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An Empirical Test of Efficiency of Exchange-Traded Currency Options in India

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Abstract: *The objective of this paper is to examine efficiency of the exchange-traded currency options market in India. Put-call-futures parity for the USD-INR currency options is studied by analyzing daily closing prices of options and futures for thirty two months on the National Stock Exchange. The study reveals frequent violations of the put-call-futures parity creating significant arbitrage opportunities. The pattern of mispricing varies when examined for time to maturity, option moneyness, liquidity and volatility of the underlying asset. These observations are consistent with those of studies of other young markets.*

Keywords: Put-call parity, efficient markets, currency options.

JEL Classification: G13, G14

1. Introduction

Integrated and well-functioning financial markets are known to have a number of benefits such as efficient allocation of capital, better price discovery and better risk-sharing. An integrated financial market would imply that identical assets with the same risk would have the same expected return. This is embodied in the theoretical principle of Law of One Price. Integration between domestic spot and derivatives markets is of prime importance. This is captured in the principle of put-call parity which states that when there are no arbitrage opportunities one can replicate a derivative instrument in terms of the spot price of the underlying asset and by borrowing or lending as appropriate. A violation of the put-call parity condition would therefore imply that the spot and derivatives markets are not integrated or efficient. Option markets are a very important component of the derivatives markets. A number of studies in finance theory have tested the efficiency of option markets in different countries either by applying specific option-pricing models or by conducting model-independent tests. The latter can be further categorized into tests of cross-market efficiency such as the put-call parity and lower boundary tests and tests of internal efficiency such as call-put spreads and box-spreads. This paper attempts to determine whether the market for exchange-traded currency options in India is efficient or not.

Exchange-traded derivatives were introduced in India only in the year 2000 when the Securities and Exchange Board of India (SEBI) permitted stock exchanges to introduce trading of index futures contracts based on the Nifty and Sensex. Trading of index options and futures and options on individual securities was allowed soon after. While trading of equity futures and options quickly gathered momentum currency derivatives continued to be traded

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in the over-the-counter market dominated by banks. The joint Reserve Bank of India-Securities and Exchange Board of India (RBI-SEBI) committee permitted the trading of futures contracts on the USD-INR pair on the National Stock Exchange (NSE) in August 2008. The success of these contracts led to the introduction of futures contracts on three other currency pairs. Trading of options on the USD-INR was allowed on the NSE as of October 29, 2010. The number of currency option contracts traded on the NSE has grown exponentially from 3,74,20,147 during 2010-2011 to 27,50,84,185 during the year 2012-2013 while the notional turnover increased from Rs.1.71 crore to Rs.15.09 crore over the same period. The average daily turnover in the currency derivatives segment of the NSE increased from Rs.13854.57 crore in 2010-2011 to Rs.21705.62 crore in 2012-2013. While average daily turnover in the currency derivatives segment is much smaller than that of the equity derivatives segment of the NSE which was Rs.1,26,639 crore during 2012-2013, it is significant considering the relative newness of the currency derivatives segment. The Futures Industry Association (FIA) 2012 Annual Volume Survey of the Futures Industry ranked the USD-INR currency futures contract traded on the NSE as the top foreign exchange futures contract traded globally during the calendar year 2012, according to number of contracts traded. Similarly the USD-INR currency options contract traded on the NSE was ranked as number four during the same period. In view of the rising global significance of the Indian exchange-traded currency derivatives segment it is imperative to examine the efficiency of this market. We test the efficiency by examining if put call parity holds for currency options and futures on the USD-INR traded on the NSE. While testing for parity we use currency futures instead of the spot exchange rate because it would be practically easier to arbitrage between the currency options and futures instead of the currency options and the spot rupee. This is because the rupee is not a liquid and fully convertible currency and hence it is not possible for retail investors or even exchange non-bank members to take large long or short positions in the rupee in order to exploit the arbitrage opportunity.

The rest of the paper is organized as follows. Section II describes the specifications of the USD-INR option contract traded on the NSE which is the subject of this study. Section III reviews the existing literature on efficiency of the options market. Section IV discusses the put-call parity condition. Section V explains the data and methodology adopted and the results of the analysis are discussed in Section VI. Section VII compares the results with those of other similar studies and concludes the paper.

2. The USD-INR Option Contract

The USD-INR option contract is a European style contract with the underlying being the exchange rate between Indian Rupee and US Dollar. Each contract is for a notional value of 1000 USD but the premium for the contract is quoted in Indian rupees. The tick size of the contract is 0.25 paise. The exchange introduces for trading three serial monthly contracts followed by one quarterly contract of the cycle March/June/September/December at any given time. It makes available at a point of time twelve in-the-money, twelve out-of-the money and one near-the-money contracts for both calls and puts with strike prices at an interval of 25 paise. The contract is traded between 9.00 am and 5.00 pm from Monday to Friday so as to coincide with the trading hours of the inter-bank forex market in India. The contract expires at 12 noon two business days prior to the last business day of the expiry month. The final settlement takes place on the last working day (excluding Saturdays) of the expiry month and the last working day is the same as that for inter-bank settlements in Mumbai. The RBI reference rate for the USD-INR on the date of expiry is the final settlement price of the option contract. The contract is settled in cash in Indian rupees. The regulators have specified separate limits for gross open positions for various market participants such as trading members who are banks, non-bank trading members and clients. The margins to be charged and the mode of margin computation have also been specified by the regulator.

