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Put-Call Parity in Equity Options Markets: Recent Evidence

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Abstract

There have been various studies of potential violations of put-call parity in US equity options markets, and the purpose of this study is to examine one potential explanation of these anomalous results. Cremers and Weinbaum [1] indicate a potential trading strategy that can obtain excess returns of up to 50 basis points per week, which is quite remarkable. However, none of these studies consider the fact that options markets have historically maintained different trading hours than those of their underlying security markets. While the US stock market has traditionally closed at 3:00 PM CST, options markets have variously closed between 3:10 and 3:02 PM CST over the past two decades. Using over ten million individual options implied volatility estimations since 1996, it is documented that these anomalies have all but disappeared since stock and option markets synchronized their trading hours. Beginning in the late 1990's, stock prices often move slightly or to a larger degree in "after-hours" trading, enabled by the advent of electronic trading platforms. Options markets that are still open may adjust to subsequent stock market movements, although closing stock prices are reported as of 3:00 PM CST. Prior studies may have ignored these effects, and this is the first study to indicate that apparent deviations from put-call parity have decreased markedly over recent years, if they were ever economically significant at all.

Keywords

Options, Put-Call Parity, Excess Returns, Nonsynchronous Trading

1. Introduction

As stated in Cremers and Weinbaum [1], "Put-call parity is one of the simplest and best-known no-arbitrage relations. It requires neither assumptions about the probability distribution of the future price of the underlying asset, nor conti-

nuous trading, nor a host of other complications often associated with option pricing models" (p. 335). The arbitrage relationships among call and put options are described by the following equation:

$$S + P = C + Ke^{-rT}$$

where S equals the current stock price, P equals a particular strike price and maturity of a put option, C equals the equivalent strike price and maturity of a call option, and Ke^{-rT} equals the present value of the strike price using the risk-free rate and time to maturity in years. If this relation is violated, potential arbitrage opportunities exist in the absence of transactions costs and/or a bid/ask spread. In their study, Cremers and Weinbaum [1], they find that differences in call and put implied volatilities create potential opportunities for excess profits. However, they do not consider the effects of "after hours" trading, which became prevalent during the late 1990's, via online the earliest electronic trading networks such as Instinet, Island, and NYSE Arca. This phenomenon may have resulted in potentially spurious put-call parity results based on non-synchronous data observations, since options markets historically have closed later than their underlying security markets. Over the past three decades, options markets have alternatively closed at 3:10, 3:02, and 3:00 CST, which may have created the appearance of arbitrage profits that did not really exist.

Regarding the implications of put-call parity, An, Ang, Bali, & Cakici [2] finds a positive relation among increases in call implied volatilities and future stock returns, which may have been artificially supported by the differences in options and stock trading hours, although they report multi-month return differences. Therefore, their results may have been given a "head start" due to nonsynchronous trading issues, although the overall results may not be perfectly valid. Nishiotis and Rompolis [3] demonstrate that "the 2008 short-sale ban significantly enhanced the return predictability of put-call parity violations and attribute the significant increase in violations to stock over-valuation". Klemkosky and Resnick [4] [5] provide early evidence of potential arbitrage profits due to violations of put-call parity. In a study of the Israeli stock options market, Nissim and Tchahi [6] find evidence that violations of put-call parity are frequent and may result in potential arbitrage opportunities.

Additional evidence on this topic is provided by Haug and Taleb [7], who indicate that options traders do not price options based on traditional options pricing formulas, but rather based on very sophisticated heuristics, lending credence to the theory that option pricing models are not utilized in a rigorous fashion, and that traders adjust option pricing theory to reflect market realities. Kamara and Miller [8] find that violations of put-call parity are observed much more frequently for American options than for European options due to stock dividends, further complicating the issue.

The present study examines the change in options market trading hours when they became consistent with stock market closing prices. Prior studies have not accounted for the non-synchronous trading issues that existed in US options and

stock market hours prior to February 2006. Therefore, these studies indicate deviations from put-call parity that may appear to be opportunities for arbitrage profits. The contribution of the present study, however, is that it demonstrates that these apparent opportunities may have been an illusion.

