Original Article

Violation of lower boundary condition and market efficiency: An investigation into the Indian options market

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PRACTICAL APPLICATION The findings of this research paper might be useful to all types of investors (especially institutional and High Net worth Individuals) and trading member organisations who trade in derivatives. Moreover, the findings might be useful to the stock exchanges, regulators and other concerned authorities of India and other countries where derivatives market is in developing stage.

ABSTRACT This paper examines the lower boundary conditions (LBCs) for the S&P CNX Nifty Index options in the Indian securities (options) market. In India, the option contracts on the index are European in nature, that is, they can be exercised only at

maturity. This study covers a period of 6 years, from 4 June 2001 (starting date for index options in India) to 30 June 2007. The results demonstrate that the violation of the LBC is more frequent and pronounced in the case of call options than that of put options. This implies that there are arbitrage opportunities on account of violation of the LBC and is indicative of the inefficiency of the Indian options market. In this study, the results have been interpreted considering the problems of nonsimultaneity, dividends, bid – ask spread, and transactions cost; that is, we have tried to adhere to the real conditions prevailing in the market in order to enhance the authenticity of the findings. Although the test conducted is *ex-post* in nature, it does not essentially comment on the exploitability of abnormal profits suggested by mispricing (underpricing) signals. The results of the study that the options market is inefficient are more suggestive and indicative in nature than conclusive.

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INTRODUCTION

The efficiency of options markets is of great importance to academicians as well as practitioners. Well-functioning financial markets are vital to a thriving economy, as these markets facilitate price discovery, risk hedging and the allocation of capital to its most productive uses. The inefficiency of a financial market (for example, an options market) indicates that it is not performing the functions mentioned above in the best manner possible.¹

In this paper, the efficiency of the Indian index options market has been investigated by applying *ex-post* analysis to daily closing observations of call and put options. The efficiency of the market, in this regard, connotes pricing efficiency. The LBC for the option prices (as specified in the literature) has been used as a tool to gauge the efficiency of the options market in India. The violation of the LBC implies that the options are underpriced and, therefore, indicates the arbitrage opportunities.

The method applied to test the efficiency of the options market is in line with other studies conducted in different markets for the same purpose. The test procedure has taken care of the dividends expected from the underlying asset during the life of the options. Although the analysis has been conducted ignoring the transaction costs and bid–ask spread, the results have been interpreted cautiously. The bid–ask spread plays a very important role in assessing the options market efficiency, as it results in significant transaction cost.^{2,3}

The violations or mispricing signals observed from the test procedures have been further classified as per time-to-maturity and liquidity thereof in order to draw some meaningful results from such violations. This classification facilitates a meaningful explanation of the exploitability of such violation, which is very crucial in assessing the efficiency of the market. This has been carried out in view of the fact that the mere presence of violations does not indicate market inefficiency; it is the exploitability and

persistence of such violations that poses serious threat to the market efficiency.

The rest of the paper is divided into four main sections. The next section discusses the LBC that has been tested for option contracts. This section is divided into two subsections, namely, the LBC and the testable hypotheses thereof. The data are discussed in the subsequent section. The further section presents analysis and results. The paper ends with the concluding observations in the last section.

LOWER BOUNDARY OF OPTION PRICES FOR INDEX OPTIONS AND MARKET EFFICIENCY

The lower boundary condition

The LBC, first proposed by Merton⁴ and further extended by Galai,⁵ assumes a major role in assessing options market efficiency. To date, a number of research studies have been carried out in different options markets using the LBC to assess the efficiency of the markets, including the first one by Galai.⁵ The other studies that tried to diagnose options market efficiency based on the violation of the LBC include Bhattacharya,⁶ Halpern and Turnbull,⁷ Chance,⁸ Puttonen,⁹ Berg *et al.*,¹⁰ Ackert and Tian,¹¹ and Mittnik and Rieken.¹²

The LBC of option prices denotes the minimum price of the option contract at a given point of time; its violation indicates arbitrage opportunities. Therefore, the price for an option contract should necessarily be equal to or higher than that suggested by the LBC. This is a necessary (although relatively weak) condition that needs to be satisfied in order to uphold the no-arbitrage argument of option pricing to ensure the correct pricing. In the literature, the LBC has been defined for both the European

options as well as American options. Because we are analysing the *S&P CNX Nifty* Index options and these are European (which can be exercised only at maturity) in nature, the condition defined for European options constitutes the basis of the study.