3. Literature Review

Two distinct strands can be observed in the existing literature on option market efficiency. One approach is a model-based one in that a specific model such as the Black-Scholes model or the Binomial model is used for deriving the theoretical option price which is then compared with the market price to identify the mispricing. The extent of mispricing is then tested for its statistical significance. A problem with the model-based approach is that it involves testing of two hypotheses simultaneously – first that the model itself is valid and the second, that the market is efficient; and the test is not able to distinguish between the two hypotheses (Galai, 1977). The second approach involves (a) testing for violation of no-arbitrage relationships between option and spot or futures prices (put-call parity or lower boundary conditions) which is known as test of cross-market efficiency or (b) testing for violation of no-arbitrage relationships between option prices alone (call-put spreads, box spreads etc) which is known as test of internal market efficiency. The second approach is less restrictive than the first because it is not based upon specific assumptions regarding the distribution of the price of the underlying and estimation of its volatility. As such it has been adopted by many researchers in different option markets. Klemkowski and Resnick (1979, 1980), Evnine and Rudd (1985), Chance (1988), Fung and Chan (1994), Kamara and Miller (1995), Lee and Nayar (1993) all study the arbitrage-free relationships between options and futures in the US market. While Evnine and Rudd (1985) find frequent violations of put call parity, Chance (1988), Fung and Chan (1994), Kamara and Miller (1995) and Lee and Nayar (1993) find less frequent violations and hold that the market is generally efficient. Capelle-Blancard and Chaudhury (2001) test violation of put-call parity in the French CAC40 index options market and find reduced violations after accounting for transaction costs. Zhang and Lai (2006) examine put-call parity in the Hong Kong derivatives market during the period 2002 -2004 and find that though put-call parity is violated the arbitrage opportunity cannot be exploited in a number of cases. Therefore they conclude that the markets are priced efficiently. Brunetti and Torricelli (2007) study the Italian Index options market and find very few arbitrage violations but higher average profits than in the US market. Vipul (2008) studies put-call-index parity and put-call-futures parity for Nifty options and finds frequent violations of both conditions. Most of the earlier research is focused on equity options and futures. To the best of our knowledge there has been no study so far in India about arbitrage between currency options and futures given the novelty of these instruments in India.

4. Put-Call Parity Explained

The put-call parity principle was first expounded by Stoll (1969) and later generalized by Tucker (1991) to put-call-futures parity. The principle states that the put, call and the underlying asset are inter-related so that any two of these can be combined so as to yield the pay-off of the third instrument. The relationship between a call and a put option on a foreign currency and the spot value of the foreign currency can be stated as:

$$c + Xe^{-r(T-t)} = p + Se^{-q(T-t)} \quad (1)$$

Where

c = European call option price expressed in domestic currency for a given strike price

p = European put option price expressed in domestic currency for the same strike as the call

X = strike price of the call and the put

S = spot price in domestic currency for one unit of foreign currency

r = domestic risk-free interest rate

q = foreign risk-free interest rate

T-t = time to expiry of the option

Since the spot price can be expressed as the discounted futures price we have

$$c + Xe^{-r(T-t)} = p + Fe^{-(r-q)(T-t)}e^{-q(T-t)}$$

Where F = the currency futures price

Or

$$c + Xe^{-r(T-t)} = p + Fe^{-r(T-t)} \quad (2)$$

From the above we can derive the theoretical or fair price of a call option as:

$$c = p + (F - X)e^{-r(T-t)} \quad (3)$$

Or

$$c - p - (F - X)e^{-r(T-t)} = \acute{\varepsilon} \quad (4)$$

The left-hand side of equation (4) above is the pricing error which we denote as έ and should ideally be equal to zero. If έ is greater than zero then the call is overpriced (put underpriced and futures underpriced). A trader can then enter into a long-futures arbitrage by shorting the call, taking a long position in the futures and the put and borrow an amount equal to present value of the strike price at the risk-free rate and hold these positions till expiry. If έ is less than zero, then the call is underpriced (put overpriced and futures overpriced). A trader can then enter into a short futures arbitrage by shorting the futures and the put, taking a long position in the call and investing an amount equal to the present value of the strike price at the risk-free rate and hold the positions till expiry. For any arbitrage to be profitable, the pricing error should exceed the explicit and implicit costs of trading.

