Arbitrage Opportunities and Efficiency of an Emerging Option Market: The Case of KOSPI 200 Options in Korea

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Abstract

This study investigates arbitrage opportunities and efficiency of the KOSPI 200 options in Korea, an emerging option market but the fastest growing and the most actively traded index option market in the world. Several no-arbitrage conditions are considered including lower boundary conditions of call and put prices, option price relations independent of underlying index, put-call parity, and box spread arbitrage conditions. Overall, there exist sizable arbitrage opportunities when the arbitrage conditions involve both options and the underlying index. However, few arbitrage opportunities exist when the arbitrage conditions are formed independent of the underlying index. There are more frequent no-arbitrage violations during opening and closing hours, on near-maturity days, and with in-the-money options.

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I. Introduction

The Korea Stock Exchange installed Korea Stock Price Index 200 (KOSPI 200) options on July 7, 1997. Since their first trading right before the dramatic economic crisis in Korea, the trading volume of the KOSPI 200 options has been increasing at a rate of about 8% per month and now they are the most actively traded index options in the world, surpassing the S&P 100 and S&P 500 options in the U.S. In year 2000, the KOSPI 200 options were listed on the top of all exchange traded derivatives in the world with the trading volume of 193,829,070 transactions while the S&P 100 index options were out of the top ten with the trading volume of mere 15,505,483 transactions.[1] As a result, the success of the KOSPI 200 options market in Korea relative to other markets has recently drawn a significant attention of the investment community in the world.

One of the critical factors for the success of a derivative market is, among others, the price volatility of the underlying asset. Even before the inception of the KOSPI 200 index futures and options in 1996 and 1997, respectively, the stock market in Korea had experienced dramatic gyrations of prices. For instance, the KOSPI Composite Index, which was 100 as of January 4, 1980, rose to 532 on January 1, 1988, and to 1,007 on April 1, 1989.[2] It was not unusual then for small investors to reap more than 100% capital gains in a little over a year. However, this upturn in the Korean stock market was not sustainable. The Composite Index bottomed out at 460 on August 21, 1992, making small investors disillusioned with the stock market. What exacerbated the investors' sentiment were the government interventions. Being blamed by the investors for the losses in the stock market, the government, for political reasons, had repeatedly intervened to

[1] See *Futures Industry*, February/March 2001 for details.
[2] See *Stock*, Korea Stock Exchange, December 2000.

prop up share prices by infusing cash from various stabilization funds. The volatility of the stock market in Korea was further fueled by the economic crisis in 1997. While going through voluntary and involuntary corporate restructuring and financial reforms as a result of the economic crisis and thus facing the uncertainties of their results, the stock market experienced unprecedented gyrations. In the first year of the economic crisis, the stock composite index plummeted to 376.31 at the end of 1997 from the closing index of 651.22 in 1996. The optimistic prospects of the economic overhaul at the beginning stage boosted the index to 562.46 in 1998 and further to 1,028 in 1999. However, a pessimistic sentiment was created in the Korean economy throughout the year 2000 partly due to the failures of some intended reforms and partly due to a turmoil in the labor market, a by-product of the reform failures.[3] As a result, the composite index dived again to 509.23 as of November 2000, yielding more than 50% change over less than a year. The success of the option market in Korea is attributed at least partly to this magnitude of the price volatility.

With the scale of trading volume of options often exceeding that of underlying stocks, index options must be important components of trading strategies. Certainly, the ability of investors to trade in different venues introduces a potentially important dimension to the notion of security market efficiency. In case of the KOSPI 200 options, the trading volume was more than quadruple of the trading volume of the underlying stocks.[4] Accordingly, information flows may differ in these two markets, providing potential arbitrage opportunities.

This study investigates arbitrage opportunities and efficiency issues of the KOSPI 200 options by considering some key no-arbitrage conditions. This analysis is of interest due to several reasons. First, there is disagreement regarding the efficiency of the market for index arbitrage opportunities. By investigating an emerging options market with different trading rules,

[3] Also, it has been pointed out that rapid inflows and outflows of speculative "hot money" of foreign investors contributed to the volatility of the stock prices in Korea.
[4] According to *Stock* (Korea Stock Exchange, December 2000) the ratio of the trading volume of the options to that of the stocks was 4.42 as of September 2000.

it is possible to evaluate the impact of different trading mechanisms. Second, we use intraday trading data which allow the investigation of intraday pattern in no-arbitrage violations. Third, we implement no-arbitrage conditions without imposing restrictions on preferences of investors or distributional assumptions on asset returns. Using these arbitrage conditions provides an attractive method to evaluate efficiency because these trades can be initiated in response to arbitrage opportunities. Fourth, we take the magnitude of transactions costs into consideration based on market determined estimates.

Based on no-arbitrage conditions of the options independent of the underlying stock index, the price formation process appears to be quite efficient. However, substantial arbitrage opportunities exist when the conditions involving both the option and the underlying index are considered. Several patterns are also uncovered in arbitrage opportunities. There are more frequent arbitrage opportunities on the dates close to maturity and with portfolios involving in-the-money options. The arbitrage opportunities also occur more frequently during opening and closing hours.

This study also investigates the possibility of non-simultaneity of information flows between the option market and the stock market. Empirical evidence supports the hypothesis that the index option market leads the stock market and that the information concerning future index returns is well reflected in the relative call and put prices.

Section II specifies some key equilibrium conditions based on general option pricing relationships. Section III describes the KOSPI 200 option in Korea and presents the test results using the KOSPI 200 options transactions data over the sample period 1998-1999. Section IV contains a brief conclusion.

II. No-arbitrage Conditions

The advantage of examining no-arbitrage conditions based on pricing relationships is that they can provide a simple way of testing market efficiency without imposing restrictions on

preferences of investors or distributional assumptions on asset returns. Four no-arbitrage conditions are employed in this study; lower boundary conditions of call and put options, option pricing relationship independent of the underlying asset, put-call parity, and box spread conditions. If these conditions are violated even after considering the bid-ask spread, investors may make arbitrage profits by taking short positions in overvalued securities or portfolios and long positions in undervalued securities or portfolios.

The notations used are as follows:

$C^a(K)$: Ask price of a European call option with exercise price K.

$C^b(K)$: Bid price of a European call option with exercise price K.

$P^a(K)$: Ask price of a European put option with exercise price K.

$P^b(K)$: Bid price of a European put option with exercise price K.

K: Exercise price.

S: KOSPI 200 index price.

D_t: Dividend paid on the index at time t.

τ: Time to maturity.

r: Risk-free interest rate.

First, the lower boundary conditions for call and put options are given as follows:

(1a) $C^a(K) \geq \max[S^n - Ke^{-r\tau}, 0]$,

(1b) $P^a(K) \geq \max[Ke^{-r\tau} - S^n, 0]$,

where

$$S^n = S - \sum D_t e^{-rt} .$$

If these inequalities are violated, the options are undervalued relative to the underlying stock index and arbitrage opportunities exist.

