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Box Spread Arbitrage Efficiency of NIFTY Index Options: The Indian Evidence

Abstract

We examine the market efficiency for the European style Nifty index options, using the box spread strategy. Time-stamped transactions data are used to identify the mispricing and arbitrage opportunities for options with this model-free approach. Profit opportunities, after accounting for the transaction costs, are quite frequent, but do not persist even for two minutes. The mispricing is higher for the contracts with higher liquidity (immediacy) risk captured by the moneyness (the difference between the strike prices and spot price) and the volatility of the underlying.

Keywords: Options, Box Spread, Arbitrage, Mispricing, Moneyness, Volatility

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1. Introduction

The box spread strategy provides a model-free method for testing the efficiency of options markets. The strategy involves only the options and risk-free assets and therefore, can test the efficiency of pricing of options even when the underlying asset is not traded. Box spreads use two pairs of European put and call options, having the same underlying and expiration dates. The put and call options of one pair have the (equal) strike prices (X_H) that are higher than the (equal) strike prices of the put and call options of the other pair (X_L). These two pairs together form a synthetic bond with a known payment ($X_H - X_L$) on expiration. If the market is efficient, then the return implicit in the synthetic bond would be the same as the yield on a risk-free asset of identical maturity. If the two returns are different, then they provide an arbitrage opportunity between the synthetic bond and the risk-free asset.

Despite the direct applicability of the box spread strategy to the testing of efficiency of options markets, the research in this area has been rather limited. The reason probably is the difficulty faced in obtaining the high-frequency data and identifying a sufficient number of temporally close option contracts. Billingsley and Chance (1985) and Chance (1987) confirm the price parity for box spreads. However, being based on the daily closing prices, both these works suffer from a possible non-synchronicity of prices. Ronn and Ronn (1989) find some small profit opportunities for the agents having low transaction costs and quick execution ability. Marchand, Lindley and Followill (1994) find a negative average gain from box spreads. Blomeyer and Boyd (1995), for the options on Treasury bond futures, find a small number of *ex post* arbitrage opportunities. All these studies use American options that may be exercised early. Hemler and Miller (1997) find significant arbitrage opportunities for S&P 500 European options post-crash. Ackert and Tian (2001) find frequent violations of the 'no-arbitrage' condition for box spreads. Bharadwaj and Wiggins (2001) find only a few low-profit arbitrage opportunities. Fung, Mok and Wong (2004), using the time-stamped bid-ask quotes and transaction data, find very few arbitrage opportunities, confirming the efficiency of Hong Kong options market. Benzion, Danan, and Yagil (2005) make box spreads using a real-time computer program. They find relatively small-gain arbitrage opportunities that vanish quickly, and support the efficiency of the Israeli options market.

The results of the studies on market efficiency, based on box spreads, are mixed. Moreover, many of them suffer from methodological weaknesses, like the use of American options and non-synchronous closing prices. Among the referred works, only those of Hemler and Miller (1997), Fung, Mok and Wong (2004), and Benzion, Danan, and Yagil (2005) are free from such weaknesses. Other than the US market, only the Israeli and Hong Kong markets have been studied. The present study extends the literature by examining the efficiency of the emerging Indian market. The Index and stock Options were introduced to the Indian market only about six months before the start of the study period, and therefore, are not adequately researched. Among the existing studies, only Fung, Mok and Wong (2004) have studied a market as young as 6-30 months. The Indian market is an open limit-order-book market, which is different from the quote-driven markets that are covered by the existing studies. The microstructure of such markets is expected to be different, because there is no bid-ask spread introduced by the market-makers. In addition, a number of other factors also facilitate the efficiency of pricing of index options in this market. First, the index options are European, which makes the arbitrages based on put-call parity, box spreads and other spreads more efficient by obviating an early exercise. The low brokerage and margin deposit requirements at the Indian exchanges also help. Second, the computerized trading of options and futures (in one segment) and the underlying shares (in another segment) in the same exchange, makes the derivatives and cash trading systems better integrated. It allows the traders to identify (through computer programs) and execute arbitrage opportunities with greater ease and speed, and lower transaction costs. Third, the order-driven trading mechanism and cash settlement of derivatives reduce the transaction costs for arbitrageurs. However, the ban on short sales in the cash market impedes the efficiency. It may cause an overpricing of put contracts owing to inefficient hedging (refer to Ofek, Richardson and Whitelaw, 2004; Bharadwaj and Wiggins, 2001). Overall, the factors favoring higher efficiency for the Indian market appear to overweigh those against it. The time-stamped transactions data for Nifty options, for a period of two years, are used to obviate non-synchronicity. The large sample size makes the results more reliable.[1] The investigation of the effects of moneyness, volatility and persistence on box-spread mispricing adds new dimensions to the understanding of this phenomenon. Despite the facilitating factors that should make the Indian market more efficient, we observe frequent instances of mispricing that provide arbitrage opportunities after accounting for the transaction costs. The mispricing persists for less than two minutes indicating only a limited inefficiency. The magnitude of mispricing is higher for the options that are farther from the money, and also during the periods of higher volatility.