The LBCs defined for the call and put options are given in equations (1) and (2) respectively; these conditions need to be satisfied in an efficient market.

$$C_t \geq \max(0, I_t - Ke^{-r(T-t)}) \quad (1)$$

$$P_t \geq \max(0, Ke^{-r(T-t)} - I_t) \quad (2)$$

In the above equations, C_t is the market price of a call option at time t , P_t is the market price of a put option at time t , I_t is the level of underlying index (*S&P CNX Nifty*) at time t , K is the strike price of the option contract, T is the expiration time of the option at the time when it was floated, r is the continuously compounded annual risk-free rate of return and $(T-t)$ is the time-to-maturity of the option at time t (measured in years).

Equations (1) and (2) describe the LBCs where the underlying asset is not expected to pay any dividends during the life of the option. Because, in general, almost all the financial assets pay dividends, equations (1) and (2) need to be modified by incorporating dividends. The treatment of dividends in the test varies based on the assumption made about the payment of dividends. Some of the studies treated it as a discrete payment¹³ and others as a continuous yield.⁸ In this study, since *S&P CNX Nifty* Index (which includes 50 scrips) based options are being analysed, it would be difficult to test the LBC, assuming discrete dividends. Therefore, following Chance,⁸ it has been assumed that dividends are paid as continuously

compounded yield. The LBC equations for call and put options, assuming that the index is paying continuously compounded annual dividend yield (δ), are given in equations (3) and (4) respectively.

$$C_t \geq \max\{0, (e^{-\delta(T-t)} I_t - Ke^{-r(T-t)})\} \quad (3)$$

$$P_t \geq \max\{0, (Ke^{-r(T-t)} - e^{-\delta(T-t)} I_t)\} \quad (4)$$

The testable form of equations (3) and (4), which has been used in this study to assess the efficiency of the options market, is given in the next subsection.

Testable form of the LBC

Equations (3) and (4) given above need to be rearranged in order to make them testable to gauge the efficiency of the options market. The testable form, to test the efficient market hypothesis in terms of the LBC, is given in equations (5) and (6) for call and put options respectively.

$$\varepsilon_t^c = \{(e^{-\delta(T-t)} I_t - Ke^{-r(T-t)}) - C_t\} \quad (5)$$

$$\varepsilon_t^p = \{(Ke^{-r(T-t)} - e^{-\delta(T-t)} I_t) - P_t\} \quad (6)$$

In the above equations, ε_t^c and ε_t^p are the absolute amount of abnormal profits (*ex-post*) or mispricing signals from call and put options respectively, if violation of the LBC takes place. A violation of the LBC is recorded if $\varepsilon_t^c > 0$ and $\varepsilon_t^p > 0$ for call and put options respectively. Although the presence of such profits is only indicative of market inefficiency, it should not be treated as a conclusive remark on the efficiency of the market, as the test procedure applied is *ex-post* in nature.

Equations (5) and (6) have been specified assuming no transaction costs and zero or

negligible bid–ask spread. It may be noted that there is always a chance that the arbitrage opportunities suggested by these equations may disappear in the presence of transaction costs and the bid–ask spread. Given the fact that the bid–ask spread for options is not included in the transaction database provided by National Stock Exchange (NSE), the bid–ask spread for the Nifty Index is difficult to estimate and is therefore excluded in the above equations. In operational terms, our study is in line with that of Halpern and Turnbull.⁷

Commenting upon the exploitability of observed mispricing signals, Trippi¹⁴ and Chiras and Manaster,¹⁵ using closing prices in their studies, concluded that the observed signals were exploitable using a specified trading strategy. In this study, however, no strategy has been specified to ensure the exploitability of abnormal profits suggested by mispricing signals, as the test procedure applied is *ex-post* in nature.

