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Efficiency in Index Options Markets and Trading in Stock Baskets

Lucy F. Ackert and Yisong S. Tian

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Abstract: Researchers have reported mispricing in index options markets. This study further examines the efficiency of the S&P 500 index options market by testing theoretical pricing relationships implied by no-arbitrage conditions. The effect of a traded stock basket, Standard and Poor's Depository Receipts (SPDRs), on the link between index and options markets is also examined. Pricing efficiency within options markets improves, and the evidence supports the hypothesis that a stock basket enhances the connection between markets. However, when transactions costs and short sales constraints are included, very few violations of the pricing relationships are reported.

JEL classification: G13, G14

Key words: index options, pricing efficiency, traded stock baskets

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Please address questions regarding content to Lucy F. Ackert, Research Department, Federal Reserve Bank of Atlanta, 104 Marietta Street, NW, Atlanta, Georgia 30303-2713, 404/521-8783, lucy.ackert@atl.frb.org, or Yisong S. Tian, Department of Finance, Schulich School of Business, York University, Toronto, Ontario M3J 1P3, 416/736-5073.

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I. Introduction

The no-arbitrage principle is a powerful tool in the pricing of financial assets because it does not rely on strong assumptions about traders' behavior or market price dynamics. The principle simply assumes that if riskless profit opportunities exist, arbitrageurs enter the market and quickly eliminate the mispricing. Arbitrage is critical to ensure market efficiency because it forces asset prices to return to their fundamental values. In some situations, market frictions limit arbitrage so that arbitrageurs just cannot take advantage of the profit opportunities presented by mispricing. For example, in a market with capital constraints, arbitrageurs may be ineffective in their attempts to move the market toward an efficient state if they cannot raise the capital necessary to form the riskfree portfolio (Shleifer and Vishny (1997)).

Some earlier studies report evidence of mispricing of index call and put options in the United States (Evnine and Rudd (1985), Chance (1986), (1987)) and Canada (Ackert and Tian (1998a)), though arbitrage may be limited due to liquidity risk (Kamara and Miller (1995)). Liquidity risk arises from the possibility of an adverse price movement before a desirable trade can be executed. If options are priced inefficiently, an arbitrage transaction requires trade in multiple assets and, in the case of index options, one of these assets is itself a stock portfolio consisting of many assets. Thus, mispricing may not be an indication of market inefficiency because the asset underlying the options is not easily or costlessly reproduced. To arbitrage from mispriced stock index options an investor may need to replicate the index, i.e., the investor may need to buy or sell a basket of stocks that is perfectly correlated with the index. This can be difficult and costly even for large investors.

In the 1990s stock exchanges introduced index derivative products that replicate stock baskets and trade just like any other share of stock. These products are not actively managed and are designed to track an existing stock index. For example, since March 1990 investors in Canada are able to trade Toronto Index Participation Units (TIPs) which are constructed to track the performance of the Toronto 35 index. In the United States, the American Stock Exchange (AMEX) introduced Standard and Poor's Depository Receipts (SPDRs), or spiders, in January 1993. This index derivative product is designed to replicate the S&P 500 stock index. Efficiency should be enhanced with the introduction of these traded stock baskets because market participants can easily replicate the asset underlying index option contracts.

The objective of this study is to empirically examine the efficiency of the market for S&P 500 index options. Earlier studies find frequent violations of theoretical option pricing relationships. In addition to providing new results on the efficiency of the S&P 500 index options market, our study extends this research by examining the effect of a traded stock basket on the effectiveness of information exchange between index and option markets and on option market efficiency. We investigate whether index options are priced correctly relative to one another by testing theoretical pricing relationships implied by no-arbitrage conditions, both before and after the inception of SPDRs trading. These no-arbitrage conditions place bounds on possible call and put option prices (boundary conditions, call and put spreads, and convexity) and imply relative pricing relationships between put and call option prices (put-call parity, box spread). We compare the number and size of violations in S&P 500 index option relations before and after the introduction of SPDRs. Significant violations of pricing relations across option and stock markets (boundary conditions and put-call parity) after the introduction of SPDRs may indicate market inefficiency because arbitrage based on these violations can be executed with relatively low cost and effort with the trading of a stock basket. Other arbitrage relations we examine are independent of the stock price (box, call, and put spreads and convexity). These tests provide insight into how the efficiency of the options market has evolved over time and are not dependent on simultaneous data from options and stock markets (Ronn and Ronn (1989)).

All of the pricing relationships we examine are independent of an option pricing model so that no assumptions concerning the process underlying the stock price is required. Thus, empirical tests of these types of relationships are true tests of market efficiency instead of joint tests of market efficiency and model specification. We adjust for discrete dividend payments and recognize the limits that transactions costs, short sales constraints, and bid-ask spreads place on arbitrage. We also examine whether no-arbitrage violations are systematically related to time, the term to maturity, movements in the stock market, or liquidity risk.

Since SPDRs were first offered in 1993, the product has become one of the most actively traded issues on the AMEX. SPDRs are securities that represent an interest in a trust with accumulated dividends paid quarterly. The cash dividend reflects a pro rata amount of regular cash dividends accumulated by the trust during the preceding quarterly period. SPDRs are designed to approximate 1/10th of the value of the S&P 500 index, so that trading prices will fall in the range of a typical stock. An investor who holds a prescribed number of SPDRs may actually redeem them for the underlying stock at any time. This feature is particularly important because it reduces liquidity risk and facilitates arbitrage (Ackert and Tian (1998b)). With this stock basket, investors can trade a single security that represents a diversified portfolio of the corporations in the S&P 500 index.[1]

The results reported subsequently indicate significant mispricing of call and put options both before and after the introduction of SPDRs. We also find that SPDRs trading reduces mispricing and enhances the connection between markets, ignoring transactions costs and short sales constraints. However, once transactions costs and constraints on short sales are included in the analysis, we report a small percentage of violations in boundary conditions and put-call parity over the entire sample period, consistent with earlier research (Kamara and Miller (1995)). When we recognize these limits to arbitrage, we do not observe a significant reduction in the mean boundary or put-call parity violation after SPDRs are introduced. Thus, the impact of SPDRs trading is limited in practical terms because of the significance of other trading costs including commissions, bid-ask spreads, and short sales constraints. We also report a decrease in violations of relationships that are independent of the stock price (box, call, and put spreads and convexity) suggesting an improvement in the pricing of options relative to each other.