The remaining article is organized as follows. The structure of box spreads is detailed in Section 2. The Indian derivatives and cash markets are introduced to provide the context of

[1] Among the studies using European options and synchronous data, the sample size of this study is probably the largest. Benzion, Danan, and Yagil (2005) identify 4,505 profitable box spreads. Fung, Mok and Wong (2004) construct 5,783 box spreads. Hemler and Miller (1997), using 38,000 quotations, identify about 2,700 profitable box spreads. As against these, the present study uses a sample of 380,120 put and 540,963 call quotations, constructs 211,838 box spreads, and identifies 15,376 to 32,930 profitable box spreads.

the study in Section 3. The sources of data, and the nature and magnitude of transaction costs prevalent in the Indian market, are detailed in Section 4. The methods adopted for identifying the mispricing in option contracts, its patterns and arbitrage opportunities, are described in Section 5. The findings are reported in Section 6, and Section 7 concludes the article.

2. Structure of box spreads

A box spread is constructed with two European calls and two European puts, all having the same underlying and the same expiration date. Out of these, one pair of put and call has a lower strike price (X_L) and the other has a higher strike price (X_H). A long position in a box spread is set up as follows:

a. Long a call option having the strike price X_L at a premium C_L
b. Short a put option having the strike price X_L at a premium P_L
c. Short a call option having the strike price X_H at a premium C_H
d. Long a put option having the strike price X_H at a premium P_H

A long box spread always requires a positive initial investment ($C_L - C_H + P_H - P_L$) because of the following reasons,

- the premium on a call with a lower strike price would be more than that on a call with a higher strike price, and
- the premium on a put with a higher strike price would be more than that on a put with a lower strike price.

The long box spread provides a certain cash inflow ($X_H - X_L$) on the expiration day, as shown in Table 1. Similarly, a short position in a box spread can be created by taking the positions opposite to these. A short box spread gives an inflow of ($C_L - C_H + P_H - P_L$) at the time of inception, and requires a certain payment ($X_H - X_L$) at the time of expiration. Now, a profitable arbitrage is possible with a box spread, if the interest rate implicit in it, is different from the risk-free interest rate for the corresponding period. This is so, because both the set-up cost ($C_L - C_H + P_H - P_L$) and the final payoff ($X_H - X_L$) do not have any uncertainty. However, the arbitrage opportunities are exploitable only if the profit exceeds the transaction costs.

3. Trading in Nifty options

The Index options on S&P CNX Nifty index (Nifty) started trading in India at National Stock Exchange (NSE) in June 2001.[2] NSE accounts for 98% of the total turnover in India, of the derivative instruments having stock indexes and individual stocks as the underlying. The 'Futures and Options Segment' and 'Equity Segment' of NSE are open for trading Monday through Friday from 9:55 AM to 3:30 PM. The trading at NSE (in both Equity, and Futures and Options Segments) is done through identical, computer-based open limit-order-book systems, without market-makers or specialists. The trading of options and futures in the same market segment makes the market for these securities better integrated, than the markets having separate trading in futures and options. The risk management system, expiration dates and settlement practices for these securities are similar. Moreover, in a different segment of the same stock exchange, the equity shares are also traded with similar settlement and trading practices. Both the 'buying' and 'selling' traders enter their orders into the computer server, which are continuously automatically matched. The best 'buy' and 'sell' orders are displayed on computer screens of the trading stations in real-time. As none of the traders is a market-maker, the *ex post* price of a transaction is actually available to the traders as an *ex ante* price quotation before the transaction. Therefore, the issue of market-makers' bid-ask spread is not

[2] S&P CNX Nifty is a market value weighted equity index, comprised of 50 equity shares, covering 22 sectors of the Indian economy.

important for an arbitrage transaction at NSE, and transaction prices are used for identifying mispricing.

The computer screen-based system allows the use of computer programs for the identification of arbitrage opportunities and ensures a quick execution. The trading of options and futures in the same market segment also helps in quick identification and execution of arbitrage transactions requiring positions in options and futures with lower margin requirements. Nifty options are cash-settled European options. The Nifty options and futures are traded in monthly series, with the last Thursday of the month as the expiration date for each series. For 'in the money' option contracts, the final exercise settlement is done at the closing value of Nifty, on the last trading day of the option contract. The closing value is the weighted average Nifty value during the last half hour of trading in the Equity Segment of NSE.

During January 2002 (the first month of the sample period), NSE-traded Nifty Options had a trade volume of 662 contracts per day (notional value: Rs 150 million).[3] This number kept increasing consistently and went up to 7,094 contracts per day (notional value: Rs 2,480 million) for December 2003 (the last month of the sample period).[4] For a daily trading time of 5½ hours at NSE, these volumes ensure that the prices reflect the judgment of the market reasonably well, at different points of time. However, most of the traded contracts belong to the 'current-month' series.[5] Trading in the 'far-month' (i.e. next to next month) contracts is negligible, and that in the 'next-month' contracts picks up only about 10 days before the expiration day of the 'current-month' contracts. Prior to that, it is less than 0.2% of the total

[3] US $ 1 = Indian Rs 45 (approximately)

[4] For December 2003, the average daily turnover at the Indian stock market was Rs 75.08 billion. The corresponding notional value of the daily turnover at the derivatives market (on stocks and indexes as the underlying) was Rs 108.59 billion.