DATA

The data considered for the analysis can be broadly classified into three categories, namely, data related to option contracts, data related to the underlying asset (that is, the main index of the NSE, formally known as the S&P CNX Nifty Index) and data on the risk-free rate of return. The data on the options consist of daily closing prices of options, strike prices, deal dates, maturity dates and number of contracts of call and put options respectively. In order to minimise the bias associated with *nonsynchronous trading*,¹⁶ only liquid option quotations (that is, contracts that have at least one contract traded) are considered for the analysis. The second data set pertains to the underlying asset, which includes the daily closing value of S&P CNX

Nifty Index and the dividend yield on it. The third data set consists of monthly average yield on 91-day Treasury-bills. The data on T-bills have been converted into a continuously compounded annual rate of return.

The data for these three categories were collected between 4 June 2001 (the starting date for index options in the Indian securities market) and 30 June 2007. The first and second data sets have been collected from the website of NSE and Centre for Monitoring Indian Economy database Prowess, and the third data set has been collected from the website of Reserve Bank of India.

ANALYSIS AND EMPIRICAL RESULTS

The *ex-post* analysis of the call and put options has been carried out on the basis of equations (5) and (6) for 6-year period from June 2001 to June 2007. The condition has been tested for 40 298 and 35 171 daily liquid quotes for call and put options respectively. As reported in Table 1, a total of 7019 and 1544 mispricing signals (that is, the value of ε_t^c and ε_t^p turn out to be positive) were found in the case of call and put options respectively. The analysis clearly reveals that the frequency of violations (mispricing signals) is significantly higher for the call options (about 17.42 per cent of the total observation analysed) than for the put options (about 4.39 per cent of the total observation analysed).

In the case of call options, more severe and frequent violations are observed, as the transaction cost, where an arbitrageur needs to short (sell the asset without actually having it) the underlying asset, is expected to be higher. This explanation is further validated in the case of the Indian options market owing to the

restrictions on shorting financial assets (securities) and the lack of proper security borrowing and lending mechanisms required to exploit arbitrage opportunities in call options. Empirically, it has been observed that exploiting mispricing signals for call options is more difficult than for put options on account of the higher transaction cost.¹²

In order to draw an international comparison, the frequency of violations can be compared with those found in some international studies, particularly those of Galai⁵ and Bhattacharya.⁶ These studies of Galai⁵ and Bhattacharya⁶ were based on call options traded on the Chicago Board Option Exchange, USA, and thus facilitate comparison of a developing economy with its developed counterpart. In the case of call options, the percentage of violations was merely 2.95 per cent⁵ and 2.38 per cent⁶ as compared to 17.42 per cent in this study. The finding clearly suggests that, in the Indian options market, the call options seem to be more incorrectly priced (underpriced) compared to its developed counterpart.

Another significant observation made in this study is that the majority of the violations, that is, 76 and 83 per cent in the case of call and put options respectively (as shown in Table 1 and Figures 1 and 2) belong to thinly traded options. This finding clearly indicates that the majority of the mispricing signals cannot be exploited owing to high bid-ask spread and a dearth of liquidity for such (thinly traded) options.

Approximately 8 per cent of the mispricing signals (as shown in Table 1 and Figure 1) belong to the highly liquid category, which constitutes only about 1.39 per cent (0.08×0.1742) of the total observations. It is this small fraction that seems to be reasonably exploitable due to the fact that the bid-ask spread is expected to be

Table 1: Violations of the lower boundary condition and liquidity levels (number of observations)

<i>Particulars</i>	<i>Call options</i>	<i>Put options</i>
Total number of observations analysed	40 298	35 171
Total number of violations observed	7019 (17.42%)	1544 (4.39%)
<i>Violations relating to the three specified levels of liquidity</i>		
(a) Thinly traded options ^a	5327 (75.89%)	1290 (83.55%)
(b) Moderately traded options ^b	1097 (15.63%)	167 (10.82%)
(c) Highly traded options ^c	595 (8.48%)	87 (5.63%)
Total	7019 (100%)	1544 (100%)

^aOptions, which have less than 100 contracts traded per day.