The remainder of the paper is organized as follows. In section II we review the evidence concerning the efficiency of index option markets. In section III we describe our methodology. The data employed in our examination of option market efficiency and the empirical results are described in section IV. Section V reports the results of additional analysis into the determinants of violations of pricing relations. The final section provides discussion of the results and concluding remarks.

II. Efficiency of Index Option Markets

Many empirical studies have tested pricing relations between put and call index options. Some of these tests are based on theoretical models for option pricing, such as the Black-Scholes (1973) Option Pricing Model or the Cox, Ross, and Rubinstein (1979) Binomial Option Pricing Model. Other tests are based on arbitrage arguments and are thus model independent, including tests based on boundary conditions, put-call parity, and the box spread. For example, Evnine and Rudd (1985) use intra-day data for a two month period in 1984 and find that S&P 100 and Major Market index options frequently violate boundary conditions and put-call parity. They also conclude that these options are significantly mispriced relative to theoretical values based on the Binomial Option Pricing Model. Chance (1987) also finds that put-call parity and the box spread are violated frequently for S&P 100 index options and the violations are significant in size. However, these results may not be an indication of market inefficiency for several reasons.

Kamara and Miller (1995) point out that prior to their study, tests of put-call parity use American options.[2] Because of the possibility of early exercise, put-call parity may not hold for American options. In their tests using S&P 500 index options that are European, Kamara and Miller find fewer and smaller violations.

Another reason why tests of put-call parity may not indicate market inefficiency is because arbitrage at low cost may not have been possible. In Canada a stock basket, TIPs, has been traded since 1990. Ackert and Tian (1998a) examine the efficiency of Canadian index and options markets by comparing the number and size of violations in theoretical pricing relationships before and after the introduction of TIPs. They conclude that although option market efficiency improved over their test period, the connection between option and stock markets did not.

In summary, the results reported in earlier studies using U.S. data suggest that put-call parity is frequently violated in index option markets and that these options are often mispriced based on theoretical models. This study extends earlier work in several ways. We test theoretical pricing relationships based on no-arbitrage conditions for European index options and compare results before and after introduction of a stock basket (SPDRs) of the underlying index, the S&P 500. We also include the effects of transactions costs, short sales constraints, bid-ask spreads, and discrete dividend payments. Finally, we examine whether deviations from pricing relations can be explained by features of the option and stock markets, including liquidity.

III. Tests Based on Arbitrage Pricing Relationships

Arbitrage pricing relationships are model independent and are based on the simple assumption that investors prefer more to less. If these pricing relationships are violated by actual prices after adjustment for the bid-ask spread and transactions costs, arbitrage profits may be possible by taking appropriate long positions in the underpriced asset(s) and appropriate short positions in the overpriced asset(s).

Several arbitrage pricing relationships are examined in this study.[3] The first two (boundary conditions, put-call parity) are joint tests of option and stock market efficiency and allow us to examine the exchange of information between these markets. The others (box, call, and put spreads and convexity) test option market efficiency and allow us to examine how pricing has evolved over time. As options on the S&P 500 index are European, the discussion below applies to European options only. The approach incorporates adjustment for discrete dividend payments. We define:

C^b: bid price of European call option;
C^a: ask price of European call option;
P^b: bid price of a European put option;
P^a: ask price of a European put option;
S^b: bid price of the index;
S^a: ask price of the index;
X: strike price;
T: maturity of the option;
r: risk-free rate of interest or treasury bill rate;
D: present value of dividends paid on the index from the current date to date T, discounted at

the risk-free rate of interest;

λ_S: percent of proceed available to short sellers in the stock market;

t_i: transactions costs (other than those arising from the bid-ask spread) of buying or selling calls, puts, shares, or t-bills, i = c, p, s, or r.

The first arbitrage pricing relationship we examine is the *boundary condition*. The relationship we test accounts for the bid-ask spread because bid-ask spreads result in significant transactions costs for participants in options markets (Baesel, Shows, and Thorpe, 1983; Phillips and Smith, 1980). The condition is given by the following inequality for a call option:

$$(C^a + t_c) - \max(\lambda_S(S^b - D) - t_s - (Xe^{-rT} + t_r),\ 0) \geq 0. \tag{1a}$$

For a put option the boundary is

$$(P^a + t_p) - \max((Xe^{-rT} - t_r) - (S^a - D + t_s),\ 0) \geq 0. \tag{1b}$$

These inequalities define the minimum value for call and put options, respectively. If a boundary condition is violated, the option is undervalued relative to the index and arbitrage profits are possible if the index can be replicated at low cost. For example, if (1a) is violated, the index call option is underpriced relative to the index. The arbitrageur would sell the index and buy the call, investing the balance in a money market account earning the risk-free rate. In the case of exercise of the call at maturity, the arbitrageur closes the index position and earns a risk-free profit at time T of $[\lambda_S(S^b - D) - t_s - (C^a + t_c)]e^{rT} - (X + t_r e^{rT}) > 0$.

The second arbitrage pricing relationship examined is *put-call parity*. Intuitively, a pair of call and put options with identical maturity and strike price should be priced correctly relative to each other. Mathematically, put-call parity is expressed as follows:

$$(C^a + t_c) - (P^b - t_p) + (Xe^{-rT} + t_r) - (\lambda_S(S^b - D) - t_s) \geq 0 \qquad (2a)$$

and

$$(P^a + t_p) - (C^b - t_c) + (S^a - D + t_s) - (Xe^{-rT} - t_r) \geq 0. \qquad (2b)$$

If either of these parity relationships is violated, arbitrage profits are possible when the index can be replicated at low cost. The call is underpriced relative to the put if (2a) is violated. In this case, arbitrage profits are generated by selling the put and the index and buying the call. The remainder of the proceeds is invested in a money market account that earns the risk-free rate. Similarly, if (2b) is violated, the put is underpriced relative to the call. Arbitrage profits are generated by selling the call and borrowing Xe^{-rT} at the risk-free rate while at the same time buying the put and the index.