[5] Based on an analysis of three months' sample

contracts. During the last 10 days before the expiration day, the trades in the 'next-month' contracts are about 14% of the total contracts, ranging between 1 and 40% (the expiration day of the 'current-month' contracts accounting for the highest trades in the 'next-month' contracts). The proportion of 'next-month' contracts is higher for the call options than that for the put options. The trades in the call options are generally more than those in the put options; with the call to put trades ratio being 60:40. In terms of moneyness, most of the contracts have their strike prices within a 10% band around the spot price.[6] About 94% of the contracts have their strike prices falling within 95 – 105% value of the spot price, and the balance 6% have these falling within 90 – 95% or 105 – 110%. The number of contracts beyond these ranges is negligible (0.1%).

4. Data and transaction costs

4.1 *Sources*

The high-frequency data on put and call options written on Nifty are used for the study. The time-stamped transaction price data on Nifty options are provided by NSE for the period from January 1, 2002 to December 31, 2003 (505 trading days). The starting time of this study is only six months after the commencement of trading in index options, which is expected to highlight the characteristics of a young market. As the trading on NSE is fully computerized, the chances of inaccuracy in the data-capture are minimal. To identify the opportunities of arbitrage, as the first step, the pairs of put and call options are made such that their strike prices and expiration dates match. In view of the lower availability of put transactions, these are taken as the starting point for pairing to use them optimally. For each put transaction, the first call transaction following it is selected for pairing. If no call transaction is found within

[6] Based on an analysis of one representative day taken from each of the 24 months

one-minute time interval, then the put transaction is excluded from the matching process. The call transactions are not repeated across pairs. As the second step, the next level of pairing is done to identify two pairs (a quartet) of put and call options, such that their expiration dates match, but the strike prices differ. All possible quartets (211,838 in total, spread over 469 days) are identified, such that the last transaction of a quartet (a call) takes place within one minute of the first transaction (a put).

The risk-free interest rates are sourced from the daily ‘zero-coupon yield curve’ database of NSE. NSE estimates the zero-coupon yield curve (ZCYC) for each day, from the market prices of the Treasury bills and Treasury bonds of the Government of India, traded on its ‘Wholesale Debt Market’ segment. ZCYC is estimated using the Nelson-Siegel functional form (Nelson and Siegel, 1987). The maturity period of box spreads covered in this study ranges between 1 – 6 weeks. The term structure for this time-range is more or less flat for the study period (469 ‘quartet’ days). The maximum difference between the one-week and six-week interest rates for the study period is 0.1076% per annum (only one instance). The average difference is 0.0132% per annum. Such a small difference between the interest rates for 0-42 days’ periods makes a negligible impact on the computation of the mispricing of box spreads.[7] Therefore, the seven-day interest rate for a day is taken to represent the risk-free rate of that day for the convenience of computations. The seven-day interest rate ranged between 4.28 – 7.20% per annum for the 469 days of identified mispricing.

[7] The maximum change made by this approximation would be only Rs 0.003 in the average mispricing of Rs 0.9245 (standard deviation: Rs 1.0387). The average change owing to the approximation would be still lower at Rs 0.0004. These marginal changes are not likely to change the results in any discernible manner.

4.2 *Costs*

If the return from a box spread is different from the risk-free return, then an arbitrage opportunity may exist. The relevant benefits and costs include the payoff ($X_H - X_L$), the set-up cost, the interest on set-up cost, the brokerage and its interest, and the interest on margin deposit. Therefore, an arbitrageur has to account for the following costs in addition to the set-up cost (and payoff).

a. ***Interest on set-up cost:*** If the arbitrageur goes long on the box spread, then he gets the payoff on the expiration day. The risk-free interest on the set-up cost for this period is his opportunity cost. However, if the arbitrageur is short on the box spread then he earns this interest.

b. ***Brokerage:*** For each of the four contracts that the arbitrageur needs for the box spread, he pays a brokerage. This is irrespective of the long or short position on the box spread. The amount of brokerage depends on the financial strength of the arbitrageur and varies for different categories of arbitrageurs as discussed later. The interest on brokerage for the holding period (though a small amount) is also an opportunity cost to the arbitrageur.

c. ***Interest on margin deposit:*** Out of the four options used in a box spread, a short position is taken in two. Margin money needs to be deposited with the Exchange for these. The margin deposit depends on the value at risk and is calculated using SPAN® (Standard Portfolio Analysis of Risk) system by NSE. The interest that could be earned during the holding period on this money is an opportunity cost for the arbitrageur. Irrespective of the long or short box spread position, the arbitrageur always loses the interest on the margin deposit.

