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Inter-transaction Time, Informed Trading, and Trade-indicator Models

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Abstract

This study demonstrates that the basic properties predicted by one-dimensional diffusion option pricing models are often violated, even in a highly liquid and leading options market. We analyze a high quality intraday dataset of KOSPI 200 index options, one of the most actively traded options markets in the world, and find that option prices often do not monotonically correlate with underlying prices. We also empirically show that option prices often do not change, despite changes in underlying prices, when options are heavily traded by individual investors, who are normally noisy and uninformed. Our evidence is partially consistent with the implications of demand-based option pricing models, which predict that investor demand can significantly influence option prices in the presence of limits to arbitrage.

Our empirical results also suggest that the duration between two consecutive options trades reveals clear and significant information and support the hypothesis that fast trading is indicative of informed trading. This finding remains robust when we examine the information content of the trade duration while considering the sizes of incoming trades or the intraday time periods. Regression analysis indicates that the information role of trade duration becomes more important when market is more volatile.

1. Introduction

Prior studies have documented that option prices often do not move as traditional one-dimensional diffusion option pricing models predict. For example, the seminal paper of Bakshi, Cao, and Chen (2000) lists three properties shared by all models in the one-dimensional diffusion class. First, call (put) prices monotonically increase (decrease) with their underlying prices (i.e., the monotonicity property). Second, option prices should be perfectly correlated with both each other and their underlying prices (i.e., the perfect correlation property). Third, options are redundant assets, since they can be replicated with the underlying and risk-free assets (i.e., the option redundancy property).[1] Though these properties should theoretically hold, Bakshi, Cao, and Chen (2000) empirically show that option prices often move in a way that violates these properties by analyzing S&P 500 index options. Such violations suggest that one-dimensional diffusion models are not consistent with observed option price dynamics, indicating that options are not redundant securities. This study

[1] Bakshi, Cao, and Chen (2000) call these three properties "monotonicity," "perfect correlation," and "option redundancy." The monotonicity property includes the others because they do not hold if option prices do not "monotonically" move with the underlying asset price changes. Though we reexamine the issues on option price movements and test all the option price violation types (i.e., types I, II, III, and IV) discussed in Bakshi, Cao, and Chen (2000), we use "monotonicity properties" for its representativeness.

extends Bakshi, Cao, and Chen (2000) by investigating the KOSPI 200 index options market—a leading emerging market characterized by its extreme liquidity and the active participation of individual investors—and analyzing the patterns in and traits of the violations according to the proportion of individual trades. Our investigation provides substantial evidence confirming Bakshi, Cao, and Chen (2000). In particular, using the high-quality trade and quote (TAQ) dataset of KOSPI 200 options, we find that call (put) prices often do not monotonically increase (decrease) with underlying asset prices and that option prices are not perfectly correlated with them. Interestingly, we also find that some violations are attributable to individual trades, which suggests that the violations may be associated with limits to arbitrage and/or demand-pressure effects in the options market.

Our empirical evidence suggests that a univariate diffusion option pricing model imposes extremely stringent constraints on option price movements in real-world financial markets. This finding is consistent with previous studies that propose option pricing models incorporating additional state variables imperfectly correlated with underlying prices to clarify option price dynamics (Amin & Ng, 1993, 1997; Bates, 1991, 1996, 2000; Heston, 1993; Hull & White, 1987; Johnson & Shanno, 1987; Liu & Pan, 2003; Madan, Carr, & Chang, 1998; Melino & Turnbull, 1990, 1995; Naik & Lee, 1990; Scott, 1997; Wiggins, 1987). Bakshi, Cao, and Chen (2000) argue that especially when the stochastic volatility factor is considered, option prices can move independently of the underlying prices, indicating that options are therefore not redundant securities. From a different angle, Gârleanu, Pedersen, and Poteshman (2009) claim that investors' demand pressures can affect option prices when options are not redundant securities. In an economy in which competitive investors can hedge perfectly, option prices can be determined by the no-arbitrage argument, suggesting that investor demand cannot affect option prices; investors appear unable to hedge options perfectly, however. Beside stochastic volatility, other impediments can render a perfect hedge impossible, such as the impossibility of continuous trading, jumps in underlying asset prices, and transaction costs. Consequently, in reality, given that no-arbitrage conditions are often violated, investors' demand pressures in the options markets can impact option prices. Gârleanu, Pedersen, and Poteshman (2009) construct a demand-based option pricing model in which competitive risk-averse intermediaries who take the side opposite the end-user—the agents with a fundamental need for option exposures—cannot perfectly hedge their option positions; their model demonstrates that end-user demand for options can impact option prices. Their evidence is interesting and motivates our study. It reveals that changes in option prices are not driven exclusively by changes in their fundamental values; they can also be driven by changes in investor demand pressures.