The next set of arbitrage pricing relationships we investigate includes *box, call, and put spreads and call and put convexity*. As only options are involved, an examination of these relationships may provide a superior test of parity among index options. For example, Billingsley and Chance (1985) and Ronn and Ronn (1989) note that put-call parity tests are joint tests of option and stock market efficiency whereas tests of the box spread consider only option market efficiency. Other advantages of these relationships are that they consider only feasible transactions and are unaffected by the different closing times in stock and option markets.

Efficiency of the option market may improve over time due to factors other than the introduction of SPDRs. Box, call, and put spreads and call and put convexity allow us to gauge whether market efficiency improved over our sample period irrespective of SPDRs trading and provide a control for changes in efficiency over the sample period. Thus, we can examine whether option market efficiency is enhanced after SPDRs trading is introduced, in addition to examining the link between the index and option markets using boundary and put-call parity relationships.

The box spread creates a riskless position by combining vertical call and put spreads. The spread relationship between call and put prices is similar to put-call parity as expressed above in (2a) and (2b) except that two pairs of matched call and put options are used and the index itself is removed from the relationship. If bid-ask spreads and transaction costs are taken into account, the box spread is expressed by the following two inequalities:

$$(C_1^a - C_2^b + 2t_c) - (P_1^b - P_2^a - 2t_p) + (X_1 - X_2)e^{\&rT} \% t_r \ \$ \ 0 \tag{3a}$$

and

$$(C_2^a - C_1^b + 2t_c) - (P_2^b - P_1^a - 2t_p) + (X_2 - X_1)e^{\&rT} \% t_r \ \$ \ 0. \tag{3b}$$

The call (put) spread combines call (put) options with identical maturity, where $X_1 < X_2$. The call spread is expressed as:

$$C_2^a - C_1^b + 2t_c + (X_2 - X_1)e^{\&rT} \ \% \ t_r \ \$ \ 0, \tag{4a}$$

and the put spread as:

$$P_1^a - P_2^b + 2t_p + (X_2 - X_1)e^{\&rT} \ \% \ t_r \ \$ \ 0. \tag{4b}$$

Similarly, call (put) convexity creates a riskless position by combining three call (put) options where $X_1 < X_2 < X_3$. Call convexity is expressed as:

$$wC_1^a + (1-w)C_3^a - C_2^b + 2t_c \geq 0, \tag{5a}$$

and put convexity is:

$$wP_1^a + (1-w)P_3^b - P_2^b + 2t_p \geq 0 \tag{5b}$$

where $w = (X_3 - X_2)/(X_3 - X_1)$. If the box, call, or put spreads are violated, arbitrage profits are possible by taking appropriate option positions. Similarly, if call or put convexity is violated, risk-free profit opportunities are present in the options market.

All five arbitrage pricing relationships are investigated for S&P 500 index options on each trading day in our sample, as described in the following section. The number and size of violations are recorded and analysed. In order to lend insight into the effect of trading in a stock basket on the efficiency of index option markets, we compare the periods prior and subsequent to the introduction of SPDRs. If the number and size of violations of relationships (1a) - (2b) are significantly lower in the later time period, the results suggest that market efficiency may be enhanced by the trading of a stock basket that replicates the index. Arbitrage based on these relationships requires a position in the underlying index and such a position can be taken at lower cost with SPDRs trading. In addition, relationships (3a) - (5b) allow us to examine the evolution of the index options market and provide insight into whether market efficiency increased over our sample period. Arbitrage based on these relationships does not require a position in the underlying asset so that SPDRs trading is not expected to have an effect.

IV. Results

SPDRs began trading on the AMEX on January 29, 1993. We empirically investigate the efficiency of the S&P 500 index option market during the twenty-four-month period from February 1, 1992 through January 31, 1994. This data set allows us to compare the efficiency of the market before (February 1, 1992 through January 28, 1993) and after (January 29, 1993 through January 31, 1994) the introduction of the stock basket. The SPDRs initial trading date divides the test period into two subperiods with approximately the same number of observations. Daily closing prices, trading volume, and open interest for S&P 500 index call and put options are from the Chicago Board Options Exchange. SPDR price and dividend data are from the CRSP daily database and S&P 500 index and dividend data are from the Standard and Poor's Corporation through the DRI database. The three-month treasury bill rate (our proxy for the risk-free interest rate) is from the Federal Reserve Bulletin. Although closing option and stock prices are nonsynchronous, these prices are representative of prices throughout the day.[4] Our approach is conservative in that we use bid and ask prices, rather than closing prices, in testing the pricing relationships.[5] We follow Harris, Sofianos, and Shapiro (1994) and Kamara and Miller (1995) and construct bid and ask prices from closing prices. We estimate the option (index) bid-ask spread by adding or subtracting one thirty-second of a point (one sixteenth) because the typical spread on the options (index) is one sixteenth (one eighth).

On each trading day during the test period, five pricing relationships are tested: boundary conditions ((1a) and (1b)), put-call parity ((2a) and (2b)), the box spread ((3a) and (3b)), call and put spreads ((4a) and (4b)), and call and put convexity ((5a) and (5b)).[6] Boundary conditions are tested for each option individually. Then, for each maturity month and trading day, all puts and calls with identical strike prices are matched to examine put-call parity. There may be more than one pair of matched puts and calls for any given maturity month. Next for each maturity month, two pairs of put and call options are used to examine the box spread. The put and call within each pair are matched with identical strike price, but two different strike prices are used for the two pairs. In contrast, the call (put) spread combines two call (put) options with identical maturity and different strike prices. Finally, call (put) convexity combines three call (put) options with identical maturity and different strike prices.