4.3 *Costs for different categories of arbitrageurs*

Based on their transaction costs, the arbitrageurs can be broadly classified into the following three categories:

a. ***General investors:*** General investors do not get any special treatment as far as the brokerage or the interest on the margin deposit is concerned. Based on the interviews with experts in the options market, the rate of brokerage for a general investor is found to be about 0.04 % of the 'strike price plus option premium' of the contract. The general investor loses the interest opportunity on the margin deposit. Besides, he also loses (gains) the interest on the set-up cost for a long (short) position. The interest on the set-up cost affects all the categories of arbitrageurs in a similar fashion.

b. ***Institutional investors:*** The transaction costs for institutional investors are similar to those for the general investors except for the brokerage. However, the institutional investors have an advantage in the brokerage because of the volumes they trade. The brokerage is about 0.03 % for them.

c. ***Members:*** The members of the exchange do not incur an opportunity cost on their margin deposits. They can deposit their margin money using non-cash instruments like term deposit receipts, bank guarantees, stocks etc. Further, the brokerage cost is not applicable to them for they themselves are brokers. But, it would be unreasonable to consider their transaction cost as nil. A more reasonable approach is to treat their back-office and other costs, as close to the lowest brokerage that they charge their most important customers. This cost is more conservative for identifying arbitrage opportunities, and is taken as 0.03% (the same as that for the institutional investors).

5. Methods

Each quartet (of two calls and two puts) is tested for arbitrage opportunities. An arbitrage is possible with either the long or the short box spread strategy. If the set-up cost (C_L-P_L+P_H-C_H) and its interest till expiration is less than the payoff (X_H - X_L), then the call at the lower strike price and the put at the higher strike price can be purchased, and the call at the higher strike price and the put at the lower strike price can be written (long box spread strategy). The long box spread strategy requires an initial cost of (C_L-P_L+P_H-C_H). More than this amount (plus interest) is paid back on the expiration day, on the closing-out of the four contracts. If the set-up cost and its interest are more than the payoff, the arbitrageur takes the opposite positions in put and call contracts and receives (C_L-P_L+P_H-C_H) as the net option premium (short box spread strategy). This, along with the interest, is more than (X_H - X_L), required to clear the liability on account of the four contracts, on the expiration day. The arbitrage profit, in either box spread strategy (long or short), should be sufficient to offset the interest on margin deposit and the brokerage (with its interest), to make the arbitrage truly profitable.

The arbitrage profit for the long box spread strategy (APLB) is,

$$APLB = (X_H - X_L) - (C_L - P_L + P_H - C_H)[1+r(T-t)] - M[r(T-t)] - B[1+r(T-t)] \quad (1)$$

where, M is the margin deposit, B is the brokerage, r is the risk-free interest rate, T is the date of expiration and t is the date of setting up the box spread. This profit is earned on an investment of the set-up cost, margin deposit and brokerage [($C_L - P_L + P_H - C_H$) + M + B] for the holding period. This is the amount paid by an arbitrageur upfront, for setting up a long box spread. Similarly, the arbitrage profit for the short box spread strategy (APSB) is,

$$APSB = (C_L - P_L + P_H - C_H)[1+r(T-t)] - (X_H - X_L) - M[r(T-t)] - B[1+r(T-t)] \quad (2)$$

This profit is earned on an investment of the margin deposit and brokerage less the net option premium received [M + B – ($C_L - P_L + P_H - C_H$)]. In either case, the investment is always positive (the margin requirement becomes much higher for the short box spreads owing to a negative 'net mark-to-market value' of the option positions). The opportunity cost of margin deposit and the brokerage differ for the three categories of arbitrageurs, which make their profit opportunities also different. All the 211,838 quartets are examined for the arbitrage opportunities (return in excess of the risk-free rate, on the investment for the holding period) for both the long and short box spread strategies. As many instances of mispricing are observed, these are further analyzed for the pattern of their occurrence. For this analysis, the mispricing is defined as follows:

$$\text{Mispricing} = (X_H - X_L) - (C_L - P_L + P_H - C_H)[1+r\,(T\text{-}t)] \qquad (3)$$

As the mispricing, whether positive or negative, is potentially a source of arbitrage opportunity, the absolute value of mispricing is considered for examining most of the patterns. For analyzing the persistence of mispricing, the sign of the mispricing is also considered.

The moneyness and the volatility of the underlying often act as the proxies of liquidity risk (refer to Kamara and Miller, 1995). Their effect on the mispricing is examined for identifying their relation with it. As there are two strike prices, and a put and a call contract for both of these, we define the moneyness of a box spread as the average absolute percent difference between the two strike prices (X_H and X_L) and the spot price.

$$\text{Moneyness} = (50/S_t)(|S_t - X_L| + |X_H - S_t|) \qquad (4)$$

where, S_t is the spot price of Nifty. Kamara and Miller, Ackert and Tian (2001), Draper and Fung (2002) and Vipul (2006) find the mispricing to increase with volatility in the context of put-call parity. Therefore, it is suspected that the mispricing may also depend on the volatility of Nifty. To examine it, three measures of daily volatility are applied separately. These are the range-based measures of volatility, suggested by Parkinson (1980), Garman and Klass (1980), and Rogers and Satchell (1991). These measures are preferred to the other measures like historical volatility, implied volatility and realized volatility. The historical (returns-based) volatility tends to pick up noise along with the true volatility (Andersen and Bollerslev, 1998). Compared to historical volatility, the range-based volatility estimators are significantly more efficient and less biased, and are easy to implement. The more recent studies (Bali and Weinbaum, 2005; Chou, 2005; Shu and Zhang, 2006; Engle and Gallo, 2006; Ghysels, Santa-Clara and Valkanov, 2006; Vipul and Jacob, 2007) find a strong support for these estimators for both the estimation and forecasting. Implied volatility is not appropriate here, as it is itself estimated from the option prices. Realized volatility, which is estimated from the high-frequency data, requires a high amount of computation and information, but does not lead to significantly different estimates (Engle and Gallo; Ghysels, Santa-Clara and Valkanov; Vipul and Jacob).