Second, three general option pricing relationships, independent of the underlying asset, are as follows:

For exercise prices K_1, K_2, and K_3, with $K_3 > K_2 > K_1$,

<Condition 1>

(2a) $C^a(K_1) - C^b(K_2) \geq 0$

(2b) $P^a(K_2) - P^b(K_1) \geq 0$

<Condition 2>

(3a) $C^a(K_2) - C^b(K_1) + (K_2 - K_1)e^{-r\tau} \geq 0$

(3b) $P^a(K_1) - P^b(K_2) + (K_2 - K_1)e^{-r\tau} \geq 0$

<Condition 3>

(4a) $$C^b(K_2) \leq \frac{K_3 - K_2}{K_3 - K_1} C^a(K_1) + \frac{K_2 - K_1}{K_3 - K_1} C^a(K_3)$$

(4b) $$P^b(K_2) \leq \frac{K_3 - K_2}{K_3 - K_1} P^a(K_1) + \frac{K_2 - K_1}{K_3 - K_1} P^a(K_3)$$

Condition 1 implies that if two options differ only in exercise prices, then the call (put) option with lower (higher) exercise price must sell for a price that is no less than the call (put) option price with higher (lower) exercise price. Condition 2 states that the price difference in two options with different exercise prices cannot exceed the present value of the difference in their exercise prices. Condition 3 is based on the convexity of option price with respect to the exercise price. These conditions hold independent of the underlying asset. If these conditions are violated, investors can make arbitrage profits by taking short and long positions in overvalued and undervalued options, respectively.

Third, the put-call parity conditions for European options are as follows:

(5a) $P^a(K) - C^b(K) + S^n - Ke^{-r\tau} \geq 0$

and

(5b) $C^a(K) - P^b(K) + Ke^{-r\tau} - S^n \geq 0$

The put-call parity is an intrinsic relationship between a call and a put option with the same maturity and the same exercise price. If inequality (5a) is violated (call price is too high relative to put price), an arbitrageur can set up a profitable strategy by writing a call and buying a "synthetic call" indirectly (i.e., buying a put and the underlying index, and borrowing the present value of the exercise price at the risk-free rate). This is often referred to as a "conversion" strategy. On the other hand, if inequality (5b) is violated (put price is too high relative to call price), a "reverse conversion" (or "reversal") can be set up. In this case, a put option would be written directly with a long position in a "synthetic put" (i.e., shorting the underlying stock index, buying a call, and lending the present value of the exercise price at the risk-free rate).

The final no-arbitrage condition to be examined is the box spread, a riskless strategy combining a bullish call spread and a bearish put spread. The box spread is expressed by the following inequalities:

(6a) $$(C^a(K_1) - C^b(K_2)) - (P^b(K_1) - P^a(K_2)) + (K_1 - K_2)e^{-r\tau} \geq 0$$

and

(6b) $$(C^a(K_2) - C^b(K_1)) - (P^b(K_2) - P^a(K_1)) + (K_2 - K_1)e^{-r\tau} \geq 0$$

Inequality (6a) is referred to as the "debit box spread" condition and (6b) as the "credit box spread" condition. If the debit box spread condition is violated (i.e., the call with lower exercise price and the put with higher exercise price are undervalued), arbitrage profits will be possible by taking long and short positions in undervalued and overvalued options, respectively, and borrowing the present value of the difference of the two exercise prices at the risk-free rate. If the credit box spread is violated, on the other hand, arbitrage would take place by taking opposite positions to the credit box spread case. The box spread involves only options and hence provides a direct way to test option market efficiency, irrespective of the underlying stock market.

Data and Empirical Results

A. Data: KOSPI 200 Options

The data consist of the KOSPI 200 options for the twenty-one month period from January 1998 to September 1999, excluding the first several months because of potential unusual activities at the beginning stage. The KOSPI 200 was updated every minute during our sample period.[5] To secure the synchronous option transactions with the index updates, we select the last option transaction within one-minute interval right before each index update. If there is no option transaction within a minute, we exclude the observations from the sample.

The KOSPI 200 option was introduced on July 7, 1997 in the Korea Stock Exchange (KSE). The KOSPI 200 options are European style. The underlying index, the KOSPI 200, is a market-value-weighted index consisting of 200 blue chip stocks traded in the Korea Stock Exchange (KSE) covering a broad range of industries including manufacturing, electricity and gas, construction, distribution and services, communication and financing. The index base date is January 3, 1990 and the base value is 100. The contract months are three consecutive near term months plus one nearest month from the quarterly cycle, March, June, September and December. Each option contract month contains at least five exercise prices with the interval of 2.5 points between the exercise prices. However, more than 95 percent of the trading is concentrated on nearest month contracts. Accordingly we limit our analysis to those contracts. For stock trading, the KSE holds a regular session from 9:00 to 15:00 except the lunch hour of 12:00- 13:00 and an after-hour session from 15:10 to 15:40 from Monday through Friday. For the options, the trading hours for the morning session are the same as those of the stock market, 9:00- 12:00, and those for the afternoon session are extended by 15 minutes, 13:00- 15:15.[6] Trading is executed by Automated Trading System (ATS) without designated market makers and the prices are determined by continuous individual auctions. Opening and closing prices are determined by batch auctions. In the stock market, both market and limit orders are allowed but only limit orders

[5] The KOSPI 200 is now updated every 30-seconds.
[6] Since May 22, 2000, the lunch hour recess for 12:00 – 13:00 has been abolished.

are permitted in the option market. The size of an option contract is determined by multiplying 100,000 Korean Won (KW) to the index level; that is, one point equals 100,000 KW.[7] Minimum tick size is 0.01 point with premium less than 3 points and 0.05 points with premium of 3 points or more. Maximum trade size is 4,999 contracts.

All the necessary data are obtained from the KSE, including the dividend payments of all 200 component stocks of the index. All the component stocks pay dividends only once a year and about 87 % of the stocks pay them in December. To obtain the present values of the dividends, 91-day CD rates are used as the discount rate. The 91-day CD rate is a short-term benchmark corresponding to the T-bill rate. Other maturity rates are not available but overnight call rates. However, due to volatile term structure of interest rates between the call rate and CD rate, we use only 91-day CD rates.

B. Empirical Results

The frequency and size of violations of the no-arbitrage conditions in the previous section are examined for the whole sample period, and for sub-sample periods of 1998 and 1999. The results are also analyzed based on maturity, exercise price, moneyness, and intraday time intervals.

Table 1 shows the test results for the lower boundary conditions. Panel A of Table 1 shows that 3.43% of call options and 0.83% of put options violate the lower boundary conditions for the whole sample period. The average size of violations is 0.411, equivalent to 41,100 KW for call options and 0.224 (22,400 KW) for put options. When the samples of 1998 and 1999 are considered separately, the proportion of violations for call options decreased from 5.88% in 1998 to 1.11% in 1999, and the size also decreased from 0.437 in 1998 to 0.281 in 1999. The change in the size is significant at the one percent significance level. For put options, the proportion of violations also significantly decreased from 1.23% in 1998 to .58% in 1999, but the violation size changed insignificantly from .222 to .227.

[7] During our sample period, one U.S. dollar was equivalent to about 1,500 KW on average.