The frequency and severity of violations of the boundary conditions, put-call parity, and the box spread are tabulated for the two sample periods.[7] Comparing the extent of boundary condition and put-call parity violations in the subperiods before and after the introduction of SPDRs gives a clear indication of the effect of trading in a stock basket on option market efficiency. In addition, examining violations in box, call, and put spreads and convexity for the two subperiods provides insight into how the efficiency of the options market has changed over time, independent of the stock market because arbitrage does not require a position in the underlying index. We examine the effect of transactions costs and short sales constraints on pricing efficiency. Transactions costs include bid-ask spreads and commissions. Following Kamara and Miller (1995), commission costs (t_i) are \$30 for treasury bills, \$2 (\$4) per options contract for 100 shares if the price is less than (greater than or equal to) \$1, and \$10 for one round lot of stock or 100 shares.

Tables 1 through 6 report the frequency and percentage of violations, as well as the mean violation in dollars. We test for significant dollar violations by testing the null hypothesis that the mean dollar violation is zero. We also investigate whether the dollar value of violations decreases after the introduction of SPDRs. To do so, we use a t-test of the null hypothesis that the mean dollar violation is equal before and after the introduction of SPDRs. All reported t-statistics use standard errors corrected for autocorrelation using a maximum likelihood procedure with a Gauss-Marquardt algorithm (Judge, Griffiths, Hill, Luktepohl, and Lee, 1985).[8]

Tables 1 and 2 report boundary violations for call and put index options before and after the introduction of SPDRs. For the call options, the percentage and dollar amount of violations is lower in the later time period (5.81% and $1.05 versus 5.34% and $0.96), though not significantly so. For the put options, the percentage of violations increases (2.04% versus 2.64%) and the mean violation in dollars decreases ($0.97 versus $0.93), though again the decrease is insignificant. However, for call and put options over both subperiods, the mean violation is large and significantly different from zero. Overall, when we ignore short sales constraints and commission costs, the tests indicate that although the size of the violation is statistically significant, market efficiency is high. Only approximately 5% of observations result in violation of the boundary conditions. When the analysis reflects commission costs ($t_i > 0$) in addition to transaction costs generated by the bid-ask spread, the frequency of violations declines substantially. Furthermore, when arbitrageurs are limited to the use of 99 percent of short-sales proceeds ($8_S = 0.99$), we observe very few violations.[9] Although there is a significant decrease in the mean dollar violation of the call boundary (t = 43.83), only 9 of 16,305 observations results in a violation. For the put boundary, Table 2 reports not even a single violation in 24,042 observations. This result is not surprising because boundary conditions do not place strong restrictions on pricing.

Tables 3 and 4 report tests of the put-call parity relationships expressed by inequalities (2a) and (2b). Many more violations of put-call parity are observed, as compared to the frequency of boundary violations. For inequality (2a) the percentage and dollar amount of violations are lower in the later time period (51.52% and $0.83 versus 38.19% and $0.73) but for inequality (2b) both measures increase over time (36.88% and \$0.85 versus 49.91% and \$0.87). We observe a statistically significant decrease in the mean violation for inequality (2a) and an insignificant increase for inequality (2b). For both inequalities and sample periods we again observe mean violations that differ significantly from zero. When the analysis reflects commission costs, the percentage of violations is cut almost in half. Furthermore, when we include short sales constraints, we observe almost no violations of either put-call parity relationship. Taken together, the results in Tables 3 and 4 suggest that the relative pricing of calls and puts conforms better to put-call parity after the inception of SPDRs trading. However, we see little practical impact once the additional costs of arbitrage are recognized because very few violations existed even in the earlier time period.

The frequency and severity of violations of the box spread, inequalities (3a) and (3b), are reported in Table 5 and 6. Note that we do not consider the case of short sales constraints ($8_S < 1.0$) because the spread relationship does not involve transactions in stock. Again we observe mean dollar violations that are significantly different from zero before and after the introduction of SPDRs. For inequality (3a) the percentage and dollar amount of violations are similar in the period before and after SPDRs are introduced (35.60% and \$0.80 versus 35.78% and \$0.79) though we see some decrease in both for inequality (3b) (40.54% and \$0.87 versus 39.13% and \$0.81). Though the average dollar violations for inequalities (3a) and (3b) decrease after SPDRs trading commenced, the decline is only significant for (3b). When commission costs are included in the analysis, the frequency of violations decreases substantially but the mean dollar value of the violations does not decline. Although these results provide some evidence that option market efficiency increased over the two test periods, the frequency of violations remains high at approximately 20% of observations after taking into account trading costs.

To provide further insight, we examine violations of call and put spreads ((4a) and (4b)) and call and put convexity ((5a) and (5b)). Though not reported in the tables, we observe significant mean dollar violations for all four relationships. However, for all four we also observe a decrease in the mean dollar violation in the later time period, with three of four decreases significant at the 5% level. Furthermore, the maximum percentage of violations across the four inequalities is only 4.36% (2.36%) when commission costs are ignored (included). These results suggest that option market valuations were very close to these theoretical predictions and market efficiency improved over the sample period.

To further investigate the persistence of violations in pricing relationships, we investigate whether arbitrage opportunities are evident the day following observed violations. Although significant violations of all three pricing relationships are observed, Galai (1977) points out that a true test of market efficiency must be an ex ante test. Ex ante test results are reported in Tables 7 through 12 for the boundary conditions, parity relationships, and box spread. In order to conduct these ex ante tests, we identify each day on which a particular violation occurs and track whether the violation persisted on the following trading day. So, for example, we observe 465 violations of the call boundary condition (see Table 1) and of those violations, 70 or 15.05% persist on the following day (see Table 7). Without exception, the ex ante tests indicate that significant abnormal profit opportunities existed even the day *following* the violation of a pricing relationship. However, when transactions costs and short sales constraints are included, we find no ex ante violation of the call and put boundaries or put-call parity.