The pattern of absolute mispricing is examined with respect to the moneyness and the volatility of the underlying. The frequency of incidence and average magnitude of mispricing are tested for similarity using the Kruskal-Wallis test for different values of these variables. This non-parametric test is preferred to ensure robustness, as the distribution of mispricing is not known with certainty. It makes less stringent assumptions about the distribution of mispricing values, and has a high power-efficiency.

The scheme for determining the persistence in mispricing is as follows. All possible pairs of quartets are identified, such that the members of each pair have the same expiry dates and strike prices (X_H and X_L), and are separated by a predefined period τ. Four sets of such pairs are made, for τ corresponding to 2 minutes, 5 minutes, 15 minutes, and 30 minutes. To ensure a reasonable number of cases for each set, the matching process allows a small window of time beyond τ (10 seconds' windows for τ = 2 minutes and 5 minutes, and 30 seconds' windows for τ = 15 minutes and 30 minutes). For each pair of a particular set, the mispricing of the first quartet (X_t) precedes the mispricing of the second quartet ($X_{t+\tau}$) by the predefined period τ (applicable to that set). Now, all the pairs are examined for the arbitrage opportunities for both the long and short box spread strategies. For those pairs, for which an arbitrage opportunity is identified for the first quartet, the arbitrage profit for the second quartet is found by implementing the same strategy. The average arbitrage profit for a set indicates the *ex post* average profit earned, if the implementation of the identified strategy is delayed by the period τ corresponding to that set.

6. Results

6.1 *Arbitrage opportunities*

The incidence of mispricing for the 211,838 quartets is reported in Table 2. The average mispricing is Rs 0.9245, which is statistically significant at any reasonable level. Most of the mispricing values are below Rs 1.50. However, for many instances, the implicit interest rate of box spreads is significantly different from the risk-free rate (for the corresponding term). This may provide profitable opportunities to arbitrageurs. Such opportunities are identified by adjusting the mispricing for transaction costs. The arbitrageurs can identify the *ex ante* arbitrage opportunities automatically by providing the price quotations feed to a computer program. The transactions to implement an arbitrage could then be initiated only for the profitable arbitrages so identified. For all the other cases, the arbitrage transactions would not be initiated and therefore, the value of arbitrage profit would be zero. This scheme is feasible because the trading at NSE is fully computerized. The opportunities of arbitrage profit for the 211,838 quartets are shown in Table 3. It includes only those cases for which the mispricing exceeds the transaction costs, and therefore, would have provided a net profit to an arbitrageur. The arbitrage profit is computed as the excess annualized return (the return in excess of the risk-free rate) on the investment for the holding period. The magnitude and frequency of arbitrage profits for the general investors, institutional investors and members of the exchange are shown in Table 3. The arbitrage profits earned on an expiration day are considered to be for a one-day period (not zero days), because that is the minimum period for which one would arrange the finances. There are many high-profit arbitrage opportunities for all the three categories of investors. The opportunities available to the institutional investors and members of the exchange are much more than those available to the general investors. This is owing to the lower brokerage paid by the institutional investors and the lower cost of execution and interest (on margin deposits) for the members of the exchange.

A general investor could earn an excess annualized return of more than 10% for 5.82% of the cases. This translates into a large number of arbitrage opportunities (average 24 opportunities per day) on 211,838 quartets for the two-year period. For 1.80% of the quartets, he could earn more than 100% excess return. For the institutional investors and members of the exchange, the number of arbitrage opportunities and their magnitude is higher. Institutional investors could earn an excess annualized return of more than 10% for 10.23% of the quartets. The members of the derivatives exchange could do it for 11.61% of the quartets. These numbers indicate the existence of about 49 opportunities of earning more than 10% excess return for these players everyday. The institutional investors and members of the exchange could earn more than 100% excess return for more than 2.9% of the quartets. The average arbitrage profit (in excess of the risk-free rate on investment) is 104.25%, 91.01%, and 82.91% for the general investors, institutional investors and members of the exchange respectively.[8] The

[8] Most of the incidences (more than 93.5%) of the larger excess returns (more than 100% p.a.) occur during the last two weeks before expiration. Such returns are not for a long period. However, the excess returns ranging

wide prevalence of arbitrage opportunities raises doubts about the efficiency of the Indian options market. These results are similar to those of Hemler and Miller (1997) for post-crash period, and Ackert and Tian (2001), but are contradictory to those of Bharadwaj and Wiggins (2001), Fung, Mok and Wong (2004), and Benzion, Danan, and Yagil (2005). The inefficiency may be partially caused by the restriction on short sales. Such restrictions are known to cause overpricing of put contracts, owing to ineffective hedging. To investigate this aspect, the market prices of puts are compared with their theoretical prices (as predicted by the put-call parity). The theoretical price (P_t) is computed for each of the put contracts included in the quartets, as follows:

$$P_t = C_t - I_t + D + X(1+r)^{-(T-t)} \tag{5}$$

where, C_t is the price of a call option at time t; I_t is the value of the underlying index at time t; X is the strike price of both the options; D is the present value (at time t) of the known dividend payable on the Index portfolio of shares between time t and T (expressed in index points).

