the market. If the values are not equal, then change the value of volatility and re-calculate the theoretical call option price and compare it again with actual call option price. The process has to be repeated till the calculated price is equal to the actual market price.Using these iterations, implied volatility of options with different strike prices for every day was calculated. There are as many implied volatilities as the number of strikes traded per day for each stock, and for every expiration date.In some cases, it was impossible to find the implied volatility. In those circumstances, the corresponding options were eliminated from the sample.

In our study, the option priceswere obtained for 1716 working days for the 28 samplecompanies, and for each working day there were many options with different strikes and different expirations. More than 500,000 implied volatilities were then calculated. Again, for each day, the averages of the above implied volatilities, ranging from 0.80 to 1.20,were calculated for 28 companies totaling 48,048 averages; which are called the Mean Implied Volatilities (MIV).Then, these MIV values for each company, and for each day, are fed into the actual BS formula along with respective risk-free interest rate, life of option, stock price, and corresponding strike price, to find the next day call option prices. Then, new mean absolute errors were calculated.They were then compared with the errors of actual BS call option prices using Historical Volatility as advocated by the original BS model. If the absolute values of the new errors are less than the corresponding original errors, then it wasconcluded that MIV improved the predictive ability of the model.

The MIV were calculated and used in the BS model to predict the new call option prices for all moneyness measures. The total observed call option prices in the market for each moneyness measure, and the corresponding mean absolute errors, theratios for the improved method and old method are given in the Table 7 below. The results above are exemplary; out of 95,956 options, the errors were reduced in 61,635 of options. The improvement percentage is 64.23%. The errors were reduced as much as 73.24% for options with moneynessmeasure of 0.84-0.86. The minimum improvement was 62.92% for moneyness measure of 1.02-1.04. The average improvement was 66.59%. Improvements were noticed in all moneynessmeasure including deep ITM and deep OTM options.

Table 7: Results Incorporating Mean Implied Volatility

Moneyness S_0 / X		Total Actual Price	Absolute Errors				Improvement	
			Historical Volatility		Mean Implied Volatility			
			No.	Ratio	No.	Ratio	No.	%
Deep OTM	0.84 - 0.86	7,265	3,720	0.51	2,375	0.33	271	73.24
Deep OTM	0.87 - 0.89	17,501	9,349	0.53	5,954	0.34	732	72.84
Deep OTM	0.90 - 0.92	54,356	28,077	0.52	17,879	0.33	2,238	70.76
OTM	0.93 - 0.95	155,569	66,442	0.43	45,901	0.30	5,911	68.17
OTM	0.96 - 0.98	383,157	127,623	0.33	87,893	0.23	11,192	65.40
ATM	0.99 - 1.01	624,996	154,049	0.25	109,584	0.18	14,022	63.78
ITM	1.02 - 1.04	660,766	114,602	0.17	82,269	0.12	11,101	62.92
ITM	1.05 - 1.07	542,341	70,111	0.13	53,595	0.10	7,076	63.23
Deep ITM	1.08 - 1.10	378,344	45,151	0.12	33,641	0.09	4,201	64.14
Deep ITM	1.11 - 1.13	251,920	26,870	0.11	22,652	0.09	2,489	64.58
Deep ITM	1.14 - 1.16	164,207	16,709	0.10	15,154	0.09	1,486	63.83
Deep ITM	1.17 - 1.19	101,157	11,043	0.11	10,619	0.10	916	66.23

Figure 3below provides a visual picture of the improvement in the predictive ability of the improved model.

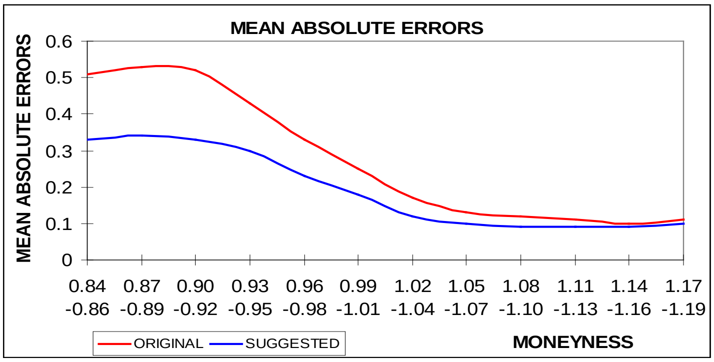


Figure 3: Comparison of Mean Absolute Errors using Original BS Model using Historical Volatility with Improved Model using Mean Implied Volatility

The improvement for different categories of lives of options is enumerated in the Table 8 and Figure 4 below.

Table 8: Improvement in Mean Absolute Errors for Different Lives of Options

S_o / X	All data			≤ 30 DAYS			31 - 60 DAYS		
	HV	I V	Imp	HV	I V	Imp	HV	I V	Imp
0.84 -0.86	0.51	0.33	0.18	0.61	0.38	0.23	0.44	0.28	0.16
0.87 -0.89	0.53	0.34	0.19	0.63	0.36	0.27	0.43	0.32	0.11
0.90 -0.92	0.52	0.33	0.19	0.58	0.32	0.26	0.44	0.34	0.10
0.93 -0.95	0.43	0.3	0.13	0.46	0.28	0.18	0.38	0.32	0.06
0.96 -0.98	0.33	0.23	0.10	0.35	0.22	0.13	0.30	0.24	0.06
0.99 -1.01	0.25	0.18	0.07	0.25	0.17	0.08	0.24	0.19	0.05
1.02 -1.04	0.17	0.12	0.05	0.17	0.12	0.05	0.20	0.15	0.05
1.05 -1.07	0.13	0.10	0.03	0.12	0.09	0.03	0.16	0.13	0.03
1.08 -1.10	0.12	0.09	0.03	0.12	0.09	0.03	0.13	0.11	0.02
1.11 -1.13	0.11	0.09	0.02	0.10	0.09	0.01	0.13	0.11	0.02
1.14 -1.16	0.10	0.09	0.01	0.10	0.09	0.01	0.10	0.09	0.01
1.17 -1.19	0.11	0.1	0.01	0.11	0.10	0.01	0.12	0.11	0.01
	AVERAGE		0.08	AVERAGE		0.11	AVERAGE		0.06