As a further check on the robustness of our results, we examined whether violations identified with the S&P 500 index could be exploited through SPDRs trading (with adjustment for dividends).

Using data for the period after SPDRs were introduced, we found that even though the tracking between SPDRs and the index is imperfect, profit opportunities persist.[10] The majority of the violations remain. The dollar value of violations remains statistically different from zero even though strategies based on the violations of some relationships require selling under-valued SPDRs.

Taken together, the results suggest that S&P 500 index options are frequently mispriced to a significant extent. We observe significant violations of arbitrage pricing relationships even using ex ante tests and after the introduction of SPDRs. SPDRs trading appears to have reduced mispricing in the inter-market relationships ((1a), (1b) ,(2a), and (2b)). However, for these relationships, when we recognize the existence of commission costs and constraints on short sales, very few violations are observed. SPDRS trading removes one of the limits to arbitrage, but other costs are significant. Our results indicate that although options market efficiency improved over time, the link between pricing in options and stock markets is dominated by other constraints on arbitrage.[11]

V. Determinants of Violations

Next we use regression analysis to examine the determinants of the size of violations in the pricing relationships. Kamara and Miller (1995) examine whether deviations from put-call parity reflect a premium for liquidity risk, rather than market inefficiency. Following Kamara and Miller we measure the violation (the dependent variable in each regression) using the dollar violation ignoring commission costs and short sales constraints, i.e., the maximum violation. In addition to examining the impact of liquidity on price, we investigate whether deviations in prices from theoretical predictions systematically vary across other market features. We use a Tobit censored regression model because when a pricing relationship holds, the dependent variable is censored or unobservable.

Following Kamara and Miller, we use a bootstrap procedure to take into account nonstandard residuals.[12] Our observations are not independent because of overlap in expiration months and strike prices. The bootstrap involves estimating the Tobit regression 500 times by sampling with replacement. The final standard error of the coefficient estimate is the standard deviation of the vector of 500 coefficient estimates.

The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. The independent variables are as follows. ln*S/X -1* is a measure of liquidity where S is the S&P 500 index value and X is the strike price. The risk of an adverse price movement before a trade can be completed (i.e., liquidity risk) must be compensated. When liquidity risk in options trading is high, greater violations in pricing relationships are expected. Most trading volume is in near-the-money options and our first independent variable measures how far an option is from at-the-money (Kamara and Miller (1995)). For the spread relationships ((3a) and (3b)) the liquidity measure is the average liquidity across the two options. In addition, we include option volume and open interest as independent variables to proxy for liquidity.

) S&P500 is the change in the S&P 500 index from the previous day's close and S&P500 is the closing value of the index. A large unexpected upward movement in the market would result in a larger violation if an arbitrage opportunity indicates that stock should be sold. The converse holds if an arbitrage profit can be made from a strategy involving buying stock. Thus, we expect a positive (negative) coefficient estimate on) S&P500 for (1a) and (2a) ((1b) and (2b)).

Three final independent variables are included in the Tobit regression. Term to maturity is the time in years until the option expires. Strike price is the exercise price of the option(s) where we include both the absolute value of the difference in strike prices and the average strike price for the spread relationships. Finally, Time is a counter for the trading date and is included to measure the trend in pricing violations over time.

Table 13 reports the results of the bootstrapped Tobit regression. The table reports the bootstrapped coefficient estimates with t-statistics below. The final row of the table reports an F-statistic that tests the null hypothesis that the coefficients are jointly equal to zero. These F-statistics are all highly significant, as are most of the individual coefficient estimates. Consistent with the results reported by Kamara and Miller, liquidity is clearly an important determinant of the size of violations in option pricing relationships. As expected, violations are larger when an option is farther from at-the-money so that liquidity is low. The estimated coefficients for volume and open interest are also generally consistent with larger violations when liquidity is low.) S&P500 has the expected signs for the boundary and parity relationships. Violations of (1a) and (2a) ((1b) and (2b)) are larger (smaller) when the stock index moves up because the arbitrageur sells (purchases) the index. In many cases the remaining variables (S&P500, Term to Maturity, Strike Price, and Time) significantly impact the size of pricing violations, though the signs are mixed.

VI. Concluding Remarks

In this paper, we examine the efficiency of the S&P 500 index option market. When we ignore commission costs and constraints on short sales, we report frequent and substantial violations of theoretical pricing relationships derived from stock index and index option no-arbitrage principles. Although these results suggest that significant inefficiencies exist in the link between index and option markets, almost no violations in boundary conditions and put-call parity remain after commission costs and short sales constraints are recognized. However, we continue to observe a large number of violations in the box spread even after the analysis reflects transactions costs. Our results also suggest that liquidity and stock index price movements are important determinants of the size of dollar violations of pricing relationships.

The results provide support for the hypotheses that options market efficiency improved over time and that the introduction of SPDRs, a stock basket, improves the link between stock and index option markets. Replicating the underlying asset with actual stock trading was not easy or costless prior to the introduction of SPDRs. However, even with trading in a stock basket, arbitrage is limited by other obstacles including transaction costs and short sales constraints.

Endnotes

1. For further information see Ackert and Tian (1998b). In addition, the AMEX web site (www.amex.com) contains detailed information on SPDRs and how they are traded, including a complete prospectus.

2. As in the early put-call parity studies, Billingsley and Chance (1985) use American options to test whether the box spread relationship holds across stock options.

3. For derivations of these relationships see Chance (1987), Cox and Rubinstein (1985), and Hull (1997).

4. The index option market closes at 4:15 (EST) and the stock market closes at 4:00 (EST). In their study of index options, Evnine and Rudd (1985) use intra-day data. They conclude that closing option prices properly represent prices observed during the trading day. Thus, in our examination of option market pricing efficiency, it is not inappropriate to use prices from the close.