5. Data and Methodology Adopted

The data for testing includes daily closing prices of options and futures on the USD-INR exchange rate traded on the NSE from October 29, 2010 till June 30, 2013. We first match a call option with a specific strike and expiry date with a put option of the same strike and expiry date and then match this pair with a futures contract with the same expiry date. We thus have 11,481 triplets of calls, puts and futures for the above period. Owing to the short trading history of USD-INR options we have considered the entire data set without omitting the early days of trading. We have also not excluded observations from the week prior to expiry as we intend to study the effect of time to maturity on the magnitude and frequency of mispricing. Using daily closing prices instead of time-stamped transaction data exposes us to the problem of non-synchronicity of data. Hence our results should be treated with caution. Similar studies based on transaction data use ex-ante tests to examine market efficiency. According to Galai (1977), ex-ante tests are the true test of market efficiency as they involve testing whether an opportunity can be practically exploited by the market participant after a time lag. We have not been able to conduct ex-ante tests in the absence of intra-day data and our results are based purely on ex-post tests.

We use the yields of Treasury Bills with the maturity closest to the maturity of the option as the risk-free rate of return. The yields have been retrieved from publications of the RBI and have been converted to continuously compounded rates by the formula:

$$r_{cc} = \ln(1 + r)$$

While incorporating transaction costs in the study we consider two scenarios; the first is a frictionless world without any trading costs and the second is a scenario with explicit trading costs. We ignore implicit trading costs in the form of the bid-ask spread because the data set of closing prices does not include the closing bid-ask quotes. Moreover it would be simplistic to assume a common bid-ask spread for all strikes because there is a wide variation in the spread according to the strike price and the expiry month. However the bid-ask spread is given due weight when we examine the mispricing from the point of view of liquidity and maturity of the options. We ignore the opportunity cost for margin deposits as it is possible for members to post collateral in the form of securities for the purpose of margin. Some brokerages also allow retail investors to place specified securities as collateral for margin. We also ignore daily mark-to-market of the futures and short option position for the sake of simplicity.

For the purpose of computing explicit trading costs, we classify the market participants into two broad categories: members of the exchange and non-members (retail investors). We ignore institutional investors as their trading cost would be largely based on their relationship with the brokers and hence difficult to estimate for all institutional investors in general.

Transaction costs for Members of the Exchange

Members do not have to pay any brokerage on their proprietary trades. The main components of explicit costs for members are as follows:

a. Transaction charges of the Exchange: The NSE collects transaction charges from its members at the rate of Rs.1.15 per lakh rupees based on the turnover in case of futures and at the rate of Rs.40 per lakh rupees of premium in case of options. The

Exchange started collecting these charges only as of August 22, 2011 and hence these charges have been deducted only for the period from this date.

b. SEBI turnover fees and Stamp Duty: These are charged on the turnover in case of futures and the sum of premium and the strike price in case of options. The SEBI turnover fees are charged at Rs.10 per crore. Since stamp duty is levied by individual state governments, we have considered the duty levied by the Government of Maharashtra which is Rs.200 per crore.

Transaction costs for Non-Members (Retail Investors)

a. Brokerage: Retail investors trade through members of the exchange and hence pay brokerage. There has been a marked shift in the manner of charging brokerage as investors became more risk-averse after the credit crisis and slowdown of 2008. A number of discount-brokerages sprang up with brokerages as low as Rs. 9 per lot. Even existing full-price brokerages started offering schemes whereby a client could pay a fixed amount for a month or a year and a low brokerage would be charged per lot traded. For the purpose of this study we have not assumed any fixed amount of brokerage for the retail investor, but a percentage cost per trade. Specifically we have assumed a brokerage of 0.01% for futures and 0.006% for options as charged by leading discount brokers.

b. Transaction charges of the Exchange: We have assumed transaction charges of Rs.160 per Rs. crore for futures transactions and Rs.7000 per crore of premium in case of options trades in line with what many discount brokerages follow. Again these have been considered only for the period from August 22, 2011.

c. SEBI turnover fees and Stamp Duty: SEBI turnover fees have been considered at Rs.10 per crore. Stamp duty has been reckoned at 0.002% and 0.01% for futures and options respectively.

If there is a mispricing a trader would execute three trades simultaneously, take a long (short) position in a futures contract and a put and a short (long) position in the call. We compute the costs for these three trades and assume that these positions are held till expiry so that there are no costs attached to the second leg of the strategy.

Computation of the arbitrage gain

The gain from mispricing arrived as per equation (4) above is converted into an annualised rate of return so as to arrive at the gross percentage of mispricing. The explicit trading costs are computed for each triplet of futures and options separately for members and non-members. The net amount of mispricing is then annualized to arrive at the actual arbitrage gain that can be exploited by members and non-members.