^bOptions, which have more than 100 but less than 500 contracts traded per day.

^cOptions, which have more than 500 contracts traded per day.

Figure 1: Violation of LBC and liquidity for call options.

negligible for such options. In contrast, in the case of put options, approximately 6 per cent of the mispricing signals (as shown in Table 1 and Figure 2) belong to the highly liquid category,

and, therefore, only 0.26 per cent (0.06×0.0439) of the total observations seem to be reasonably exploitable. This is very low compared to call options.

In addition to the above findings, the violations have been classified as per the maturity of the option contracts. The results are summarised in Table 2. For both the call and put options, the majority of violations are concentrated around the maturity levels of 0–7 and 8–30 days; about 85 and 93 per cent of the total violation for call and put options respectively fall into this category. Whereas for the call options the majority of the violations are clustered around 8–30 days to maturity, in the case of the put options, the majority of the violations had 0–7 days to maturity. The clustering of violations is quite similar to that reported by Bhattacharya,⁶ where 42 per cent of the total violations had 1 week or less to maturity.

Figure 2: Violation of LBC and liquidity for put options.

Table 2: Violations of lower boundary condition and maturity of option contracts (number of observations)

Maturity (in days)	Violations			
	Call options		Put options	
	Numbers	Percentage	Numbers	Percentage
0–7	2025	28.85	988	63.99
8–30	4000	56.99	450	29.14
31–60	926	13.19	98	6.35
61–90	68	0.97	8	0.52
Total	7019	100	1544	100

To better comprehend the clustering and exploitability of the violations, cross-tabulation across specified levels of maturity and liquidity have been provided in Tables 3 and 4 for the call and put options respectively.

Table 3: Violations of lower boundary condition for the call options cross-tabulated across specified levels of maturity and liquidity (number of observations)

	Maturity			
	0–7	8–30	31–60	61–90
	days	days	days	days
<i>Liquidity</i>				
Thinly traded	1416	3055	788	68
Moderately traded	336	651	110	0
Highly traded	273	294	28	0
Total	2025	4000	926	68

Table 4: Violations of lower boundary condition for the put options cross-tabulated across specified levels of maturity and liquidity (number of observations)

	Maturity			
	0–7	8–30	31–60	61–90
	days	days	days	days
<i>Liquidity</i>				
Thinly traded	779	409	94	8
Moderately traded	129	35	3	0
Highly traded	80	6	1	0
Total	988	450	98	8

In a relatively less liquid market, the time-to-expiration assumes significance for assessing the exploitability of abnormal profits suggested by mispricing signals. In the Indian market, the mispricing signals might be concentrated around

0–7 days to maturity (especially for the put options) in view of the fact that in a less liquid market, if one takes a position to exploit an opportunity suggested by mispricing signals, there are relatively fewer chances that one would successfully wind up one's position owing to fewer days to maturity and a dearth of liquidity for such options (as shown in Tables 3 and 4). Therefore, the violations with 0–7 days to maturity are less exploitable in the case of put options, as 78.85 per cent of these options fall in the thinly traded category, versus call options where this percentage is 69.93. Similarly, the violations with 8–30 days to maturity depict the same trend, as 90.88 per cent of these options fall in the thinly traded category, versus 76.38 per cent in the case of call options.

The above finding, along with the majority clustering of the call options in 8–30 days to maturity, suggests that the violations in the case of call options seem to be more exploitable than those of put options. The exploitability of violations in the case of call options is, however, subject to higher transaction cost, as reported by Mittnik and Rieken.¹²

In order to gain better insights into the magnitude of the violations, the absolute amount of the violations expressed in rupees has been analysed with respect to time-to-maturity and different specified levels of liquidity. The descriptive statistical properties of the absolute amount of violations have been calculated separately, namely, maturity-wise and liquidity-wise. The descriptive statistics are given in Tables 5 and 6.