Prior to February 2006, when options markets closed at 3:02 PM CST, market price movements in electronic trading networks distorted the appearance of put-call parity relationships, because option market-makers adjusted their bid and ask prices even though stock prices are reported as of 3:00 PM CST. Overall, a statistically significant decline in the differences between put and call implied volatilities occurs over time. This effect is clear even in a subset of the sample that only includes the two years prior to and after the change in option market closing time from 3:02 PM to 3:00 PM CST. Some part of this decline may be attributed to general overall improvements in market liquidity, but the previously documented deviations from put-call parity were also likely affected by the non-synchronicity of stock and option closing market hours.

2. Data and Methodology

The data for the present study is obtained from the Option Metrics® database, and includes 30-day standardized at-the-money call and put option implied volatilities (IV) for the period from January 4, 1996 to August 29, 2014, representing almost nineteen years of options trading activity for approximately 2500 individual stock options series. Implied volatilities for these stock options are calculated using the same methodology that the CBOE® employs to calculate the VIX index for S & P 500 index options, which is robust to dividends for American equity options.

After trimming the data for obviously erroneous entries (negative or missing IV estimates are removed from the database), there are 10,366,256 individual observations. The missing or erroneous observations most likely occur during expiration weeks for US equity options, when implied volatility can be notoriously volatile and difficult to measure. These observations number just 366,769, or 2.78 percent of the initial sample of 13,177,147. Additionally, this phenomenon is random and affects all US equities equally, therefore, the removal of these observations does not create an issue related to selection bias. Finally, the empirical analysis below examines deviations from put-call parity before and after periods of stock and option market trading time synchronicity. Therefore, only stocks with options that traded during the full sample period are included in the analysis of the final sample database.

Summary statistics for this data are presented in **Table 1**. As is evident from these statistics, the average of closing bid-ask put volatilities are significantly higher than call volatilities, which indicate potential violations of put-call parity, as noted by previous studies (e.g. Cremers and Weinbaum [1], Klemkosky and Resnick [4] [5], and Nishiotis and Rompolis [3]). The average call implied volatility is 44.72%, while that for puts is slightly higher at 44.89%. In both cases, the medians of these values are significantly lower than the means, indicating

Table 1. Summary statistics.

Variable	Obs.	Mean	Median	Std. Dev.	Minimum	Maximum
Put Implied Volatility	10,366,256	0.4489	0.3924	0.2426	0.0018	7.0449
Call Implied Volatility	10,366,256	0.4472	0.3872	0.2546	0.0015	13.9038
Average Implied Volatility	10,366,256	0.4480	0.3904	0.2454	0.0028	7.0472
IV Difference (Put Minus Call)	10,366,256	0.0016	0.0050	0.0805	−13.7131	0.2000
IV Difference Percent (Put/Call-1)	10,366,256	0.0141	0.0142	0.1392	−1.9548	1.9415

Data Source: OptionMetrics Implied Volatility Database US.

the presence of some outlying observations at high volatilities. The average IV difference in percentage points indicates that, on average, at-the-money put volatilities are approximately 1.41 percent higher than call volatilities, indicating a potential opportunity for arbitrage profits. However, the economic significance of these differences is the most important aspect of this study. Therefore, the question that needs to be answered is whether this difference is economically significant and whether it can be exploited in an economically significant way.

3. Empirical Results

In order to examine the nature of these differences and how they have evolved over time, two pairwise tests of means are conducted for the periods prior to February 1, 2006 and thereafter. This date reflects that change in option market closing times from 3:02 PM CST (US Central Standard Time—Chicago) to 3:00 PM CST. For a short time in the sample period under study, options markets closed at 3:10 PM CST, but that practice ended on June 23, 1997 (the data for the current study starts in January 1996), when the closing time was changed to 3:02 PM CST. The purpose of these tests is to determine whether, because of observations that occur prior to and after the change in trading hours, the results indicate violations of put-call parity that may not be economically significant, asposited by Cremers and Weinbaum [1].

The results of two pairwise comparisons of means are contained in **Table 2** below and indicate that the deviations from put-call paritymaynot be as significant as previously believed. In the first period, from January 1996 to January 2006 (Panel A), the mean difference in put and call volatilities is 1.60%. It should be noted that market participants often assume a 1.50% bid/ask spread in option implied volatilities, which would almost fully negate any potential gains from a strategy attempting to capitalize on potential "violations" of put-call parity. Additionally, this mean difference declines in the later period to 1.20% (starting in February 2006, when the change in the close of option trading hours from 3:02 CST to 3:00 CST occurred) indicating that some part of this decline may be attributed to previous asynchronous trading problems that may have risen from the advent of electronic trading networks that move market prices after the

Table 2. Pairwise comparison of means. (a) Average differences between put and call implied volatilities—full sample; (b) Average differences between put and call implied volatilities—sub-periods; (c) Pairwise comparison of means for full and sub-period samples.