5. See Ronn and Ronn (1989) who demonstrate that the use of bid-ask prices is conservative.

6. In relationships involving the underlying asset, results reported in the paper use the S&P 500 index. We examined the correlation in SPDRs prices and the S&P 500 index. Over our sample period they were highly correlated with correlation coefficient of 0.999. In order to test the sensitivity of our results, we repeated all analyses using SPDRs as the asset underlying the option. The conditions we tested using SPDRs also reflected a discrete dividend stream as SPDRs pay out quarterly. Although not reported, the results are similar to those reported subsequently.

7. In some cases, we detected a few extreme outliers. After checking and re-checking the original data sources, these outliers remained. However, when these outliers are removed statistical inferences are unchanged.

8. Autocorrelation in the dollar violations might be expected because the time to maturity for sample options may overlap. Diagnostic tests confirmed the presence of significant positive autocorrelation. However, inferences are unchanged if OLS standard errors are used.

9. Though not reported, we also examined the number and size of violations when 97 percent of short-sales proceeds are available following Kamara and Miller (1985). We observe virtually no violations of call and put boundary conditions and put-call parity.

10. Although the correlation between SPDRs and the S&P 500 index is 0.999, the SPDRs' price is at times out of line with the index. In general, SPDRs are under-priced when adjusted for dividend payments (Ackert and Tian (1998b)).

11. Although the conclusions differ, these results are not inconsistent with Ackert and Tian's (1998a) study of trading in Canadian options markets. Ackert and Tian conclude that trading in a stock basket does not improve the link between option and index markets. Their study does not investigate

the effect of other limits to arbitrage, such as commission fees and short sales constraints.

12. In fact, inferences are unaffected when we use Ordinary Least Squares analysis or a standard Tobit regression model.

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TABLE 1
Violations of Call Boundary (1a) Before and After the Introduction of SPDRs

	$8_S = 1.0$, $t_i = 0$		$8_S = 1.0$, $t_i > 0$		$8_S = 0.99$, $t_i > 0$	
	2/1/92- 1/28/93	1/29/93- 1/31/94	2/1/92- 1/28/93	1/29/93- 1/31/94	2/1/92- 1/28/93	1/29/93- 1/31/94
Frequency of Violations						
Number of Observations	8,002	8,303	8,002	8,303	8,002	8,303
Number of Violations	465	443	335	304	4	5
Percentage of Violations	5.81	5.34	4.19	3.66	0.05	0.06
Violations in Dollars						
Mean	1.05	0.96	1.05	0.98	1.97	1.31
Standard Deviation	1.02	0.95	1.03	1.00	3.22	1.02
t-statistic for nonzero mean	22.10***	21.08***	18.64***	17.10***	1.22	2.87*
t-statistic for equality of means	1.38		0.86		43.83***	

This table compares the frequency and dollar size of violations of the call boundary (1a) before and after the introduction of SPDRs. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. 8_S is the percent of proceeds available to short sellers of stock and t_i is the cost of transactions in calls, puts, or shares. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.

TABLE 2
Violations of Put Boundary (1b) Before and After the Introduction of SPDRs

	$8_S = 1.0$, $t_i = 0$		$8_S = 1.0$, $t_i > 0$		$8_S = 0.99$, $t_i > 0$	
	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94
Frequency of Violations						
Number of Observations	11,499	12,543	11,499	12,543	11,499	12,543
Number of Violations	235	331	158	231	0	0
Percentage of Violations	2.04	2.64	1.37	1.84	0	0
Violations in Dollars						
Mean	0.97	0.93	1.03	0.93	0	0
Standard Deviation	0.97	0.93	0.98	0.96	0	0
t-statistic for nonzero mean	15.38***	18.23***	13.22***	14.71***	-	-
t-statistic for equality of means	0.46		1.00		-	

This table compares the frequency and dollar size of violations of the put boundary (1b) before and after the introduction of SPDRs. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. 8_S is the percent of proceeds available to short sellers of stock and t_i is the cost of transactions in calls, puts, or shares. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.

TABLE 3
Violations of Put-Call Parity (2a) Before and After the Introduction of SPDRs

	$8_S = 1.0$, $t_i = 0$		$8_S = 1.0$, $t_i > 0$		$8_S = 0.99$, $t_i > 0$	
	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94
Frequency of Violations						
Number of Observations	5,811	5,874	5,811	5,874	5,811	5,874
Number of Violations	2,994	2,243	1,719	1,094	12	8
Percentage of Violations	51.52	38.19	29.58	18.62	0.21	0.14
Violations in Dollars						
Mean	0.83	0.73	0.81	0.81	2.76	1.05
Standard Deviation	0.81	0.78	0.87	0.86	3.07	1.11
t-statistic for nonzero mean	55.95***	44.49***	38.64***	31.31***	3.11***	2.82**
t-statistic for equality of means	4.51***		-0.12		149.99***	

This table compares the frequency and dollar size of violations of put-call parity (2a) before and after the introduction of SPDRs. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. 8_S is the percent of proceeds available to short sellers of stock and t_i is the cost of transactions in calls, puts, or shares. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.

TABLE 4
Violations of Put-Call Parity (2b) Before and After the Introduction of SPDRs

	$8_S = 1.0, t_i = 0$		$8_S = 1.0, t_i > 0$		$8_S = 0.99, t_i > 0$	
	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94
Frequency of Violations						
Number of Observations	5,811	5,874	5,811	5,874	5,811	5,874
Number of Violations	2,143	2,932	1,131	1,618	0	0
Percentage of Violations	36.88	49.91	19.46	27.55	0	0
Violations in Dollars						
Mean	0.85	0.87	0.95	0.91	0	0
Standard Deviation	0.87	0.85	0.93	0.94	0	0
t-statistic for nonzero mean	45.63***	55.00***	34.40***	39.20***	-	-
t-statistic for equality of means	-0.49		1.00		-	

This table compares the frequency and dollar size of violations of put-call parity (2b) before and after the introduction of SPDRs. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. 8_S is the percent of proceeds available to short sellers of stock and t_i is the cost of transactions in calls, puts, or shares. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.