Panel B of Table 1 lists top 30 days with most frequent violations of the lower boundary conditions (Inequalities (1a) and (1b)). All of the 30 dates occurred in 1998, with eight of them on maturity dates. Panel C shows that the percentage of violations on maturity dates is 10.71%, much greater than 1.77% on non-maturity dates. However, the average size of violations on maturity dates is 0.19 (19,000 KW), which is much smaller than that on non-maturity dates (0.39 or 39,000 KW). The difference is significant at the level of one percent. The results suggest that arbitrage opportunities are more frequent but the arbitrage profit sizes are much smaller on maturity dates than on non-maturity dates.

The intraday patterns of the lower boundary condition violations are reported on Panel D. The frequency and size of violations are higher during periods from 9:30 to 10:00, right after the market open, and from 15:00 to 15:15, right before the market close than other periods.
Table 2 reports the violations of the three no-arbitrage conditions based on the general option pricing relationships independent of the underlying asset. In this paper, at-the-money options are defined as the options where the underlying stock index is within the range of the exercise price plus minus 2.5 points. In-the-money and out-of-money options are outside of the range in appropriate directions. For Condition 1, there are only 16 violations, eight for call and eight for put options. Besides, the violations are limited to out-of-the-money options. Executing arbitrage transactions for out-of-the-money options can be more difficult partly due to a lack of liquidity for those options and partly due to relatively high transactions costs. The frequencies of violations for Condition 2 are higher for call options (0.05%) than for put options (0.02%), but the mean sizes of violations for call and put options are not statistically different. While the frequencies of violations decreased, the average sizes of violations actually increased from 1998 to 1999 for both call and put options. Panel A also shows that the frequencies of violations for Condition 3 are 0.43% for call options and 0.73% for put options, higher than those for Conditions 1 and 2. More frequent violations for Condition 3 relative to those for Conditions 1 and 2 may be due to higher execution risk and transaction costs combining three options at the

same time. The size of violation is significantly higher for calls than for puts. Also, the frequencies of violations increased from 1998 to 1999 for both calls and puts, but the violation sizes decreased especially for put options.

Panel B of Table 2 compares the violations of in-the-money, at-the-money, and out-of-the-money options. In-the-money options are most often violated for Condition 2, while out-of-the-money options are most often violated for Condition 3. The average violation size is much higher for in-the-money options than for other options. The lack of liquidity when implementing arbitrage transactions with in-the-money options may explain why the violation size is higher for in-the-money options[8].

In Panel C of Table 2, the percentage of violations of Condition 2 on maturity days is 0.62%, which is much higher than 0.02% of those days prior to maturity. However, the magnitudes of average violation size on maturity days are significantly smaller than those on non-maturity days.

The patterns of intraday violations for Condition 2 and Condition 3 are reported on Panel D. The frequency of violations for Condition 2 is the highest during 15:00 – 15:15 interval, right before the market close, and the next high is during 14:30 – 15:00. The violations also tend to occur frequently right after the market open (09:00 – 09:30). Also, the average size of violations is the highest during 9:00 – 9:30. The frequency and size of violations for Condition 3 show similar intraday patterns.

Table 3 presents the test results of the put-call parity conditions.[9] As shown in Panel A of Table 3, for the whole sample period, the percentages of arbitrage opportunities violating the put-call parity are 39.3% for conversion (condition given by (5a)) and 36.2% for reverse conversion (condition given by (5b)). The violation size for reverse conversion (0.715) is greater than that

[8] A casual investigation of trading formation reveals that the strategies involving in-the-money options represented only about 1% of the total in 1999.

[9] Since the implementation of arbitrage transactions using the put-call parity condition requires a combination of both call and put options with the same exercise price, our sample sizes in Table 3 are reduced.

for conversion (0.662) for the whole sample. The frequency and size of the put-call parity violations are much higher than those reported in Tables 1 and 2. The predominant violation of the put-call parity condition is attributable to the difficulty of implementing the arbitrage strategy involving baskets of the underlying stocks of the index. Also, the lack of liquidity for in-the-money options may restrict investors from constructing arbitrage strategies.

For conversion, the percentage of violations increased to 46.1% in 1999 from 30.9% in 1998, but the magnitude decreased significantly from .705 to .639. On the other hand, the frequency of reversal arbitrage opportunities decreased to 25.4% in 1999 from 49.8% in 1998, while the violation size increased. The rapid economic recovery of Korea from the financial crisis and thus a strong bullish stock market in 1999 might cause overvaluation of call options and thus the arbitrage opportunities.

Panel B compares the put-call parity violations across different exercise prices. The violations of both conversions and reverse conversions occur most frequently for at-the-money options. The mean size of violations tends to increase with the strike price for conversions while it is lower for at-the-money options than for in-the-money or out-of-the-money options for reverse conversions.[10]

Panel C reports the analysis of the intraday patterns of the put-call parity violations. The percentage and average size of violations for conversions are highest during 09:00-9:30 interval. But there does not exist any specific trend for reverse conversions.

Table 4 reports the results of the box spread tests as given by inequalities (6a) and (6b). Since there can be so many possibilities of constructing box spreads, the analysis is restricted to

[10] We also investigated 30 most-frequent violation dates as in Panel B of Table 1 (not reported here to conserve the space). Most arbitrage opportunities of conversion occurred during the period of mid December, 1998 – mid January, 1999. During this time period, the stock market experienced a substantial price volatility, futures prices had huge deviations from their theoretical prices, and implied volatilities of call options were much higher than those of put options. On the other hand, for reverse conversion, most frequent violation dates are in May-June and August-September in 1998. During this period the market was bearish, the futures were undervalued, and put options were more volatile than call options. The arbitrage opportunities from the put-call parity seem to take place in the bullish markets for conversions

the cases where two exercise prices are not distant. In Panel A of Table 4, the violation of the box spread conditions represents 3.9% for the debit box spread and 3.8% for the credit box spread. They are much less than those of put-call parity conditions. The average size of violations for credit box spread (.052) is significantly less than that for the debit box spread (.065) at the significance level of one percent. The proportion of violations for the debit box spread reduced from 4.5% in 1998 to 3.5% in 1999, but the average size of violations increased from .06 to .07. The violations of the credit box spread condition show similar trends. Panel B reports a comparison of violations among different exercise prices. At-the-money options have 5.3% and 4.5% of violations for the debit and credit box spread conditions, respectively, higher than those of other exercise price options.

Our investigation of most-frequent violation dates for the box spread conditions again reveals that the violations tend to be concentrated around maturity days. However, as shown on Panel C, the average size of violations is significantly smaller on maturity days than that on non-maturity days. Panel D also shows intraday patterns of the violations of the box spread conditions. Similar to previous results, the average size of violations is highest right after the market open and right before the market close.