The put contracts are overpriced in 56.8% of the cases and underpriced in 43% of the cases. This confirms the widespread overpricing of put contracts owing to the restriction on short sales. This phenomenon is also corroborated by Vipul (2006) for the Indian market. However, this systemic overpricing of put contracts does not cause significant mispricing in box spreads owing to its mutual cancellation in the term ($P_H - P_L$). Out of 53% of the quartets, that have both their put contracts overpriced, only 8.8% provide profitable arbitrage. As against these, 14.1% of the 39% quartets, which have both the put contracts underpriced, provide profitable arbitrage. As expected, the quartets with one put contract overpriced and

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between 10 – 30% are available in many instances even for about five weeks before expiration. These returns are not small as the risk-free return for the study period is itself only 4 – 7%.

the other underpriced (8% of the total quartets), provide a much higher opportunity of profitable arbitrage (41.5% of the cases). Therefore, the mispricing in box spreads is largely caused by the instantaneous underpricing of some put contracts owing to certain new information, market microstructure or volatility. The widespread overpricing owing to the restriction on short sales apparently is not the main reason. A further examination of the cases providing arbitrage profit to the institutional investors, confirms a higher mispricing of those put contracts, whose strike prices are farther from the spot price. The put contracts below the median moneyness (within ± 1.34% of the spot price) had an average mispricing of Rs 3.74 as compared to Rs 4.81 for those beyond this range. This indicates that the moneyness may be associated with the arbitrage profits for box spreads. The patterns for the general investors and members of the exchange are similar. The mispricing of box spreads may be partly explainable by the early phase of introduction of options to the Indian market. A period of 6 to 30 months is, perhaps, not enough for the traders and the operators to assimilate the nuances of these contracts. In view of the prevalence of widespread mispricing, which gives rise to significant arbitrage opportunities, it is of interest to identify its relation with its possible determinants including the moneyness and volatility.

6.2 *Moneyness*

Using the definition of moneyness as the average absolute percent difference between the two strike prices (X_H and X_L) and the spot price [refer to Equation (4)]; its relation with the mispricing is reported in Table 4. The mispricing consistently increases as the strike prices move farther from the spot price (represented by a higher value of the moneyness measure) with only two discontinuities. The high value of Kruskal-Wallis H-statistic (645.23) and its insignificant p-value confirm that the levels of mispricing are significantly different for different moneyness groups. The increase of mispricing with higher moneyness reflects the liquidity risk premium. The lower liquidity of the high-moneyness contracts appears to discourage the arbitrageurs from exploiting the arbitrage opportunities. The inclusion of 'far from the money' options in a box spread also makes its payoff higher. As such a box spread would have a higher mispricing (owing to liquidity risk of 'far from the money' options), a high level of mispricing appears in the high-payoff box spreads also (the detailed results not reported for brevity).

6.3 *Volatility*

The relation between the mispricing and the volatility of Nifty (of that day) is reported in Table 5. The mispricing increases consistently as volatility increases from 0.2% to 5.0%. The higher the volatility, the higher is the average mispricing. The high value of Kruskal-Wallis H-statistic and its insignificant p-value (nearly zero) confirm that the levels of mispricing significantly differ across volatility groups. This pattern is observed for all the three measures of volatility, confirming the robustness of the inference. Therefore, volatility significantly explains the mispricing. Since the price of the option itself captures the expected (implied) volatility, perhaps the difference between the expected and the observed volatility is responsible for this relation. Moreover, volatility often acts as a proxy of the liquidity risk (refer to Kamara and Miller, 1995). The higher mispricing for more volatile markets reflects the apprehension of arbitrageurs, of not being able to implement the arbitrage transactions at the desired price. Our findings are in line with those of Kamara and Miller, Ackert and Tian (2001), Draper and Fung (2002), and Vipul (2006), who find the mispricing to increase with volatility in the context of put-call parity.