HV - Historical Volatility IV - Implied Volatility Imp - Improved

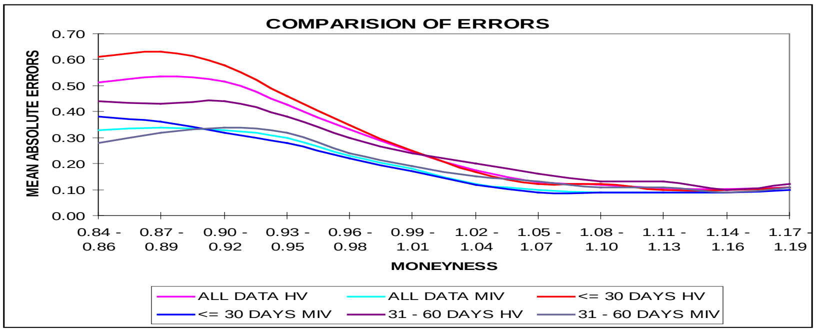


Figure 4: Comparison of Mean Absolute Errors using Historical and Mean Implied Volatility for Various Lives of Options

The improvement is higher for the options with lives less than 30 days when compared to lives between 31 to 60 days. The percentage improvement in deep out-of-the-money options is also very high when compared to options that are deep in-the-money. Let us now examine more closely on the quantum of improvement in predictive abilityof each option. The options were divided into groups having various percentages of improvement like 0 to 5%, 5 to 10 %, 10 to 20 %, etc., till 100%. The number of improvements, cumulative number of improvements, percentage of improvements in each group, and cumulative percentage of improvements in each group, are given below in the Table 9 and Figure 5.

Table 9: Percentage Improvement in Predictive Ability of Call Option Prices using Mean Implied Volatility

Percentage Improvement	**No. of Improvements**	**Cumulative Improvements**	**Percentage Improvements**	**Cumulative Percentage Improvements**
90-100	10154	10,154	10.55	10.55
80-90	8576	18,730	8.91	19.46
70-80	7498	26,228	7.79	27.24
60-70	6629	32,857	6.89	34.13
50-60	5883	38,740	6.11	40.24
40-50	5158	43,898	5.36	45.60
30-40	4745	48,643	4.93	50.53
20-30	4375	53,019	4.55	55.07
10-20	4057	57,076	4.21	59.29
5 to10	2169	59,245	2.25	61.54
0 to 5	3205	62,450	3.33	64.87

It is important to note that the quantum of improvement is not only on the higher side but also the quantity is high for the high quantum improvement. For example, 90-100% of improvement occurs for more than 10,154 options (10.55%), and 80-90% improvement occurs in 8,576 options. The percentage increase is far less at 0-5 % for only 3,205 options (3.33%). In 38,740 options out of the total sample size of 95,956 options, the percentage improvement is more than 50 %. In 26,228 cases, the improvement is more than 70%.The histogram below in Figure5 summarizes the extent of improvement using the improved model.

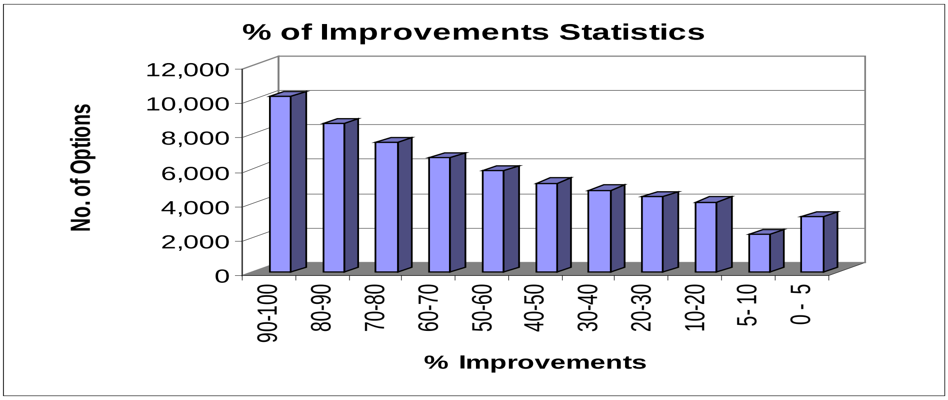


Figure 5: Percentage Improvement in Predictive Ability of the Improved Model

6 Conclusion

The BS model is robust in pricing Indian stock call options. However, the residual analysis indicated there may be some misspecification and possibilities for improvement in the predictive ability of the model. A correlation analysis suggested that the misspecification may lie with the volatility variable. The implied volatility was then incorporated into the BS model to see if there was an improvement in the predictive ability of the model. The newly constituted model improved the predictive ability for 64.23% of the call option prices. The improvements were broad based across all moneyness measures and lives of options.

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