6. Results

All results are detailed in Tables 1 to 15 in this section. Of the 11,481 triplets analysed, the call option is correctly priced only in three cases. The call is overpriced (put underpriced) in 5471 cases while the call is underpriced (put overpriced) in 6007 cases. The mean amount of mispricing is Rs.0.06 for both cases of mispricing. The mean annualized return before trading costs is 4.54%. However the mean gross annualized return is 4.66% which is slightly higher for positive mispricing or overvalued calls and long futures arbitrage than the gross annualized return of 4.44% for overvalued puts or short futures arbitrage. This result is in line with that of Fung et al (1997) and Cheng et al (1998) who find that long futures arbitrage is more profitable. Despite the very large number of instances of mispricing (99.97%) the instances of profitable arbitrage (after accounting for explicit costs) are 9,268 (80.75%) for members of the exchange and only 5,147 (44.84%) for retail investors. As may be expected members are in a better position to exploit the arbitrage due to their lower trading costs. The mean annualized return on the arbitrage after accounting for explicit costs is 5.25% for members and 7.93% for retail investors. The higher net return for non-members is contrary to expectations because non-members always face higher trading costs. However in case of non-members the marginal trades get removed and only the profitable ones remain. It is possible to earn a net return of 1.5% to 2% in a single day which translates to an annualized return of more than 500%.

Table 1. Descriptive Statistics of absolute mispricing

Mean	0.064356
Standard Error	0.001462
Median	0.015866
Mode	0.005000
Standard Deviation	0.156622
Sample Variance	0.024531
Kurtosis	42.693231
Skewness	5.695963
Range	2.177249
Minimum	0.000004
Maximum	2.177253
Sum	738.674918
Count	11478

Table 2. Gross mispricing before trading cost

	Instances of mispricing	Mean (Rs.)	Median (Rs.)	Standard Deviation
Absolute mispricing	11478	0.0644	0.0159	0.1566
Positive mispricing	5471	0.0639	0.0158	0.1637
Negative mispricing	6007	-0.0648	-0.0160	0.1499

Table 3. Mispricing net of trading costs

	Instances of mispricing	Mean (Rs.)	Median (Rs.)	Standard Deviation	Percentage of total mispricing
Members	9268	0.0748	0.0190	0.1708	80.75%
Non-members	5147	0.1144	0.0363	0.2137	44.84%

We analyze the absolute amount of mispricing with respect to five parameters: the type of option, moneyness of the option, time to maturity, traded volume and level of underlying volatility. Thus we categorize the data of absolute mispricing into: (i) mispricing for calls and puts, (ii) mispricing for different levels of moneyness, viz. at-the-money, in-the-money, deep-in-the-money and out-of-the-money options (iii) mispricing according to volume traded, viz: thin, moderate and high volume (iv) mispricing according to time remaining till maturity of the option, viz: up to 7 days, between 8 and 30 days and greater than 30 days and (v) mispricing according to level of underlying volatility, viz. low, medium and high volatility. We then test whether there is a statistically significant difference in the mean level of mispricing across the various sub-categories. In each case our null hypothesis is that there is no significant difference in the mean level of mispricing across the various categories. In order to test this hypothesis we first need to examine whether the distribution of the absolute mispricing series is normal in each sub-category under study. If the distribution of the mispricing series is normal then parametric tests such as ANOVA can be used for testing the significance of difference in means. In the absence of normality in the data nonparametric tests such as the Mann-Whitney U test or the Wilcoxon Rank Sum test are used.

We first examine whether mispricing is higher in case of calls than for puts. Table 2 shows that the mean overpricing for calls is Rs.0.0639 while the mean overpricing for put options is Rs.0.0648.

For the purpose of analyzing the absolute amount of mispricing with respect to moneyness we define moneyness of call options as S/X and use the following classification: (a) S/X > 1.15: Deep-in-the-money (b) S/X >1.05 and <=1.15: In-the-money (c) S/X >0.95 and <=1.05: At-the-money (d) S/X >0.85 and <=0.95: Out-of-the-money and (e) S/X <0.85: Deep-out-of-the-money. The analysis in Table 4 reveals that about 89% of the cases of mispricing are at-the-money options. However the magnitude of absolute mispricing for at-the-money options is Rs.0.05 as compared to Rs.0.49 for deep in-the-money and Rs.0.20 for out-of-the-money options. Thus there is an inverse relation between the number of instances of mispricing and the average magnitude of mispricing. This result is in line with the study of put -call parity for Nifty futures and options (Vipul, 2008).

Table 4. Mispricing as per moneyness of strike

Moneyness	S/X	Type of mispricing	Instances of mispricing	Mean (Rs.)	Median (Rs.)	Standard Deviation	Percentage of mispricing instances
Deep ITM	>1.15	Positive	10	0.1417	0.1692	0.0824	
		Negative	20	-0.6777	-0.8198	0.4581	
		Absolute	**30**	**0.4991**	**0.2397**	**0.4535**	**0.26%**
ITM	1.05-1.15	Positive	454	0.1333	0.0501	0.2300	
		Negative	508	-0.2076	-0.0711	0.3128	
		Absolute	**962**	**0.1726**	**0.0589**	**0.2792**	**8.38%**
ATM	0.95-1.05	Positive	4886	0.0517	0.0139	0.1346	
		Negative	5375	-0.0482	-0.0136	0.1043	
		Absolute	**10261**	**0.0498**	**0.0138**	**0.1197**	**89.40%**
OTM	0.85-0.95	Positive	121	0.2875	0.0765	0.4565	
		Negative	104	-0.1097	-0.0381	0.1790	
		Absolute	**225**	**0.2053**	**0.0518**	**0.3664**	**1.96%**
Total			**11478**				