The results so far can be summarized as follows: First, no-arbitrage conditions for the portfolios containing both the options and the underlying index are often violated and thus the information flow between the option and underlying stock markets may not be simultaneous. However, the price formation process in the option market per se appears to be quite efficient as revealed by very low frequency of no-arbitrage condition violations for the portfolios of options without the underlying index. Chance (1987) argues that even though the size of violations is greater than zero, if the violation is not frequent and the distribution of violations is skewed, it may still support the efficiency of the option market. Second, the violations tend to occur more frequently on and close to maturity dates. This tendency is common to all the conditions

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and in the bearish markets for reverse conversion.

examined in the paper. Practitioners suggest that demand and supply imbalances cause high index volatilities during the last trading days. More arbitrage opportunities seem to exist due to the high volatility of spot index. Third, the violations occur most frequently during opening and closing hours. The concentration of violations on the trading hours right after the market open and right before the market close may be due to high trading volumes and high price volatilities. Fourth, in-the-money options are more often associated with violations of no-arbitrage conditions than out-of-the-money options. Also, the average violation size tends to be higher for in-the-money options than for other options. This can be due to the lack of liquidity of in-the-money options. Fifth, for the arbitrages involving only options, the average size of violations tends to be smaller for at-the-money options. Since at-the-money options are relatively more liquid than other options, it should be easier for market participants to execute trading strategies involving these options. However, for the put-call parity conditions involving both the index and options, the violations occur more frequently with at-the-money options. Due to margin requirements for writing call options and lack of understanding about options, speculative investors typically prefer call options and they tend to overprice the call options. This seems to contribute to the frequent violations of put-call parity conditions.

C. Alternative Specifications

An alternative explanation to our results of no-arbitrage violations involving both the index and options contracts is that prices in no-arbitrage conditions are mismatched. Even if a quote on the underlying KOSPI index can be exactly matched to an option transaction, we still face three serious challenges. First, the quoted index level will not be the proper underlying value for the option, because all 200 component stock prices will not trade simultaneously at the quoted time. Also, quoted index ignores the bid-ask spreads in trading underlying index. The second challenge is to determine the expected future dividend of the component stocks. The ex post dividends we used in our tests may not match the ex ante expectation at the time of the option transactions. The

third challenge is that arbitrageurs typically do not attempt to trade the index. It will probably be more sensible for arbitrageurs to trade the futures contract.

We address these challenges we reanalyze the put-call parity conditions of equations (5a) and (5b) for which we found most significant violations. By adopting the procedure used by Poteshman (2001), we determine $S^n = Se^{-\delta\tau}$ based on the following spot-futures parity:

$$Se^{-\delta\tau} = Fe^{-r\tau}$$

where F is the futures price, δ is the dividend rate for the index, and other notations are as previously defined.

KOSPI 200 futures maturity months are March, June, September, and December while options maturity months are three consecutive nearest months plus the quarterly cycle with March. Also, futures and options with the same maturity month mature at the same date. For options with these maturity months, we take the futures prices that trade at the time closest to the observation of the option bid-ask quotes and compute $Se^{-\delta\tau}$ based on the spot-futures parity. The size of a contract is determined by multiplying 100,000 KW for options contract while it is determined by multiplying 500,000 KW for futures contract. Accordingly, we apply 5 options to each futures contract in constructing the put-call parity conditions. Also, to account for the bid-ask spread, we use ask futures price for conversion (equation 5a) and bid futures price for reverse conversion (equation 5b).

The results using futures contracts in testing the put-call parity conditions are shown in Table 6. On Panel A, for the whole sample period, the percentages of violations of the put-call parity are 32.4% (39.4% in Table 3) for conversion and 40.5% (36.2% in Table 3) for reverse conversion. The violation sizes are .638 (0.662 in Table 3) for conversion and .519 (0.715 in Table 3) for reverse conversion for the whole sample. The frequency does not change much but the size of violations tends to be smaller when using futures contracts. The patterns of changes over time are also similar to those found in Table 3.

The results in Table 6 suggest that substantial barriers to transmitting information exist between options and futures markets as well as between options and spot markets. Other studies also find significant violations of put-call parity condition. For example, Kamara and Miller (1995) find that the put-call parity condition is violated in 23 percent cases for S&P 500 index. For S&P 100 index, Evnine and Rudd (1985) report 22.4 percent to 52 percent violations and Chance (1987) reports 38.2 percent to 43.4 percent violations of the put-call parity conditions. Klemkosky and Resnick (1979) find more than 50 percent violations for CBOT equity options.

On Panel B of Table 6, we further report the violations of the put-call parity across different exercise prices. The violations of both conversions and reverse conversions occur most frequently for at-the-money options (39.8 percent and 45.4 percent, respectively). The mean size and the percentage of violations are the lowest for the low strike price contracts in the case of conversions while they are the lowest for high strike price contracts in the case of reverse conversions. It appears that arbitrage opportunities from the put-call parity take place in the bullish markets for conversions and in the bearish markets for reverse conversion.

We also analyze the intraday patterns of the put-call parity violations. Unlike our previous results, we do not find unusual frequencies and sizes of violations either during opening or closing hours and the results are not reported. Less frequent violations during opening hours when using futures contracts seem to suggest that the futures price reflects the index level than the quoted index. Some of index component stocks would reflect previous day's prices. Accordingly there exists a disparity between the futures price and the underlying spot index level.

We further investigate most-frequent violation dates for the put-call parity conditions. Most-frequent violation dates are concentrated between May 1998 and October 1998. During this time period, the spot index is sharply declining and futures prices tend to be lower than the spot index. The uncertainty and the volatility of the stock market increase put-call parity violations. We also observe more violations around maturity days.

D. Transaction Costs and Economic Significance of Violation

As we find significant violations for some conditions, now an important question remains to be addressed: that is, how significant is the violations economically. In this section we are trying to address the issue by considering transaction costs of implementing these arbitrages.

For stock trading, individual investors pay commission and trading taxes and member firms pay member fees, commission, exchange fees and trading taxes. For futures and options, trading taxes are exempt and individual investors pay only commission while member firms pay member fees and exchange fees. Commission is only about 30 percent of the general commission when individual investors trade electronically through the Home Trading System (HTS). The overall average transaction costs of individual investors (member firms) are 44 (31) basis points for stock trading, 4.5 (0.084) basis points for futures trading and 54 (3.94) basis points for options trading. Table 7 summarizes transaction costs for both individual investor and member firms. The transaction costs are relatively low for Korean markets and they are not significant enough to justify the existence of arbitrage opportunities.

E. Lead-Lag Relationship between Spot and Option Markets.

As pointed out before, the results suggest that the price formation process in the option market per se is efficient but the information flow between the option and underlying stock markets may not be simultaneous. Accordingly, a further investigation is conducted whether either the option market or the stock market plays a leading role in price formation.[11]
In this study, the approach of Finucane (1991), which does not require specification of an option pricing model or estimation of the volatility of the underlying asset, is used. Finucane (1991) derives "relative put and call prices" which, in the presence of market frictions, contain

[11] There are numerous studies on the lead-lag relations between the option and the stock markets. While a number of studies suggest that option prices are likely to reflect new information before the underlying asset prices, the existing empirical evidence is not conclusive yet. See Vijh (1988, 1990), Conrad (1989), DeTemple and Jorion (1993), Damodoran and Lim (1991), Sheikh and Ronn (1994), Mayhew, Sarin and

information concerning future returns of the underlying asset. A measure of relative prices is derived from the put-call parity relationship for index options as follows:

$$E_t = C - P - S - Ke^{-r\tau} + D,$$

where E_t is a measure of relative put-call prices. High and low values of E_t imply relatively high call prices and put prices, respectively. Accordingly, the hypothesis that the index option market conveys information concerning future returns of the underlying index can be tested by examining the correlation between the index return and a measure of the relative put-call prices.