In light of the evidence of prior studies, we examine whether the demand-pressure effect allowed by an imperfect option hedging can help explain option price movements. Specifically, we reexamine the violations discussed by Bakshi, Cao, and Chen (2000), and investigate whether the violation frequencies differ across the proportions of the trades initiated by individual investors, who are normally noisy and uninformed. Our intent is not to determine what makes a perfect hedge impossible but, assuming an imperfect hedge, to test the hypothesis that investors' demand pressures can affect option prices by investigating whether option price movements and underlying price changes are associated with demand pressures. We expect that violation frequencies are related to the trading activities of individual investors, under the presumption that more end-users exert greater demand pressures on those options. We specifically presume that individual investors are the end-users as in the model of Gârleanu, Pedersen, and Poteshman (2009) and that the options with higher individual trading proportions (ITPs) experience greater demand pressures.

Our empirical findings can be summarized as follows. First, we confirm the basic argument of Bakshi, Cao, and Chen (2000) about the limitations of the monotonicity properties of option price dynamics in an extremely liquid options market. Our analysis of the intraday dataset of KOSPI 200 index options indicates that option prices do not often monotonically and perfectly correlate with underlying equity prices; in our sample period of 2010 and 2011, call (put) prices move in the direction opposite that of the underlying index 18.78% (17.79%) of the time (type I violation), and that the underlying index changes, but call (put) prices do not 22.58% (24.05%) of the time (type II violation) where we use the bid–ask midpoint prices of KOSPI 200 options sampled at five-minute intervals.[2] Option quotes appear to be over-adjusted in response to changes in the underlying stock prices (type IV violation). Type IV violations occur as frequently as 11.61% of the time for calls and 10.89% of the time for puts at five-minute intervals.

Second, we find that violation rates differ across option moneyness. In-the-money (ITM) options are more vulnerable to type IV violations than to type II violations, while out-of-the-money (OTM) options are more vulnerable to type II violations than to type IV violations. Of a given maturity, OTM option prices remain unchanged when the underlying asset price changes more often than ITM option prices. By contrast, ITM option prices are over-adjusted more often than OTM options. These patterns across moneyness suggest that the market microstructural effects (e.g., tick-size restrictions) play a role in such violations. Interestingly, we find that type I violation rates are also related to the moneyness in the KOSPI 200 options market. This is in stark contrast to the finding of Bakshi, Cao, and Chen (2000), who see no clear relationship between option moneyness and type I violation rates in the US options market. We observe that ITM options lead to more frequent type I violations than OTM options do in the Korean options market.

Third, we find that OTM options heavily traded by individual investors experience the most frequent type II violations. In the OTM options market where individual investors are dominant players, type II violations significantly increase with ITP. We conjecture that greater demand pressures

[2] We use various intraday sampling intervals to control for the effect of time decay in option premiums on our results. The details are introduced in sections 4 and 5.

on OTM options allow a more significant relationship between ITP and violation frequency, inspired by the demand-pressure effects on option prices, as argued in prior studies.[3] Our finding on the ITP effect on violation frequencies in the OTM options market reflects the market lore in the KOSPI 200 options market, whereby many individual traders tend to regard trading OTM options as buying lotteries.[4] Since OTM options are more heavily traded by individual traders than ITM or at-the-money (ATM) options, OTM option prices would be more vulnerable to the demand-pressure effect. Our additional regression analysis confirms that the significant relationship between ITP and the type II violation rate is robust after controlling for other options market variables such as trading volume, bid-ask spreads, and time to expiration.

Finally, we provide evidence that the KOSPI 200 index appears to be more vulnerable to the stale component than the S&P 500 index. The violations occur regardless of whether the KOSPI 200 index or the lead-month KOSPI 200 index futures are used as proxies for the underlying asset. The violation rates are higher when we use the KOSPI 200 index. Bakshi, Cao, and Chen (2000) also find that the overall violation rates decrease when the S&P 500 index futures are used instead of the spot index. In our case, however, the decrease in violation rates is more significant and substantial.

We contribute to the extant literature by analyzing the intraday movements of option prices with large and recent samples and informative datasets. First, we supplement previous studies that use old and/or restrictive datasets. For example, Lin, Chen, and Tsai (2011) test the empirical validity of the monotonicity properties of option prices using restrictive transaction data for option contracts traded on the Taiwan Futures Exchange. Their analysis is based on only one-year transaction data containing insufficient information, while our study examines an extensive, high-quality TAQ dataset containing detailed information. Analyses of the KOSPI 200 options market are urgently needed, as it is characterized by extremely high liquidity and has been examined by few studies despite its substantial trading volume and importance as a leading derivatives market. We analyze this most actively traded options market to obtain comprehensive evidence using the informative dataset.

Second, we go beyond merely confirming the findings of prior studies by offering possible

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[3] Gârleanu, Pedersen, and Poteshman (2009) conjecture that OTM options are subjected to stronger demand pressures, making them more expensive.