We next analyse gross mispricing with respect to traded volumes. Traded volume up to 400 contracts is classified as 'thin', between 400 and 35000 contracts is termed 'moderate' and greater than 35000 contracts is defined as 'high'. The analysis in Table 5 shows that roughly 50% of the instances of mispricing are in respect of moderately traded options with a mean magnitude of mispricing of Rs.0.06. The frequency of mispricing is lower (25%) for thinly traded options but the mean magnitude of mispricing is higher (Rs.0.13).

Table 5. Mispricing as per traded volume

Traded contract volume	**Traded number of contracts**	**Instances of Absolute mispricing**	**Mean (Rs.)**	**Median (Rs.)**	**Standard Deviation**	**Percentage of mispricing instances**
Thin	Upto 400	2915	0.1296	0.0516	0.2125	25.40%
Moderate	400-35000	5762	0.0568	0.0162	0.1488	50.20%
High	> 35000	2801	0.0120	0.0057	0.0266	24.40%
Total		**11478**				

The gross absolute mispricing is analyzed with respect to time to maturity in Table 6 revealing that 73% of the instances of mispricing are in respect of options maturing in the range of 0 to 30 days. The remaining 27% of the cases are options maturing beyond 30 days. There are just 65 cases (0.57% of cases) of mispricing in respect of options with time to maturity beyond 90 days. The mean magnitude of mispricing is higher (Rs.0.08) in case of options with maturity beyond 30 days than in case of options with up to 30 days maturity (Rs.0.06). Thus we can conclude that while the frequency of mispricing is higher for shorter-dated options the magnitude of mispricing is higher for longer-dated options. Analysing the options with respect to time to maturity and traded volume we find that within all maturity buckets the frequency of mispricing is lowest and mean mispricing is highest in case of thinly traded options.

Table 6. Mispricing as per time to maturity

Time to maturity	**Traded Volumes**	**Instances of Absolute mispricing**	**Mean (Rs.)**	**Median (Rs.)**	**Standard Deviation**	**Percentage of mispricing instances**
Up to 7 days	Thin	440	0.1398	0.0490	0.2333	
	Moderate	1027	0.0510	0.0164	0.1280	
	High	566	0.0125	0.0055	0.0300	
	Total	**2033**	**0.0595**	**0.0147**	**0.1494**	**17.71%**
8-30 days	Thin	1312	0.1360	0.0528	0.2312	
	Moderate	3030	0.0565	0.0142	0.1634	
	High	1971	0.0117	0.0056	0.0254	
	Total	**6313**	**0.0590**	**0.0129**	**0.1614**	**55.00%**
Greater than 30 days	Thin	1163	0.1185	0.0514	0.1794	
	Moderate	1705	0.0610	0.0205	0.1324	
	High	264	0.0130	0.0063	0.0274	
	Total	**3132**	**0.0783**	**0.0255**	**0.1506**	**27.29%**

We lastly analyze the gross mispricing with respect to volatility of the underlying USD-INR rate. We measure volatility using a simple 10-day moving average of the standard deviation of daily logarithmic return of the closing exchange rate observed in the Mumbai inter-bank market. During the period under study, the annualized volatility of the USD-INR ranged from 3.06% to 24.29%, the average being 9.78%. We classify the data set into periods of low volatility (volatility less than 6%), moderate volatility (between 6% and 15%) and high volatility (greater than 15%). Table 7 reports a higher average mispricing (Rs.0.08) for the high volatility period as against Rs. 0.03 for the low and Rs.0.06 for the moderate volatility period.

Table 7. Mispricing as per volatility of the underlying

Annualized volatility	**Instances of mispricing**	**Mean (Rs.)**	**Median (Rs.)**	**Standard Deviation**
<0.06	593	0.0322	0.0063	0.1005
>0.06 < 0.15	8636	0.0616	0.0152	0.1533
> 0.15	2249	0.0834	0.0241	0.1777

Table 8. Tests of Normality for mispricing data categorized as per different parameters