The mean absolute amount of the violations across different specified levels of liquidity has been given in Table 5. It shows a decreasing trend, as the liquidity increases in the case of call as well as put options. This gives a very meaningful insight into the exploitability of the observed abnormal profits suggested by mispricing signals. The result shows a very interesting finding: the abnormal profits in the case of moderately and highly traded options (where the violations may be exploited because bid–ask spread is assumed to be low for such options) might disappear in the presence of transaction cost as the magnitude of absolute amount of violations seems to be significantly lower than that of thinly traded options.

Table 5: Descriptive statistics of the absolute amount of the violations across the three specified levels of liquidity (figures in rupee per contract)

<i>Liquidity</i>	<i>Mean</i>		<i>Standard deviation</i>		<i>Minimum</i>		<i>Maximum</i>	
	<i>Call</i>	<i>Put</i>	<i>Call</i>	<i>Put</i>	<i>Call</i>	<i>Put</i>	<i>Call</i>	<i>Put</i>
Thinly traded	955.80	994.11	1985.70	2332.55	0.03	0.23	32987.27	32647.46
Moderately traded	456.17	566.16	456.16	1867.90	0.25	4.03	4966.10	16895.58
Highly traded	378.89	289.01	375.50	283.80	1.15	2.50	2113.22	1455.00
Total	828.80	908.09	1757.24	2229.15	0.03	0.23	32987.27	32647.46

Table 6: Descriptive statistics of the absolute amount of the violations across the four specified levels of maturity (figures in rupee per contract)

<i>Maturity(in days)</i>	<i>Mean</i>		<i>Standard deviation</i>		<i>Minimum</i>		<i>Maximum</i>	
	<i>Call</i>	<i>Put</i>	<i>Call</i>	<i>Put</i>	<i>Call</i>	<i>Put</i>	<i>Call</i>	<i>Put</i>
0–7	836.17	772.85	2016.06	1895.65	0.09	0.23	26534.86	20 855
8–30	777.36	1175.85	1472.22	2808.01	0.03	1.65	32275.71	34647.46
31–60	980.59	935.16	2162.76	2151.28	0.46	1.67	32987.27	19566.03
61–90	1568.52	2217.05	2383.92	3068.48	23.50	116.36	11784.15	9484.34
Total	828.80	908.09	1757.24	2229.15	0.03	0.23	32987.27	32647.46

Table 7a: ANOVA table for the call options

<i>Variance</i>	<i>Sum of squares</i>	<i>Degree of freedom</i>	<i>Mean square</i>	<i>F</i>	<i>Significance</i>
Between groups	358673607.17	2	179336803.58	59.038 ^a	0.000
Within groups	21312166370.66	7016	3037651.99		

^aIndicate statistical significance at the 5 per cent level. All *t*-tests are two-tailed tests.

Table 7b: Tukey's HSD statistics for the multiple comparisons among the three specified levels of liquidity for the call options

	<i>(I) Liquidity</i>	<i>(J) Liquidity</i>	<i>Mean difference (I–J)</i>	<i>Standard error</i>	<i>Significance</i>
Tukey's HSD	Thin	Moderate	499.623 ^a	57.786	0.000
		High	576.907 ^a	75.336	0.000
	Moderate	Thin	–499.623 ^a	57.786	0.000
		High	77.283	88.737	0.659
	High	Thin	–576.907 ^a	75.336	0.000
		Moderate	–77.283	88.737	0.659

^aIndicate statistical significance at the 5 per cent level. All *t*-tests are two-tailed tests.

On the contrary, although the mean absolute amount of the violations is quite high for the thinly traded options, they might not be exploitable because of the higher bid–ask spread.

In addition to this, the mean absolute amount of the violations has been further classified as per the specified levels of time-to-expiration/maturity. The results are summarised in Table 6.

Table 8a: ANOVA table for the put options

<i>Variance</i>	<i>Sum of squares</i>	<i>Degree of freedom</i>	<i>Mean square</i>	<i>F</i>	<i>Significance</i>
Between groups	62413167.933	2	31206583.966	6.323 ^a	0.002
Within groups	7604890939.029	1541	4935036.300		

^aIndicate statistical significance at the 5 per cent level. All *t*-tests are two-tailed tests.