Table 5 reports correlation coefficients between E_t and the index returns calculated as $\ln(S_{t+\Delta t}/S_t)$, for time intervals of 0.5, 1, 1.5, 2, 2.5, 3, and 5 minutes. All correlations are positive and significant. The magnitude of correlations is the highest when the returns are calculated with two and a half minute interval. The magnitudes of the correlations tend to increase with the deviations from the put-call parity. When the correlations are calculated using a set of relative put-call prices greater than .5 ($|E_t|>.5$), the returns are more highly correlated to relative option

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Shastri (1993), Fleming, Ostdiek, and Whaley (1996), and O'Connor (1999).

prices in the KOPSI 200 options market.[12] It appears that the KOSPI 200 option market leads the underlying index by about two and a half minutes.

Since the component stocks of the KOSPI 200 index do not trade simultaneously, the index level at any point in time may reflect a number of stale prices for the underlying stocks. To assess the extent of asynchronous prices, the correlations are recalculated using a 30-second delay; that is, the index returns are calculated 30 seconds after the measure of relative put-call prices (E_{t-30}). Although these new correlations are lower than those without considering delay, they are still significantly greater than zero.

As previous studies point out, informed traders may turn to the options markets first due to some advantages such as lower trading costs, greater leverage, and fewer restrictions on short sales, etc. Considering that the KOSPI 200 option market is the most liquid index option market in the world and that its trading costs are lower than those of the underlying stocks, the supporting evidence for the hypothesis that the options contain information concerning future returns in the stock market in advance is not surprising. It is also notable that the time lead of options is only about 3 minutes, much shorter than that of S&P 100 index options. Finucane (1991) found that the S&P 100 index options lead the S&P 100 index returns by at least 15 minutes. The recent increase in online trading, easy access of market information, lower transaction costs, and greater speed of execution should have contributed to reducing the time gap between the stock and option markets' information flow.

III. Conclusions

This study investigates arbitrage opportunities and efficiency of the KOSPI 200 options in Korea. Specifically, it tests some properties of option prices including lower boundary conditions of call and put options, option price relationships independent of underlying index, put-call parity, and box spread arbitrage conditions.

[12] This is equivalent to implementing a filter rule in a trading strategy.

Major findings include that if the option market is considered separately from the underlying stock market, the price formation process in the option market seems to be efficient. This is evidenced by few violations of no-arbitrage conditions involving only option contracts. However, when we consider no-arbitrage conditions involving both options and the underlying index, substantial arbitrage opportunities exist. This suggests that the information flow between the option market and the underlying stock market may not be simultaneous and thus not efficient. To explore this possibility, it is investigated whether the option or the stock market plays a leading role, if any, in price formation. The empirical evidence supports the hypothesis that the option market leads the stock market, but that information concerning future stock index returns is well reflected in relative call-put prices. The time lead of the KOSPI 200 options in Korea appears to be much shorter than that of the S&P 100 index options in the U.S.

The results also reveal several discernable patterns. There tends to be more frequent violations on the dates close to maturity, and the tendency is true for all the conditions examined in this paper. The violations tend to occur more frequently during opening and closing hours. In-the-money options are more often associated with the violations of no-arbitrage conditions than out-of-the-money options. For no-arbitrage conditions involving only options, the average size of violations tends to be smaller for at-the-money options than for out-of-the-money or in-the-money options. Liquidity and transactions costs in implementing the arbitrage strategies appear to be important factors of the observed violation patterns of the conditions.

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Table 1. Lower Boundary Conditions Violations

$$C^a(K) \geq \max[S^n - Ke^{-r\tau}, 0],$$

$$P^a(K) \geq \max[Ke^{-r\tau} - S^n, 0],$$

where

$$S^n = S - \sum D_t e^{-rt} .$$

Panel A. Summary Results

	Call		Put		Call	Put
	1998.01 – 1998.12	1999.01 – 1999.09	1998.01 – 1998.12	1999.01 – 1999.09	1998.01 – 1999.09	1998.01 – 1999.09
Number of Violations	20,638	4,151	4,103	3,109	24,789	7,212
Number of Observations	350,816	372,540	333,247	535,182	723,356	868,429
Percentage of Violations	5.88	1.11	1.23	0.58	3.43	0.83
Mean Size of Violations	0.437***	0.281***	0.222***	0.227***	0.411***	0.224***
Standard Deviation of Violations	0.402	0.394	0.207	0.235	0.405	0.220
T-statistic for Equality of Means		23.20***		-0.94		50.29***

Mean size of violations is in terms of a hundred thousand Korean Won. T-statistic is to test the mean size difference of violations. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Panel B. Dates with frequent violations of the low boundary conditions

Rank	Date	Number of Observations	Number of Violations	Percentage of Violations	Mean Size of Violations	Standard Deviation of Violation Size
1	98.09.05	836	250	29.9	0.41	0.23
2	98.09.07	1,921	541	28.2	0.40	0.13
3	98.09.04	1,705	472	27.7	0.36	0.21
4	**98.01.08**	1,145	311	27.2	0.21	0.14
5	**98.04.09**	1,257	325	25.9	0.30	0.16
6	98.05.12	2,105	540	25.7	0.26	0.17
7	**98.09.10**	1,184	291	24.6	0.20	0.18
8	98.06.10	1,790	429	24.0	0.35	0.18
9	98.09.03	1,727	396	22.9	0.44	0.30
10	**98.10.08**	1,104	250	22.6	0.07	0.06
11	98.06.09	1,914	426	22.3	0.47	0.26
12	**98.02.12**	1,231	264	21.4	0.31	0.24
13	98.01.06	2,285	456	20.0	0.44	0.23
14	98.09.09	1,642	327	19.9	0.32	0.11
15	98.06.08	2,903	404	19.3	0.51	0.19
16	**98.06.11**	1,364	261	19.1	0.35	0.16
17	98.08.11	1,573	300	19.1	0.19	0.10
18	98.09.08	1,885	349	18.5	0.12	0.07
19	98.08.08	1,034	176	17.0	0.25	0.14
20	98.08.07	2,016	343	17.0	0.34	0.13
21	98.06.03	2,388	388	16.2	0.94	0.34
22	**98.07.09**	1,191	191	16.0	0.10	0.22
23	98.05.13	1,834	293	16.0	0.14	0.11
24	98.09.02	1,962	313	16.0	0.48	0.19
25	98.04.03	2,800	437	15.6	0.32	0.20
26	98.05.29	2,778	424	15.3	1.25	0.53
27	98.09.01	1,914	291	15.2	0.73	0.15
28	**98.05.14**	1,481	223	15.1	0.13	0.12
29	98.08.28	2,074	312	15.0	0.63	0.20
30	98.05.28	2,801	417	14.9	1.03	0.46

Mean size of violations is in terms of a hundred thousand Korean Won. Bold-typed date indicates maturity date.