6.4 *Persistence*

The persistence of mispricing is examined for four time lags (2 minutes, 5 minutes, 15 minutes, and 30 minutes). The results are presented in Table 6. The maximum numbers of pairs that could be made at these time lags, for the quartets having the same expiry date and strike price, are given in the second column. In all, 14,186 pairs of quartets could be made, which had the same strike prices and expiry dates, but whose times of occurrence were separated by 2 minutes to 2 minutes and 10 seconds. Similarly, 9,809 pairs could be made of similar quartets separated by 5 – 5.10 minutes. Sufficient numbers of such pairs are identified for time lags of up to 30 minutes, as indicated in Table 6. However, each quartet not necessarily provides an arbitrage opportunity. For those pairs, in which an arbitrage opportunity was indicated by the first quartet (the number of instances given in Column 3), the arbitrage transaction was implemented with a time lag indicated in Column 1. On implementing the arbitrage for all these pairs, the average profits that could be earned, are reported in the last column. The average profits for all the time lags (even for two minutes) are large negative amounts. This implies that the arbitrage strategy, suggested by the leading quartet of the pair, would not give consistent gains even if the implementation takes as little as two minutes. For higher lags in the implementation also, the same conclusion holds. This is true for all the three classes of arbitrageurs. It indicates that the arbitrage opportunities, though present in the Indian market, do not persist even for two minutes. This finding is in line with that of Benzion, Danan, and Yagil (2005) for the Israeli market, but is contradictory to the five-minute persistence of Hemler and Miller (1997) for post-crash period.

7 Conclusion

The instances of mispricing of options in the Indian market are frequent, providing numerous arbitrage opportunities. Such opportunities are more frequent and profitable for the members of the exchange owing to their lower transaction costs as expected. But, more significantly, even a general investor has many such opportunities. Often an abnormally high excess return (higher than 100%) is also available. These results are contrary to the results of most of similar studies carried out with the high-frequency data and European options (for instance refer to Bharadwaj and Wiggins, 2001; Fung, Mok and Wong, 2004; and Benzion, Danan, and Yagil, 2005). Only Hemler and Miller (1997), for post-crash period, have similar findings. The violations of box spread parity in the Indian market may be owing to its young age. This is despite the facilitating factors including order-driven computerized trading, cash settlement, better integration of cash and derivatives market, and low transaction costs. However, the arbitrage opportunities do not persist even for two minutes. This indicates that the arbitrageurs do not ignore the mispricing for a long time. To that extent, the market is reasonably efficient.

The mispricing increases if the strike prices are away from the spot price. Such far-from-the-money options have low liquidity in the Indian market. Higher volatility of Nifty also increases the mispricing. Both these variables appear to act as the proxies of liquidity (immediacy) risk as suggested by Kamara and Miller (1995). The arbitrageur may not be able to implement his strategy at the desired prices if the market is highly volatile or the option instruments are not liquid. The premium for this risk is reflected as the mispricing.

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Table 1

Long Box Spread

Pair	*Strike price*	*Options*	*Payoff on expiration*	*Set-up cost*
1	X_L	Long call: short put	$S_T - X_L$	$C_L - P_L$
2	X_H	Short call: long put	$X_H - S_T$	$P_H - C_H$
		Total	$\mathbf{X_H - X_L}$	$\mathbf{C_L - C_H + P_H - P_L}$

A long box spread requires positions in four option contracts. The two pairs of one call and one put option each, at 'low' and 'high' strike prices, provide an expiration-day payoff of $X_H - X_L$. The setup cost is $C_L - C_H + P_H - P_L$ on the trading day. S_T is the expiration-day settlement value of index. C_H and C_L are the call premiums for strike prices X_H and X_L, and P_H and P_L are the put premiums for strike prices X_H and X_L.

Table 2

Incidence of Mispricing

Range of mispricing (Rs)	*Number of box spreads*	*Percent of total box spreads*
0.0 – 0.5	89,145	42.08
0.5 – 1.0	54,027	25.50
1.0 – 1.5	29,818	14.08
1.5 – 2.0	16,231	7.66
2.0 – 3.0	14,253	6.73
More than 3.0	8,364	3.95
Total	**211,838**	**100.00**
Average mispricing	0.9245	
Std. Dev. of mispricing	1.0387	
Skewness	5.420	
Kurtosis	133.180	
t-statistic	409.653	
p-value	0.000	

All the option contracts constituting a box spread have a common expiration day. Absolute mispricing of a box spread is the difference between the payoff on the expiration day and the setup cost (and interest).