Table 8b: Tukey's HSD statistics for the multiple comparisons among the three specified levels of liquidity for the put options

	<i>(I) Liquidity</i>	<i>(J) Liquidity</i>	<i>Mean difference (I–J)</i>	<i>Standard error</i>	<i>Significance</i>
Tukey's HSD test	Thin	Moderate	427.944	182.692	0.050
		High	705.099 ^a	246.069	0.012
	Moderate	Thin	–427.944	182.692	0.050
		High	277.154	293.727	0.613
	High	Thin	–705.099 ^a	246.069	0.012
		Moderate	–277.154	293.727	0.613

^aIndicate statistical significance at the 5 per cent level. All *t*-tests are two-tailed tests.

We could not, however, draw a pattern of mean absolute amount of violations across different specified levels of maturity, unlike its decreasing trend *vis-à-vis* different specified levels of liquidity.

Following the descriptive statistics of the absolute amount/magnitude of violations, further analysis has been carried out to ascertain whether there exists a difference across the three levels of liquidity as specified in Table 1. This has been implemented by applying a well-known statistical technique: one-way analysis of variance (ANOVA). This statistical test has facilitated analysis of the behaviour of the absolute amount of the violations *vis-à-vis* different specified levels of liquidity. The analysis provides better insights into the exploitability of

abnormal profits indicated by the observed mispricing signals. The results of ANOVA are summarised in Tables 7(a) and (b) and 8(a) and (b) for call options and put options respectively.

The analysis of differences for specified levels of liquidity and further diagnosis of the significant differences between constituents of all possible pairs (for example, thinly traded and moderately traded, thinly traded and highly traded, and so on), which has been carried out using ANOVA and Tukey's honestly significant difference (HSD) statistics respectively, is summarised in Tables 7(a) and (b) and 8(a) and (b). The results clearly indicate that the difference among the three specified levels is significant at 5 per cent level of confidence for both call and put options.

The post-ANOVA diagnosis (that is, Tukey's HSD test) shows that the absolute amount of violations for the thinly traded call options is significantly different from those for the moderately traded and highly traded call options. In the case of put options, however, the absolute amount of violations for the thinly traded options is significantly different from that for the highly traded options, but not from that for the moderately traded options. This finding and those given in Tables 5 and 6 show that the majority of the violations of moderately traded call options are more consistent (as their standard error of mean is lower than in the case of put options) and are thus more consistently exploitable compared to those in the case of put options.

CONCLUDING OBSERVATIONS

This study reveals that violations of the LBC are more frequent in the Indian options market than those observed in the US market during the developing stage of the options market. In the Indian options market, the put options seem to be more correctly priced compared to call options, as we have found significantly fewer violations in the former. Another fact that indicates relatively less inefficiency in the case of put options is the lower exploitability of violations. This is because the majority of the violations had 0–7 days to maturity and only about 0.26 per cent seem to be exploitable even in the presence of bid–ask spread *vis-à-vis* call options where the majority of the violations had 8–31 days to maturity and about 1.39 per cent seem to be exploitable. This suggests that call options are relatively more underpriced compared to put options. The finding that the options are underpriced is consistent with that in

the study by Varma.¹⁷ This study indicates that the call options market is more inefficient compared to the put options market.

Because the mispricing signals or violations have been arrived at without considering the transaction costs that might be a potential source of error, as suggested by Phillips and Smith³ and Bhattacharya,⁶ the results need to be interpreted cautiously. Although the magnitude of violation is very high, the transaction cost needs to be gauged while interpreting the results.

The violation of the LBC indicates that the options are underpriced. This could entail a major stumbling block for the market-makers, which are instrumental in the development of nascent markets such as India. In another study on the Indian options market, Dixit *et al.*,¹⁸ commenting upon pricing inefficiency, conclude that it might have very serious implications for an emerging derivatives market such as India. The two notable implications in this regard are as follows: (1) if the price formation in the options market is not in line with the sound principles of option pricing, it might not be helpful for price discovery in the underlying market and (2) it might also hamper the overall hedging efficiency of the market because the advanced dynamic hedging techniques such as delta hedging might turn out to be ineffective.

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