Panel C. Comparison of Lower Boundary Condition Violations Between Maturity Date and Non-Maturity Date

	Non-Maturity Date	Maturity Date
Number of Violations	42,621	4,564
Number of Observations	1,549,164	27,437
Percentage of Violations	1.77	10.71
Mean Size of Violations	0.3944***	0.1885***
Standard Deviation of Violations	0.3880	0.2264
T-statistic for Equality of Means		50.34***

Mean size of violations is in terms of a hundred thousand Korean Won. T-statistic is to test the mean size difference of violations. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Panel D. Intraday Lower Boundary Condition Violations

Time Interval	Number of Observations	Number of Violations	Percentage of Violations	Mean Size of Violations	Standard Deviations
09:00-09:30	108,115	1,049	0.97	0.33	0.36
09:30-10:00	188,620	4,583	2.43	0.40	0.37
10:00-10:30	178,437	4,118	2.31	0.39	0.44
10:30-11:00	171,975	3,766	2.19	0.39	0.42
11:00-11:30	168,962	3,534	2.09	0.39	0.39
11:30-12:00	100,678	869	0.86	0.27	0.29
13:00-13:30	161,825	3,284	2.03	0.35	0.34
13:30-14:00	154,019	3,146	2.04	0.35	0.37
14:00-14:30	158,530	3,324	2.10	0.34	0.34
14:30-15:00	162,515	3,439	2.12	0.34	0.32
15:00-15:15	35,195	889	2.53	0.38	0.38

Mean size of violations is in terms of a hundred thousand Korean Won.

Table 2. Option Pricing Relationship Violations

Panel A: Summary Results

Condition 1 : $C^a(K_1) - C^b(K_2) \geq 0$ and $P^a(K_2) - P^b(K_1) \geq 0$

	Call		Put		Call	Put
	1998.01 – 1998.12	1999.01 – 1999.09	1998.01 – 1998.12	1999.01 – 1999.09	1998.01 – 1999.09	1998.01 – 1999.09
Number of Violations	3	5	2	6	8	8
Number of Observations	242,528	275,998	227,754	404,901	518,526	632,655
Percentage of Violations	0.00	0.00	0.00	0.00	0.00	0.00

Condition 2 : $C^a(K_2) - C^b(K_1) + (K_2 - K_1)e^{-r\tau} \geq 0$ and $P^a(K_1) - P^b(K_2) + (K_2 - K_1)e^{-r\tau} \geq 0$

	Call		Put		Call	Put
	1998.01 – 1998.12 (A)	1999.01 – 1999.09 (B)	1998.01 – 1998.12 (C)	1999.01 – 1999.09 (D)	1998.01 – 1999.09 (E)	1998.01 – 1999.09 (F)
Number of Violations	139	105	89	59	244	148
Number of Observations	242,582	274,684	227,754	400,841	517,266	628,595
Percentage of Violations	0.06	0.04	0.04	0.01	0.05	0.02
Mean Size of Violations	0.077***	0.154***	0.116***	0.159***	0.110***	0.133***
Standard Deviation of Violations	0.144	0.304	0.255	0.373	0.230	0.307
T-statistic for Equality of Means	-2.40*** (between A and B)		-0.77 (between C and D)		-0.79 (between E and F)	

Condition 3: $C^b(K_2) \leq \frac{K_3 - K_2}{K_3 - K_1} C^a(K_1) + \frac{K_2 - K_1}{K_3 - K_1} C^a(K_3)$ **and**

$$P^b(K_2) \leq \frac{K_3 - K_2}{K_3 - K_1} P^a(K_1) + \frac{K_2 - K_1}{K_3 - K_1} P^a(K_3)$$

	Call		Put		Call	Put
	1998.01 – 1998.12 (A)	1999.01 – 1999.09 (B)	1998.01 – 1998.12 (C)	1999.01 – 1999.09 (D)	1998.01 – 1999.09 (E)	1998.01 – 1999.09 (F)
Number of Violations	585	1,072	776	2,775	1,657	3,551
Number of Observations	171,817	213,384	157,701	330,737	385,201	488,438
Percentage of Violations	0.34	0.50	0.49	0.84	0.43	0.73
Mean Size of Violations	0.058***	0.051***	0.039***	0.032***	0.054***	0.034***
Standard Deviation of Violations	0.108	0.131	0.052	0.074	0.123	0.070
T-statistic for Equality of Means	1.17(between A and B)		3.00***(between C and D)		6.17***(between E and F)	

Mean size of violations is in terms of a hundred thousand Korean Won. T-statistic is to test the mean size difference of violations. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Panel B: Comparison of Violations for In-the-money, At-the-money, and Out-of-the-money options

	Condition 1			Condition 2			Condition 3		
	In-the-money	At-the-money	Out-of-money	In-the-money	At-the-money	Out-of-money	In-the-money	At-the-money	Out-of-money
Number of Violations	4	1	11	364	27	1	323	262	4,623
Number of Obs.	118,158	321,510	706,193	118,158	321,510	706,193	104,660	126,287	642,692
Percentage Violations	0.00	0.00	0.00	0.31	0.00	0.00	0.31	0.21	0.72
Mean Size of Violations	0.58	0.50	0.15	0.12***	0.07***	0.37	0.148	0.084	0.030
Standard Deviation				0.27	0.13		0.279	0.112	0.046

Mean size of violations is in terms of a hundred thousand Korean Won. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Panel C. Comparison of Violations Between Maturity Date and Non-Maturity Date for Condition 2

	On Maturity (A)	Prior to Maturity (B)	On Maturity and One Day Before Maturity (C)	Prior to One Day Before Maturity (D)
Number of Violations	127	265	210	182
Number of Observations	20,474	1,125,387	55,270	1,090,591
Percentage of Violations	0.62	0.02	0.38	0.02
Mean Size of Violations	0.055***	0.150***	0.064***	0.182***
Standard Deviation of Violations	0.127	0.301	0.136	0.345
T-statistic for Equality of Means	-4.39*** (between A and B)		-4.33*** (between C and D)	

Mean size of violations is in terms of a hundred thousand Korean Won. T-statistic is to test the mean size difference of violations. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Panel D. Intraday Violations

1. Condition 2

Time Interval	Number of Observations	Number of Violations	Percentage of Violations	Mean Size of Violations	Standard Deviations	T-statistic for Means Equality
09:00-09:30	82,664	38	0.05	0.26	0.39	2.47***
09:30-10:00	136,904	39	0.03	0.08	0.10	
10:00-10:30	128,321	19	0.02	0.03	0.04	
10:30-11:00	121,581	26	0.02	0.08	0.13	
11:00-11:30	119,069	37	0.03	0.10	0.20	
11:30-12:00	73,260	14	0.02	0.20	0.50	
13:00-13:30	114,758	44	0.04	0.15	0.34	
13:30-14:00	108,810	35	0.03	0.12	0.34	
14:00-14:30	114,554	43	0.04	0.08	0.16	
14:30-15:00	118,741	75	0.06	0.09	0.16	
15:00-15:15	25,049	22	0.09	0.19	0.33	-1.26

2. Condition 3

Time Interval	Number of Observations	Number of Violations	Percentage of Violations	Mean Size of Violations	Standard Deviations	T-statistic for Means Equality
09:00-09:30	68,874	897	1.30	0.058	0.096	6.32***
09:30-10:00	105,486	604	0.57	0.040	0.065	
10:00-10:30	96,742	529	0.55	0.030	0.040	
10:30-11:00	90,030	434	0.48	0.045	0.183	
11:00-11:30	87,649	343	0.39	0.037	0.092	
11:30-12:00	57,809	308	0.53	0.038	0.134	
13:00-13:30	86,554	465	0.54	0.034	0.053	
13:30-14:00	80,806	343	0.42	0.030	0.075	
14:00-14:30	86,960	466	0.54	0.032	0.050	
14:30-15:00	91,478	692	0.76	0.036	0.061	
15:00-15:15	19,510	126	0.65	0.054	0.075	