Table 3

Opportunities of Excess Arbitrage Returns

Excess annualized return	Arbitrage opportunities with days to expiration						Total opportunities	Percent of quartets
	0-6	7-13	14-20	21-27	28-34	More than 35		
Panel A : General investors								
0 – 10%	308	981	964	620	237	8	3,118	1.47%
10 – 30%	520	1,478	1,067	507	206	11	3,789	1.79%
30 – 50%	463	887	540	168	46	2	2,106	0.99%
50 – 100%	841	1,181	410	151	43	1	2,627	1.24%
100 – 500%	1,951	993	190	38	19	0	3,191	1.51%
> 500%	555	54	0	0	0	0	609	0.29%
Total	**4,638**	**5,574**	**3,171**	**1,484**	**551**	**22**	**15,440**	**7.29%**
Mean 104.25		**Standard deviation 216.71**			**Skewness 5.849**		**Kurtosis 57.618**	
Panel B : Institutional investors								
0 – 10%	660	2,223	2,088	1,282	443	18	6,714	3.17%
10 – 30%	965	2,739	2,118	1,017	322	14	7,175	3.39%
30 – 50%	859	1,687	876	288	97	2	3,809	1.80%
50 – 100%	1,551	2,003	740	197	51	1	4,543	2.14%
100 – 500%	3,294	1,592	272	61	22	1	5,242	2.47%
> 500%	846	59	0	0	0	0	905	0.43%
Total	**8,175**	**10,303**	**6,094**	**2,845**	**935**	**36**	**28,388**	**13.40%**
Mean 91.01		**Standard deviation 196.23**			**Skewness 6.454**		**Kurtosis 70.427**	
Panel C : Members of exchange								
0 – 10%	639	2,580	2,615	1,838	618	29	8,319	3.93%
10 – 30%	1,038	3,162	2,710	1,402	444	18	8,774	4.14%
30 – 50%	954	1,881	1,071	424	117	5	4,452	2.10%
50 – 100%	1,586	2,206	887	225	63	1	4,968	2.35%
100 – 500%	3,395	1,705	304	73	23	1	5,501	2.60%
> 500%	857	59	0	0	0	0	916	0.43%
Total	**8,469**	**11,593**	**7,587**	**3,962**	**1,265**	**54**	**32,930**	**15.54%**
Mean 82.91		**Standard deviation 184.88**			**Skewness 6.833**		**Kurtosis 79.031**	

These arbitrage opportunities provide excess returns over the risk-free return after transaction costs. These are identified from 211,838 possible box spreads that could be made between January 1, 2002 and December 31, 2003.

Table 4

Mispricing and Moneyness

Moneyness (%)	*Average mispricing (Rs)*	*Instances*
0 – 1	0.860195	63,021
1 – 2	0.897207	83,127
2 – 3	0.987925	40,307
3 – 4	1.053644	17,383
4 – 5	1.129605	5,782
5 – 6	1.046939	1,662
6 – 7	1.079715	412
7 – 8	1.404855	94
8 – 9	1.333108	42
9 – 10	1.380314	8
Total	**0.924497**	**211,838**
Kruskal-Wallis *H*-statistic 645.23		
p-value less than 10^{-132}		

Mispricing of a box spread is the absolute value of the difference between the payoff and the setup cost (and interest) on the expiration day. The effect of the magnitude of moneyness (reflected by the average difference between the spot rate and the high and low strike prices) on the mispricing of box spreads is reported. The Kruskal-Wallis test is applied to test the difference between the mispricing of the ten different 'moneyness' groups.

Table 5

Mispricing and Volatility

Daily Volatility (%)	*Average mispricing*		
	Parkinson's measure	*Garman & Klass measure*	*Rogers & Satchell measure*
0.2 – 0.6	0.514274	0.493257	0.605450
0.6 – 1.0	0.704822	0.734260	0.748935
1.0 – 1.5	0.877571	0.833115	0.875566
1.5 – 2.0	1.019546	1.109285	1.191305
2.0 – 3.0	1.212199	1.411215	1.308251
3.0 – 4.0	1.204025	1.514135	1.718234
4.0 – 5.0	1.992905	1.992905	1.770590
Kruskal-Wallis *H*-statistic	9566*	12350*	12173*

**p*-value for Kruskal-Wallis *H*-statistic is insignificant (nearly 0) for all the measures of volatility

Mispricing of a box spread is the absolute value of the difference between the payoff and the setup cost (and interest) on the expiration day. The effect of the magnitude of volatility (of the underlying) on the mispricing of box spreads is reported. The Kruskal-Wallis test is applied to test the difference between mispricing of the six different 'volatility' groups.

Table 6

Persistence in Arbitrage Profits (after Transaction Costs)

Time lag (minutes*)	***Matched quartets***	***Cases with arbitrage opportunity in the first box spread***	***Percent cases with persistent arbitrage opportunity***[@]	***Average profit for the first box spread (%)***	***Average profit for the second box spread (%)***
Panel A : General investors					
2 – 2.10	14,186	1,169	12.23%	109.66	-176.17
5 – 5.10	9,809	839	14.18%	82.88	-123.93
15 – 15.30	15,864	1,418	9.38%	113.48	-176.07
30 – 30.30	10,627	793	14.00%	104.64	-259.35
Panel B : Institutional investors					
2 – 2.10	14,186	2,116	17.96%	94.47	-125.66
5 – 5.10	9,809	1,524	19.88%	80.51	-99.07
15 – 15.30	15,864	2,516	14.15%	100.20	-126.50
30 – 30.30	10,627	1,455	15.74%	99.00	-174.64
Panel C : Members of exchange					
2 – 2.10	14,186	2,472	16.67%	85.32	-115.46
5 – 5.10	9,809	1,750	18.63%	74.77	-91.99
15 – 15.30	15,864	2,857	14.14%	92.72	-114.76
30 – 30.30	10,627	1,655	16.56%	91.64	-157.07

*The numbers after the decimal point indicate seconds.

[@] This column shows the cases where the second box spread provides an arbitrage profit after the specified time lag (after identification of the arbitrage opportunity in the first box spread). The percentage is computed on the cases in the third column.

These are all the possible cases out of a total 211,838 box spreads made within one-minute time windows.