TABLE 5
Violations of the Box Spread (3a) Before and After the Introduction of SPDRs

	$\lambda_S = 1.0$, $t_i = 0$		$\lambda_S = 1.0$, $t_i > 0$	
	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94
Frequency of Violations				
Number of Observations	18,796	17,854	18,796	17,854
Number of Violations	6,691	6,389	3,604	3,399
Percentage of Violations	35.60	35.78	19.17	19.04
Violations in Dollars				
Mean	0.80	0.79	0.88	0.87
Standard Deviation	0.72	0.72	0.75	0.74
t-statistic for nonzero mean	90.87***	87.20***	70.72***	68.26***
t-statistic for equality of means	1.30		0.78	

This table compares the frequency and dollar size of violations of the box spread (3a) before and after the introduction of SPDRs. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. λ_S is the percent of proceeds available to short sellers of stock and t_i is the cost of transactions in calls, puts, or shares. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.

TABLE 6
Violations of the Box Spread (3b) Before and After the Introduction of SPDRs

	$\lambda_S = 1.0$, $t_i = 0$		$\lambda_S = 1.0$, $t_i > 0$	
	2/1/92- 1/28/93	1/29/93- 1/31/94	2/1/92- 1/28/93	1/29/93- 1/31/94
Frequency of Violations				
Number of Observations	18,796	17,854	18,796	17,854
Number of Violations	7,620	6,987	4,240	3,842
Percentage of Violations	40.54	39.13	22.56	21.52
Violations in Dollars				
Mean	0.87	0.81	0.95	0.86
Standard Deviation	0.84	0.71	0.85	0.73
t-statistic for nonzero mean	89.47***	94.45***	73.02***	72.06***
t-statistic for equality of means	4.63***		5.26***	

This table compares the frequency and dollar size of violations of the box spread (3b) before and after the introduction of SPDRs. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. λ_S is the percent of proceeds available to short sellers of stock and t_i is the cost of transactions in calls, puts, or shares. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.

TABLE 7
Ex Ante Violations of Call Boundary (1a) Before and After the Introduction of SPDRs

	$8_S = 1.0, t_i = 0$		$8_S = 1.0, t_i > 0$		$8_S = 0.99, t_i > 0$	
	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94
Frequency of Violations						
Number of Observations	465	443	335	304	4	5
Number of Violations	70	62	36	32	0	0
Percentage of Violations	15.05	14.00	10.75	10.53	0	0
Violations in Dollars						
Mean	1.11	0.68	1.22	0.48	0	0
Standard Deviation	1.07	0.48	1.12	0.46	0	0
t-statistic for nonzero mean	8.71***	11.12***	6.55***	5.89***	0	0
t-statistic for equality of means	2.92***		3.52***		0	

This table compares the frequency and dollar size of ex ante violations of the call boundary (1a) before and after the introduction of SPDRs. An ex ante violation occurs when a particular violation persists into the following trading day. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. 8_S is the percent of proceeds available to short sellers of stock and t_i is the cost of transactions in calls, puts, or shares. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.

TABLE 8
Ex Ante Violations of Put Boundary (1b) Before and After the Introduction of SPDRs

	$8_S = 1.0$, $t_i = 0$		$8_S = 1.0$, $t_i > 0$		$8_S = 0.99$, $t_i > 0$	
	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94
Frequency of Violations						
Number of Observations	235	331	158	231	0	0
Number of Violations	28	53	13	23	0	0
Percentage of Violations	11.91	16.01	8.23	9.96	0	0
Violations in Dollars						
Mean	0.69	0.76	0.69	0.80	0	0
Standard Deviation	0.64	0.75	0.66	0.86	0	0
t-statistic for nonzero mean	5.67***	7.33***	3.78***	4.48***	-	-
t-statistic for equality of means	0.41		-0.40		-	

This table compares the frequency and dollar size of ex ante violations of the put boundary (1b) before and after the introduction of SPDRs. An ex ante violation occurs when a particular violation persists into the following trading day. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. 8_S is the percent of proceeds available to short sellers of stock and t_i is the cost of transactions in calls, puts, or shares. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.

TABLE 9
Ex Ante Violations of Put-Call Parity (2a) Before and After the Introduction of SPDRs

	$8_S = 1.0, t_i = 0$		$8_S = 1.0, t_i > 0$		$8_S = 0.99, t_i > 0$	
	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94
Frequency of Violations						
Number of Observations	2,994	2,243	1,719	1,094	12	8
Number of Violations	1,115	666	325	143	0	0
Percentage of Violations	37.24	29.69	18.91	13.07	0	0
Violations in Dollars						
Mean	0.73	0.61	0.76	0.60	0	0
Standard Deviation	0.81	0.66	1.04	0.76	0	0
t-statistic for nonzero mean	29.97***	23.98***	13.30***	9.51***	-	-
t-statistic for equality of means	3.12***		1.69*		-	

This table compares the frequency and dollar size of ex ante violations of the put-call parity (2a) before and after the introduction of SPDRs. An ex ante violation occurs when a particular violation persists into the following trading day. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. 8_S is the percent of proceeds available to short sellers of stock and t_i is the cost of transactions in calls, puts, or shares. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.

TABLE 10
Ex Ante Violations of Put-Call Parity (2b) Before and After the Introduction of SPDRs

	$8_S = 1.0, t_i = 0$		$8_S = 1.0, t_i > 0$		$8_S = 0.99, t_i > 0$	
	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94
Frequency of Violations						
Number of Observations	2,143	2,932	1,131	1,618	0	0
Number of Violations	509	1,049	116	320	0	0
Percentage of Violations	23.75	35.78	10.26	19.78	0	0
Violations in Dollars						
Mean	0.66	0.74	0.85	0.83	0	0
Standard Deviation	0.76	0.80	0.93	0.98	0	0
t-statistic for nonzero mean	19.79***	29.77***	9.84***	15.12***	-	-
t-statistic for equality of means	1.78*		0.22		-	

This table compares the frequency and dollar size of ex ante violations of the put-call parity (2b) before and after the introduction of SPDRs. An ex ante violation occurs when a particular violation persists into the following trading day. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. 8_S is the percent of proceeds available to short sellers of stock and t_i is the cost of transactions in calls, puts, or shares. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.