Mean of violations is in terms of a hundred thousand Korean Won. T-statistic is to test the mean size difference with the time interval 09:30-15:15. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Table 3. Put-Call Parity Violations

Conversion: $P^a(K) - C^b(K) + S^n - Ke^{-r\tau} \geq 0$

Reverse Conversion: $C^a(K) - P^b(K) + Ke^{-r\tau} - S^n \geq 0$

Panel A: Summary results for the whole period

	Conversion			Reverse Conversion		
	1998.01 - 1998.12 (A)	1999.01 - 1999.09 (B)	1998.01 - 1999.09	1998.01 - 1998.12 (C)	1999.01 - 1999.09 (D)	1998.01 - 1999.09
Number of Violations	53,603	100,636	154,239	86,283	55,400	141,683
Number of Observations	173,016	218,173	391,189	173,016	218,173	391,189
Percentage of Violations	31.0	46.1	39.4	49.9	25.4	36.2
Mean Size of Violations	0.707***	0.639***	0.662***	0.706***	0.728***	0.715***
Standard Deviation of Violations	0.851	1.058	0.992	0.649	0.767	0.697
T-statistic for Equality of Means	(13.70)***(between A and B)			-5.59*** (between C and D)		

Mean size of violations is in terms of a hundred thousand Korean Won. T-statistic is to test the mean size difference of violations. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Panel B: Comparison of the Put-Call Parity Violation across Different Exercise Prices

	Conversion			Reverse Conversion		
	High	At-the-Money	Low	High	At-the-Money	Low
Number of Violations	27,308	101,395	25,536	19,237	96,233	26,213
Number of Observations	73,275	232,227	85,687	73,275	232,227	85,687
Percentage of Violations	37.3	43.7	29.8	26.3	41.4	30.6
Mean Size of Violations	0.929***	0.610***	0.584***	0.799***	0.664***	0.840***
Standard Deviation of Violations	1.878	0.668	0.548	0.797	0.645	0.776

Mean size of violations is in terms of a hundred thousand Korean Won. * indicates significance at the 10% level. ** indicates significance at the 5% level. * indicates significance at the 1% level.**

Panel C. Intraday Violations

1. Conversion

Time Interval	Number of Observations	Number of Violations	Percentage of Violations	Mean Size of Violations	Standard Deviations	T-statistic for Means Equality
09:00-09:30	30,371	13,341	43.9	1.039	1.885	
09:30-10:00	46,997	16,928	36.0	0.662	0.993	
10:00-10:30	43,527	15,830	36.4	0.633	0.942	
10:30-11:00	41,103	15,114	36.8	0.585	0.827	
11:00-11:30	39,894	14,833	37.2	0.587	0.723	
11:30-12:00	25,208	11,975	47.5	0.651	0.754	
13:00-13:30	40,897	15,294	37.4	0.629	0.970	
13:30-14:00	37,197	14,904	40.1	0.587	0.693	
14:00-14:30	39,930	16,869	42.2	0.620	0.782	
14:30-15:00	46,065	19,151	41.6	0.657	0.854	

2. Conversion

Time Interval	Number of Observations	Number of Violations	Percentage of Violations	Mean Size of Violations	Standard Deviations	T-statistic for Means Equality
09:00-09:30	30,371	6,967	22.9	0.675	0.687	
09:30-10:00	46,997	18,345	39.0	0.726	0.683	
10:00-10:30	43,527	17,643	40.5	0.722	0.697	
10:30-11:00	41,103	16,701	40.6	0.731	0.719	
11:00-11:30	39,894	16,301	40.9	0.738	0.726	
11:30-12:00	25,208	6,720	26.7	0.706	0.771	
13:00-13:30	40,897	15,379	37.6	0.720	0.719	
13:30-14:00	37,197	13,980	37.6	0.720	0.700	
14:00-14:30	39,930	14,091	35.3	0.696	0.669	
14:30-15:00	46,065	15,556	33.8	0.678	0.626	

Mean of violations is in terms of a hundred thousand Korean Won. T-statistic is to test the mean size difference with the time interval 09:30-15:15. * indicates significance at the 10% level. ** indicates significance at the level 5% level. * indicates significance at the 1% level.**

Table 4. Box Spread Conditions Violations

$(C^a(K_1) - C^b(K_2)) - (P^b(K_1) - P^a(K_2)) + (K_1 - K_2)e^{-r\tau} \geq 0$: Debit Spread

$(C^a(K_2) - C^b(K_1)) - (P^b(K_2) - P^a(K_1)) + (K_2 - K_1)e^{-r\tau} \geq 0$: Credit Spread

Panel A: Summary results for the whole period

	Debit Box Spread			Credit Box Spread		
	1998.01 – 1998.12 (A)	1999.01 – 1999.09 (B)	1998.01 – 1999.09	1998.01 – 1998.12 (C)	1999.01 – 1999.09 (D)	1998.01 – 1999.09
Number of Violations	3,885	4,294	8,179	4,077	3,906	7,983
Number of Observations	86,591	123,925	210,516	86,591	123,925	210,516
Percentage of Violations	4.5	3.5	3.9	4.7	3.2	3.8
Mean Size of Violations	0.060***	0.070***	0.065***	0.049***	0.055***	0.052***
Standard Deviation of Violations	0.110	0.121	0.116	0.090	0.105	0.098
T-statistic for Equality of Means	-3.91*** (between A and B)			2.74*** (between C and D)		

Panel B: Comparison of the Violations for Box Spread Conditions across Different Exercise Prices

	Debit Box Spread			Credit Box Spread		
	Low Exercise (A)	ATM Exercise (B)	High Exercise (C)	Low Exercise (D)	ATM Exercise (E)	High Exercise (F)
Number of Violations	1,386	5,889	904	1,637	4,965	1,381
Number of Observations	53,969	111,077	45,470	53,969	111,077	45,470
Percentage of Violations	2.6	5.3	2.0	3.0	4.5	3.0
Mean Size of Violations	0.092***	0.053***	0.100***	0.077	0.038	0.073
Standard Deviation of Violations	0.171	0.084	0.169	0.121	0.063	0.148
T-statistic for Equality of Means		8.26*** (between A and B)	-8.21*** (B and C)		12.49*** (D and E)	-8.57*** (E and F)

Panel C. Comparison of Box Spread Condition Violations Between Maturity Date and Non-Maturity Date

	Debit Box Spread			Credit Box Spread		
	On Maturity (A)	Prior to Maturity (B)	On Maturity Week (C)	On Maturity (D)	Prior to Maturity (E)	On Maturity Week (F)
Number of Violations	611	5,235	2,944	946	4,534	3,449
Number of Observations	6,973	165,177	45,339	6,973	165,177	45,339
Percentage of Violations	8.8	3.2	6.5	13.6	2.7	7.6
Mean Size of Violations	0.050***	0.071***	0.055***	0.031***	0.059***	0.042***
Standard Deviation of Violations	0.071	0.133	0.077	0.040	0.108	0.082
T-statistic for Equality of Means	-6.15*** (A and B)		6.88*** (B and C)	-13.6*** (D and E)		8.00*** (E and F)