Group	**Sub-category**	**Kolmogorov-Smirnov(a)**			**Shapiro-Wilk**		
		Test Statistic	**df**	**Significance**	**Test Statistic**	**df**	**Significance**
Option type	Calls	0.34825	5471	0.0000	-	-	-
	Puts	0.33275	6007	0.0000	-	-	-
Moneyness	DITM	0.23823	30	0.0001	0.86438	30	0.0013
	ITM	0.26838	962	0.0000	0.61615	962	0.0000
	ATM	0.33857	10261	0.0000	-	-	-
	OTM	0.30268	225	0.0000	0.58153	225	0.0000
Maturity	Upto 7 days	0.34529	2033	0.0000	0.38815	2033	0.0000
	8 - 30 days	0.35733	6313	0.0000	-	-	-
	> 30 days	0.30154	3132	0.0000	0.51048	3132	0.0000
Traded Volume	Thin	0.27105	2915	0.0000	0.58460	2915	0.0000
	Moderate	0.35128	5762	0.0000	-	-	-
	High	0.32616	2801	0.0000	0.34864	2801	0.0000
Volatility	Low	0.37445	593	0.0000	0.29425	593	0.0000
	Moderate	0.34396	8636	0.0000			
	High	0.31942	2249	0.0000	0.46259	2249	0.0000

(a) Lilliefors Significance Correction

While results clearly reveal differences in the mean level of mispricing across option moneyness, maturity, traded volume and level of underlying volatility, the statistical significance of such differences needs to be examined. We start with the null hypothesis that there is no significant difference in the mean level of absolute mispricing across the various sub-categories. We first examine the distribution of the absolute mispricing series in each sub -category in order to decide whether parametric or nonparametric tests of significance may be used.

Results of Kolmogorov-Smirnov and Shapiro-Wilk tests at a 5% level of significance reveal that the mispricing data are not normally distributed across any of the categories (Table 8). We therefore use nonparametric tests to test for difference in mean level of mispricing across the various categories.

We use the Wilcoxon Rank Sum test for two independent samples to test our null hypothesis that the difference in mispricing between calls and puts is not statistically significant. The Wilcoxon test statistic is -0.84974 which corresponds to a p-value of Pr(Z>-0.84974), i.e. 0.802264. Hence we cannot reject the null hypothesis and conclude that there is no significant difference between the mispricing for calls and puts.

We use the Kruskal-Wallis test to test for significance of difference in mean level of absolute mispricing in case of the other four parameters. This test is the nonparametric equivalent of the ANOVA and is an extension of the Mann-Whitney U test for two independent samples

Table 9. Results of Kruskal-Wallis test for significance of difference in mean mispricing across categories

Group	Sub-category	Sample size	Mean Rank	Test Statistic-H	Df	Asymp. Significance
Moneyness	DITM	30	10157.5000	785.3937	3	0.0000
	ITM	962	8205.8586			
	ATM	10261	5442.9761			
	OTM	225	8128.1867			
	Total	**11478**				
Maturity	Upto 7 days	2033	5605.6303	306.9866	2	0.0000
	8 - 30 days	6313	5350.3163			
	> 30 days	3132	6610.8519			
	Total	**11478**				
Traded Volume	Thin	2915	7946.8005	2696.6458	2	0.0000
	Moderate	5762	5762.7663			
	High	2801	3394.5012			
	Total	**11478**				
Volatility	Low	593	4087.0169	271.7201	2	0.0000
	Moderate	8636	5654.8110			
	High	2249	6500.4146			
	Total	**11478**				

Table 9 shows results of the the Kruskal-Wallis test at a 5% level of significance when the mispricing data is tested across various categories. The test-statistic H is high with a p-value of zero for each category. We therefore reject our null hypothesis and conclude that the differences in mispricing are statistically significant when analyzed across option moneyness, maturity, traded volume and underlying volatility.

While the Kruskal-Wallis test results show that mispricing differs significantly across various categories they do not show which particular pairs are significantly mispriced. We therefore perform post-hoc procedures for the Kruskal-Wallis test by running a Mann-Whitney U test for each pair with a simple Bonferroni correction. A simple Bonferroni correction involves dividing the threshold p-value to be achieved for significance (0.05 in our case) by the number of paired comparisons to be done. The number of paired comparisons to be made is equal to k(k-1)/2 where k is the number of groups.

Table 10. Results of Mann-Whitney U test comparing mispricing across moneyness groups

Pair	**Sub-group**	**Sample size**	**Mean Rank**	**Sum of Ranks**	**Mann-Whitney U**	**Z**	**Asymp. Significance. (2-tailed)**
DITM-ITM	DITM	30	744.7333	22342	6983	-4.8189	0.0000
	ITM	962	488.7588	470186			
DITM-ATM	DITM	30	9258.5333	277756	30539	-7.5930	0.0000
	ATM	10261	5133.9762	52679730			
DITM-OTM	DITM	30	185.2333	5557	1658	-4.5247	0.0000
	OTM	225	120.3689	27083			
ITM-ATM	ITM	962	8083.8399	7776654	2557631	-24.7474	0.0000
	ATM	10261	5380.2575	55206822			
ITM-OTM	ITM	962	596.2599	573602	106051	-0.4696	0.6386
	OTM	225	584.3378	131476			
ATM-OTM	ATM	10261	5190.7424	53262208	613017	-12.0518	0.0000
	OTM	225	7649.4800	1721133			