(a)

Period	n	Mean	Std Err	Min	Max
01/1996-01/2006	4,248,288	0.016	0.117	−1.955	1.922
02/1006-08/2014	6,117,968	0.012	0.153	−1.947	1.941

(b)

Period	n	Mean	Std Err	Min	Max
02/2004-01-2006	918,346	0.022	0.102	−1.955	1.667
02-2006-01-2008	1,149,926	0.021	0.115	−1.947	1.841

(c)

Period	*t*-statistic
01/1996-01/2006 vs. 02/2006-08/2014	46.12
02/2004-01/2006 vs. 02/2006-01/2008	3.50

Data Source: OptionMetrics implied volatility database US.

"official" 3:00 CST stock exchange closing price is observed. The statistical difference between these results is highlighted in Panel C of Table 2 where the *t*-statistic of 46.12 is extremely highly significant at the one-percent level. While this result may be inferred to be the result of the general increase in market efficiency over recent years, further analysis may indicate otherwise.

As noted, this result may be due to increased market efficiency over the past several decades, and a more specific approach may supply more direct results. This is because, although these results may be strongly statistically significant, some observers may point out that they may just be related to increased efficiency in markets created as electronic systems and increased market liquidity have affected options markets. In order to examine this issue more directly, the two-year periods immediately preceding and following the change in trading hours are examined in Panel B of Table 2. The mean level of IV differences increases during this period which presages and occurs during the global financial crisis (GFC), but there is still a marked difference in the "before and after" periods. Mean implied volatility differences between call and put options decline from 2.20% to 2.10% surrounding this event. While the difference in these elevated spread levels (due to the GFC) may seem small and the decline may not seem to be that great, the *t*-statistic for the difference remains strong at 3.50, which is once again significant at the one-percent level. Therefore, there may have been an effect on put-call parity relationships from the changing market closing hours.

As a test of robustness, one other unique US stock and option market pheno-

menon is examined relative to this issue. As of April 9, 2001, the Securities and Exchange Commission (SEC) issued a regulation that all US stock and option markets are required to trade securities in decimals, as opposed to the prior fractional price environment. If there is a decrease in the pre- and post-decimal eras, that may account for some of the decrease in deviations from put-call parity, as a measure of increased market efficiency. Therefore, a pairwise comparison of means test is conducted in similar fashion to Panel A of table two, but using April 9, 2001 as the defining date. The results indicate that while the decrease in average differences in put and call implied volatilities in the original analysis was approximately 0.40% (from 1.60% to 1.20% in Panel A of **Table 2**), this reduction was only of 0.08% for the decimalization event. Thus, while up to 20 percent of the decrease surrounding 2006 may have been due to decimalization, the vast majority of the decrease seems to be attributable to the synchronization of stock and option market trading hours.

4. Conclusions

The results of the present exploratory study do not include the extensive asset-pricing tests that are conducted by Cremers and Weinbaum [1] and other studies referenced in this article. However, the analysis indicates that these previously documented results may have been affected by changes in option exchange trading hours that were not previously noted. The implications of the study are relevant to researchers in financial markets where non-synchronous trading hours of related securities may create the appearance of arbitrage opportunities where there are none. Future research may apply the empirical framework of this study to the vast array of related financial market instruments, especially when they trade during different market hours and/or time zones.

The analysis indicates that a decline in differences in otherwise identical put and call implied volatilities has occurred over time, especially during the period when options market trading hours change from a closing time from 3:02 PM to 3:00 PM CST. The rise of electronic trading networks (and electronic options markets) clearly contributed to overall market efficiency. However, their effect on option market makers and designated primary market-makers (DPM's) after the stock market close may have created the appearance of potential arbitrage opportunities that did not exist in reality.

Overall, the paper documents increased efficiency in equity options markets, despite the disruptions that occurred during the global financial crisis. These efficiencies may have been responsible for eliminating potential arbitrage opportunities that have been documented in previous research, especially when considering the effects of changing option market closing times.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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