TABLE 11
Ex Ante Violations of the Box Spread (3a) Before and After the Introduction of SPDRs

	$8_S = 1.0, t_i = 0$		$8_S = 1.0, t_i > 0$	
	2/1/92-1/28/93	1/29/93-1/31/94	2/1/92-1/28/93	1/29/93-1/31/94
Frequency of Violations				
Number of Observations	6,691	6,389	3,604	3,399
Number of Violations	1,335	1,153	375	258
Percentage of Violations	19.95	18.05	10.41	7.59
Violations in Dollars				
Mean	0.71	0.68	0.80	0.82
Standard Deviation	0.72	0.74	0.73	0.74
t-statistic for nonzero mean	35.67***	31.03***	21.00***	17.51***
t-statistic for equality of means	0.90		-0.33	

This table compares the frequency and dollar size of ex ante violations of the box spread (3a) before and after the introduction of SPDRs. An ex ante violation occurs when a particular violation persists into the following trading day. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. 8_S is the percent of proceeds available to short sellers of stock and t_i is the cost of transactions in calls, puts, or shares. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.

TABLE 12
Ex Ante Violations of the Box Spread (3b) Before and After the Introduction of SPDRs

	$\lambda_S = 1.0$, $t_i = 0$		$\lambda_S = 1.0$, $t_i > 0$	
	2/1/92- 1/28/93	1/29/93- 1/31/94	2/1/92- 1/28/93	1/29/93- 1/31/94
Frequency of Violations				
Number of Observations	7,620	6,987	4,240	3,842
Number of Violations	1,586	1,315	457	342
Percentage of Violations	20.81	18.82	10.78	8.90
Violations in Dollars				
Mean	0.83	0.69	0.99	0.77
Standard Deviation	1.25	0.73	1.60	0.81
t-statistic for nonzero mean	26.57***	33.97***	13.22***	17.61***
t-statistic for equality of means	3.80***		2.30**	

This table compares the frequency and dollar size of ex ante violations of the box spread (3b) before and after the introduction of SPDRs. An ex ante violation occurs when a particular violation persists into the following trading day. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. λ_S is the percent of proceeds available to short sellers of stock and t_i is the cost of transactions in calls, puts, or shares. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.

Table 13
Bootstrap Tobit Regression Analysis of the Determinants of the Size of Violations

Independent Variable	Call Boundary (1a)	Put Boundary (1b)	Put-Call Parity (2a)	Put-Call Parity (2b)	Box Spread (3a)	Box Spread (3b)
Constant	-1.5367 (-2.60)***	2.5579 (5.16)***	4.1200 (0.47)	-2.0376 (-2.85)***	3.1263 (8.73)***	3.0626 (8.26)***
ln*S/X -1*	0.3150 (24.96)***	0.1875 (25.66)***	0.1623 (16.82)***	0.1102 (12.20)***	0.0481 (5.99)***	0.0612 (7.35)***
Volume	0.000019 (2.75)***	-0.000024 (-4.23)***	-0.000002 (-0.50)	-0.000024 (-5.09)***	-0.000003 (-1.95)*	0.000001 (1.08)
Open Interest	-0.000019 (-12.81)***	-0.000008 (-8.51)***	-0.000010 (-12.54)***	-0.000001 (-1.40)	-0.000001 (-0.11)	-0.000001 (-2.64)***
) S&P500	0.1096 (31.74)***	-0.0863 (-29.45)***	0.1935 (37.36)***	-0.2383 (-50.84)***	-0.0177 (-8.87)***	0.0079 (4.12)***
S&P500	0.0173 (11.54)***	-0.0295 (-23.81)***	-0.0045 (-2.62)***	0.0018 (1.00)	-0.0026 (-2.74)***	-0.0015 (-1.64)*
Term to Maturity	-5.4288 (-56.38)***	-3.2735 (-58.16)***	-1.5104 (-19.62)***	2.5459 (43.06)***	-0.0249 (-0.44)	0.0210 (0.36)
Strike Price	-0.0090 (-27.78)***	0.0263 (79.65)***	-0.0018 (-4.25)***	0.0026 (6.10)***	-	-
Difference in Strikes	-	-	-	-	0.0005 (1.66)*	0.0007 (2.64)***
Average Strike	-	-	-	-	0.0009 (2.48)**	0.0001 (0.27)
Time	-0.0012 (-5.52)***	0.0012 (11.21)***	-0.0009 (-3.70)***	0.0013 (5.16)***	0.0003 (2.04)**	0.0001 (0.92)
F-statistic	40,182***	36,419***	28,710***	12,396***	37,160***	33,055***

This table contains bootstrapped Tobit regression results to examine the determinants of the dollar size of violations in each pricing relationship. The analysis uses daily data for the S&P 500 index and index options from February 1, 1992 through January 31, 1994. ln*S/X -1* is a measure of liquidity where S is the S&P 500 index value and X is the strike price. For the spread relationships ((3a) and (3b)) the liquidity measure is the average liquidity across the two options. Volume and open interest are for the specific options.) S&P500 is the change in the S&P 500 index from the previous day's close and S&P500 is the closing value of the index. Term to maturity is the time in years until the option expires. Strike price is the exercise price of the option(s) where we include both the absolute value of the difference in strike prices and the average strike price for the spread relationships. Finally, Time is a counter for the trading date and is included to measure the trend in pricing violations over time. The F-statistic tests the null hypothesis that the coefficients are jointly equal to zero. Asterisks *,**, or *** denote significance at the 10%, 5%, and 1% levels, respectively, in a two-tailed test.