We test whether there is a significant difference in mispricing between different moneyness sub-groups by running a Mann-Whitney U test for each pair. The threshold p-value of 0.05 is divided by 6 since the comparisons are made across six pairs. Hence the result for any pair is significant only if the resulting p-value is less than 0.00833 (0.05/6). With the Bonferroni correction it is evident from Table 10 that there is a statistically significant difference in mispricing for all moneyness pairs except the ITM-OTM pair for which the p-value is higher than the corrected threshold value of 0.0083 and hence not significant. This is also apparent from the fact that the average ranks of the ITM and OTM sub-groups are 596.2599 and 584.3378 respectively which are quite close. Table 10 reveals that the mean level of absolute mispricing in DITM options is significantly higher than that of ITM options (mean rank =744.73 for DITM options as against 488.76 for ITM options) and also that of ATM (mean rank = 9258.53 for DITM as against 5133.97 for ATM) and OTM options (mean rank = 185.23 for DITM as against 120.37 for OTM options). Similarly the average mispricing in ITM options is higher than that in ATM options and the average mispricing in ATM options is higher than that in OTM options.

Table 11. Results of Mann-Whitney U test comparing mispricing across groups of different traded volumes

Pair	Sub-group	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Asymp. Significance (2-tailed)
Thin - Moderate	Upto 400	2915	5504.47	16045526	5000775	-30.8258	0.0000
	Between 400 and 35000	5762	3749.39	21603978			
Thin – High	Upto 400	2915	3900.33	11369468	1045517	-48.6930	0.0000
	Greater than 35000	2801	1774.27	4969718			
Moderate – High	Between 400 and 35000	5762	4894.88	28204285	4538280	-32.9046	0.0000
	Greater than 35000	2801	3021.24	8462481			

Table 12. Results of Mann-Whitney U test comparing mispricing across groups of different maturities

Pair	Sub-group	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Asymp. Significance (2-tailed)
Upto 7 days with 8 - 30 days	Upto 7 days	2033	4318.157	8778814	6123077	-3.1125	0.0019
	8 - 30 days	6313	4126.915	26053218			
Upto 7 days with greater than 30 days	Upto 7 days	2033	2304.473	4684994	2617433	-10.8153	0.0000
	Greater than 30 days	3132	2763.793	8656201			
8 - 30 days with greater than 30 days	8 - 30 days	6313	4380.4008	27653470	7723329	-17.3364	0.0000
	Greater than 30 days	3132	5413.5584	16955265			

Results of pair-wise Mann-Whitney tests run for groups with different traded volumes are shown in Table 11. It is evident that there is a statistically significant difference in the mean level of mispricing across the different groups as the p-value is zero for each of the tests (lower than the corrected threshold p-value of 0.01667). We conclude that the mean mispricing is higher for thinly traded contracts (average rank: 5504.47) as against moderately traded contracts (average rank: 3749.39) and highly traded contracts (average rank: 1774.27). Again moderately traded contracts exhibit a higher mean level of mispricing (average rank: 4894.88) as against highly traded contracts (average rank: 3021.24).

Results of pair-wise Mann-Whitney U tests on options within different maturity groups show that the mean level of mispricing differs significantly across different maturity groups (p -value = 0 for all 3 tests which is less than the corrected threshold p-value of 0.01667). We can further conclude that the average mispricing is higher for options maturing within 7 days (mean rank = 4318.16) as compared to options maturing within 30 days (mean rank = 4126.92). Also options with a maturity longer than 30 days exhibit higher average mispricing than those maturing within 7 days and within 30 days.

Table 13. Results of Mann-Whitney U test comparing mispricing across periods of different volatilities

Pair	Sub-group	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Asymp. Significance (2-tailed)
Low - Medium	Low volatility	593	3416.14	2025773	1849652	-11.3273	0.0000
	Medium Volatility	8636	4697.32	40566062			
Low - High	Low volatility	593	967.874	573949	397828	-15.1333	0.0000
	High Volatility	2249	1541.11	3465954			
Medium -High	Medium Volatility	8636	5275.99	45563452	8268886	-10.8658	0.0000
	High Volatility	2249	6084.31	13683604			

Table 13 shows the results of Mann-Whitney tests run for sub-periods with different exchange rate volatility. The difference in mispricing is statistically significant across the different volatility periods as evident from the p-value of zero which is lower than the corrected threshold p-value of 0.01667. The mean level of mispricing is higher in the medium volatility period (average rank: 4697.32) as compared to the low volatility period (average rank: 3416.14). The high volatility period exhibits a higher level of mispricing as against the low volatility period and the medium volatility period.

Lastly we examine whether the behaviour of the market participants has changed over the period since trading of options started. The frequency of mispricing is expected to decline over a period as market participants become more familiar with the new instrument. We divide the total period of thirty two months into four eight-month periods and examine the magnitude and instances of mispricing in each period. The number of instances of mispricing shows an increase in all four periods which is contrary to expectations. The average magnitude of mispricing increased from Rs.0.04 in the first period to Rs.0.076 in the third period and then declined to Rs.0.0529 in the fourth period.