Mean size of violations is in terms of a hundred thousand Korean Won. T-statistic is to test the mean size difference of violations. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Panel D: Intraday Violations

1. Debit Box Spread

Time Interval	Number of Observations	Number of Violations	Percentage of Violations	Mean Size of Violations	Standard Deviations	T-statistic for Means Equality
09:00-09:30	17,901	722	4.0	0.126	0.193	9.33***
09:30-10:00	25,853	1,157	4.5	0.075	0.107	
10:00-10:30	22,890	819	3.6	0.056	0.108	
10:30-11:00	20,880	838	4.0	0.052	0.096	
11:00-11:30	20,121	787	3.9	0.049	0.098	
11:30-12:00	13,333	388	2.9	0.065	0.126	
13:00-13:30	22,058	803	3.6	0.042	0.087	
13:30-14:00	18,656	724	3.9	0.048	0.090	
14:00-14:30	20,844	804	3.9	0.057	0.095	
14:30-15:00	22,537	926	4.1	0.065	0.111	
15:00-15:15	5,443	211	3.9	0.091	0.156	-2.98***

2. Credit Box Spread

Time Interval	Number of Observations	Number of Violations	Percentage of Violations	Mean of Violations	Standard Deviations	T-statistic for Means Equality
09:00-09:30	17,901	550	3.1	0.102	0.167	7.64***
09:30-10:00	25,853	980	3.8	0.058	0.092	
10:00-10:30	22,890	838	3.7	0.045	0.083	
10:30-11:00	20,880	737	3.5	0.041	0.079	
11:00-11:30	20,121	732	3.6	0.039	0.070	
11:30-12:00	13,333	407	3.1	0.053	0.140	
13:00-13:30	22,058	896	4.1	0.049	0.080	
13:30-14:00	18,656	752	4.0	0.042	0.105	
14:00-14:30	20,844	882	4.2	0.043	0.073	
14:30-15:00	22,537	972	4.3	0.053	0.077	
15:00-15:15	5,443	237	4.5	0.079	0.139	-3.52***

Mean of violations is in terms of a hundred thousand Korean Won. T-statistic is to test the mean size difference with the time interval 09:30-15:00. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Table 5. Correlation of Relative Put-Call Prices (E_t) with Underlying Index Returns over Various Time Intervals

	Time Interval (Minutes)						
	0.5	1	1.5	2	2.5	3	5
E_t	0.059	0.076	0.083	0.087	0.089	0.082	0.072
$\|E_t\| > 0.5$	0.079	0.104	0.115	0.117	0.116	0.115	0.101
E_{t-30}	0.028	0.073	0.107	0.111	0.111	0.111	0.106

Index Returns are calculated as $\ln(S_{t+\Delta t}/S_t)$.

Table 6. Put-Call Parity Violations With Futures Contracts

Conversion: $P^a(K) - C^b(K) + Fe^{-r\tau} - Ke^{-r\tau} \geq 0$

Reverse Conversion: $C^a(K) - P^b(K) + Ke^{-r\tau} - Fe^{-r\tau} \geq 0$

Panel A: Summary results for the whole period

	Conversion			Reverse Conversion		
	1998.01 - 1998.12 (A)	1999.01 - 1999.09 (B)	1998.01 - 1999.09	1998.01 - 1998.12 (C)	1999.01 - 1999.09 (D)	1998.01 - 1999.09
Number of Violations	79,088	44,420	123,508	54,537	99,992	154,529
Number of Observations	163,237	218,253	381,490	163,237	218,253	381,490
Percentage of Violations	48.4	20.4	32.4	33.4	45.8	40.5
Mean Size of Violations	0.621***	0.668***	0.638***	0.645***	0.562***	0.591***
Standard Deviation of Violations	0.542	0.829	0.660	0.853	0.536	0.667
T-statistic for Equality of Means	(-10.73)***(between A and B)			20.61*** (between C and D)		

Mean size of violations is in terms of a hundred thousand Korean Won. T-statistic is to test the mean size difference of violations. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Panel B: Comparison of the Put-Call Parity Violation across Different Exercise Prices

	Conversion			Reverse Conversion		
	High	At-the-Money	Low	High	At-the-Money	Low
Number of Violations	17,872	89,688	15,948	20,609	102,247	31,673
Number of Observations	72,859	225,198	83,433	72,859	225,198	83,433
Percentage of Violations	24.5	39.8	19.1	28.3	45.4	38.0
Mean Size of Violations	0.745***	0.631***	0.556***	0.498***	0.576***	0.699***
Standard Deviation of Violations	0.716	0.648	0.646	0.580	0.669	0.698

Mean size of violations is in terms of a hundred thousand Korean Won. * indicates significance at the 10% level. ** indicates significance at the 5% level. * indicates significance at the 1% level.**

Panel C Intraday Violations

1. Conversion.

Time Interval	Number of Observations	Number of Violations	Percentage of Violations	Mean Size of Violations	Standard Deviations	T-statistic for Means Equality
09:00-09:30	28,090	5,033	17.9	0.600	0.753	
09:30-10:00	45,470	15,318	33.7	0.626	0.610	
10:00-10:30	42,332	15,136	35.8	0.637	0.629	
10:30-11:00	39,941	14,101	35.3	0.631	0.632	
11:00-11:30	38,757	14,170	36.6	0.614	0.645	
11:30-12:00	23,978	5,456	22.8	0.676	0.807	
13:00-13:30	39,536	13,149	33.3	0.636	0.678	
13:30-14:00	35,997	12,335	34.3	0.626	0.649	
14:00-14:30	38,230	13,252	32.6	0.670	0.688	
14:30-15:00	40,103	3,097	33.0	0.664	0.652	

2. Reverse Conversion.

Time Interval	Number of Observations	Number of Violations	Percentage of Violations	Mean Size of Violations	Standard Deviations	T-statistic for Means Equality
09:00-09:30	28,090	11,013	39.2	0.553	0.518	
09:30-10:00	45,470	17,389	38.2	0.612	0.681	
10:00-10:30	42,332	17,105	40.4	0.607	0.690	
10:30-11:00	39,941	16,444	41.2	0.610	0.712	
11:00-11:30	38,757	15,467	39.9	0.602	0.698	
11:30-12:00	23,978	10,870	45.4	0.582	0.565	
13:00-13:30	39,536	15,749	39.8	0.586	0.675	
13:30-14:00	35,997	15,275	42.4	0.565	0.670	
14:00-14:30	38,230	15,957	41.7	0.578	0.675	
14:30-15:00	40,103	16,052	40.0	0.579	0.666	

Table7. Detailed Transaction Costs

(basis points)

	Member fees	Commission	Trading taxes	Exchange fees	Total
I. Stock Trading					
1. Individual investors		45 (14)	30		75 (44)
2. Institutional members	0.65		30	0.44	31.09
II. Futures Trading					
1. Individual investors		4.5			4.5
2. Institutional members	0.06			0.024	0.084
III. Options Trading					
1. Individual investors		140 (54)			140 (54)
2. Institutional members	3.6			0.34	4.0