Following Mittnik and Rieken (2000) we test the pattern of mispricing over the four eight-month periods by running an Ordinary Least Squares regression for equation (3) which we rewrite as:

$$c - p = \alpha + \beta * (F - X)e^{-r(T-t)} + \acute{\omega}$$

If put-call parity holds, the intercept α should not be statistically different from zero and the coefficient β should not be statistically different from 1. The results of regression in Table 15 show that the p-value of the intercept term is greater than 0.05 in three of the four periods and in one of the periods it is 0.045. Thus we can conclude that overall the intercept is not statistically different from zero as we cannot reject the null hypothesis. The intercept is positive in the three of the periods indicating that at-the-money calls in these periods were on an average overpriced relative to at-the-money puts. A negative intercept in the last period suggests underpricing of at-the-money calls in this period. The β values are close to one but the p-values are all equal to zero and hence we reject the null hypothesis that β is statistically not different from 1. We therefore conclude that even though the mispricing is very small as evidenced by the α which is not statistically different from zero, put-call parity does not hold because the β values are statistically different from 1.

Table 15. Regression results for sub-periods of the data set

Period	Intercept	p-value	Beta	p-value	F	Significance	R squared
Oct2010-June2011	0.0044	0.1775	0.9868	0.0000	37340.87	0.0000	0.9578
Jul2011-Feb2012	0.0060	0.0880	0.9722	0.0000	248792.26	0.0000	0.9884
Mar2012-Oct2012	0.0070	0.0456	0.9811	0.0000	296495.41	0.0000	0.9888
Nov2012-June2013	-0.0015	0.5544	0.9978	0.0000	469910.39	0.0000	0.9925

7. Conclusion

Our study of put-call parity in respect of USD-INR options and futures shows the following:

a. In general put-call parity does not hold as the regression shows that β values are statistically different from 1.

b. A positive intercept for the regression in three of the four sub-periods examined suggests relative overpricing of at-the-money call options during those periods.

c. Despite the large number of instances of mispricing the number of profitable opportunities are smaller, 80.75% for members of the exchange and 44.84% for retail investors.

d. The frequency of mispricing is higher for at-the-money options but the magnitude of mispricing is larger for deep-in-the-money and in-the-money options as compared to at-the-money and out-of-the-money options.

e. The frequency of mispricing is smaller but the magnitude of mispricing is larger for thinly traded options.

f. The frequency of mispricing is higher for options with maturity up to 30 days but the magnitude of mispricing is larger for options maturing beyond 30 days.

g. The mean amount of mispricing is higher for periods of high volatility than for periods of low and moderate volatility.

h. The instances of mispricing have continued to grow since the inception of trading in currency options which is contrary to expectations of the learning behaviour.

Our findings regarding the frequency of violations are consistent with those of Evnine and Rudd (1985) who also found frequent violations in the S&P100 index options when the market was young. The number of profitable opportunities also points to an inefficient market. Members could make a net annualized return of more than 50% in 177 cases (1.91% of the sample) and in excess of 100% in 73 cases (0.79%). Retail investors with no special edge in the market in terms of trading costs could also have made net annualized return in excess of 50% in 159 cases (3.09% of the sample) and in excess of 100% in 67 cases (1.3% of the sample). Again these results are in line with those of Vipul (2008) who studied the violations of PCP in early stages of the Nifty options market. The result that mispricing is more severe for less liquid, deep in-the-money and out-of-the money options and during periods of higher volatility is consistent with those of Kamara and Miller (1995), Ackert and Tian (1999) and Draper and Fung (2002) for the US and UK markets. Our finding that the average magnitude of mispricing declines as options approach maturity is similar to that of Klemkosky and Lee (1991). The high execution risk in all these cases leads to higher mispricing. Contrary to the finding of Vipul (2008) that put options are more frequently overpriced than call options we report relative overpricing of calls in three sub-periods of our data set. Relative overpricing of puts in many studies by Chesney et al, (1994), Mittnik and Rieken (2000), Vipul (2008) has been attributed to short-sale restrictions which make it difficult for investors to short the index and thus exploit the mispricing. Since our study is based upon futures which can be shorted easily the question of short sale restrictions does not arise. The findings regarding learning behaviour or improvement in market efficiency are similar to those of Ackert and Tian (2000) who study spread relationships in the S&P 500 index options during the period 1986-1996 and find no marked improvement in market efficiency over that period. Mittnik and Rieken (2000) also conclude that put-call parity does not hold on the basis of their testing of the sample data from 1992-1995. They find consistent overpricing of puts throughout the sample period.

On the basis of the sample data set we conclude that there are frequent violations of put-call parity in the USD-INR currency options market and ex-post tests show profitable arbitrage opportunities. We therefore conclude that the market is not efficient. However since our study is based upon closing prices of options and futures it is exposed to the problem of non-synchronous data. Moreover our results are based on ex-post tests as ex-ante tests could not be conducted due to lack of intra-day data. There is scope for further research in this area using transaction data.

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