[4] In the KOSPI 200 options market, only the nearest maturity options, for which time-to-maturities are on average less than 20 trading days are actively traded, and even the second-nearest maturity options are barely traded. Even in the maturity days of KOSPI 200 options, the trading volume of the nearest maturity options is much higher than that of options that mature at the upcoming delivery month. Therefore, the likelihood of getting “in-the-money” of OTM options until the maturity dates is quite small. Considering that the probability of making money from investing in OTM options is relatively low and that the values of OTM options are normally lower than their nominal prices, the trading motives of OTM investors are fairly speculative, as in lottery buying (Ahn, Kang, & Ryu, 2008, 2010; Han, Guo, Ryu, & Webb, 2012; Kim & Ryu 2015b; Ryu, 2011).

explanations for the violations. Some studies have already attempted this. For example, Dennis and Mayhew (2009) demonstrate that microstructure noises can lead to incorrect inferences with respect to the univariate diffusion test of Bakshi, Cao, and Chen (2000). Specifically, they argue that the reported violations can be caused to some extent by microstructural effects, when option prices are observed with noise. Pérignon (2006) argues that the frequent violations of monotonicity properties are attributable to tactical trading effects, suggesting that price/time priority and moderate liquidity may cause violations of monotonicity properties. In contrasts, our study argues that the demand pressures allowed by limits to arbitrage can lead to such violations.

Finally, we provide empirical evidence that option prices can be influenced by investors' trading activities by investigating options heavily traded by individual investors.[5] The possibility that option prices can be affected by trading pressures has been examined in several studies, including Bollen and Whaley (2004) and Gârleanu, Pedersen, and Poteshman (2009). We seek a link between individual investors' trading activities and no-arbitrage violations to shed light on the role of noise traders in a highly liquid options market. Buraschi and Jiltsov (2006) demonstrate that heterogeneity in beliefs can cause market incompleteness and yield to deviations from arbitrage bounds. Specifically, they show that a model that considers information heterogeneity can explain type I and IV violations. Our study also contributes to the literature on the efficiency of options markets. For noise traders to have a significant effect on option prices, there should be limits to the ability of informed traders to offset the effects of noise trading (Barber, Odean, & Zhu, 2009; Shleifer, 2000). Therefore, our evidence of the relationship between the option price dynamics and individual trading may indicate that arbitrage can be limited even in the highly liquid options market.

The rest of this paper is organized as follows. Section 2 describes the characteristics of the KOSPI 200 options market and explains why we analyze this market. Section 3 explains the violations of model predictions. Section 4 explains how the sample data are constructed for analysis. Section 5 provides the main empirical results and discussions. Finally, section 6 presents the conclusions.

2. KOSPI 200 Options Market

[5] Many studies, including Barber, Odean, and Zhu (2009), Brandt, Brav, Graham, and Kumar (2009), Dorn, Huberman, and Sengmueller (2008), assume that individual investors are noise traders. This conjecture is supported by empirical evidence that mispricing occurs more frequently among stocks that are heavily traded by individual investors (Han & Kumar, 2013; Kumar & Lee, 2006). Recent empirical studies on the Korean index derivatives markets including the KOSPI 200 options market also argue that individual investors are less informed and noisy (Ahn, Kang, & Ryu, 2008, 2010; Kang, Lee, Lee, & Park, 2012; Kim & Ryu, 2015a; Kim, Ryu, & Seo, 2015; Lee, 2015; Lee and Ryu, 2014, Ryu, 2012a, 2012b, 2013b, 2015).

The KOSPI 200 index options market is one of the most liquid and actively traded derivatives markets in the world, and the options product is definitely the most successful derivative asset of the Korea Exchange (KRX). Since its first transaction in 1997, the KOSPI 200 options market has become a top-tier, world-class derivative market. Until recently, KOSPI 200 options had the largest trading volume in the world.[6] Panel A of Table 1, showing the rankings in the global derivatives markets during the sample period of this study (2010 and 2011), indicates that Korea's index futures and options market dominate other derivatives markets. In addition to their ample liquidity, the KOSPI 200 options market has other unique characteristics in terms of investor participation rate and trading purpose. The KOSPI 200 options market features substantial individual investor activity, in stark contrast to the derivatives markets of developed countries, where institutional investors conduct most of the derivatives transactions. Panel B of Table 1, presenting the trading activities of three investor types (domestic individuals, domestic institutions, and foreign investors), shows that trades by domestic individual investors account for about one-third of the total trading volume in the KOSPI 200 options market. The active participation of individual investors indicates that the KOSPI 200 options market is highly speculative but also highly liquid. Most of the individual investors in the Korean index derivatives markets are extremely short-term investors and day traders, and their trades can largely be characterized as noisy. Against the intentions of the government and the KRX, which have promoted index derivatives trading, individuals do not use the derivatives as hedging tools or trading vehicles for long-term portfolio management (Kim & Ryu, 2012; Ryu, 2011, 2013a). Their trading tends to make the market more volatile, unstable, and excessively speculative. On the other hand, market participants can enjoy the ample liquidity provided by numerous and diverse individual investors, which has enabled the KOSPI 200 options market to remain a world-class index options market.

[Table 1 inserted]

The ample liquidity and unique investor participation rate of the KOSPI 200 index options market provide an ideal setting for this study. For example, we expect to obtain uncontaminated results by analyzing the high-quality intraday dataset of the KOSPI 200 options because the options market experiences little friction and can absorb almost all the demands of derivatives investors in the Korean financial market. Bid–ask spreads are fairly narrow, market depths are great, and the KOSPI 200 options market has no trading or capital gain taxes. Our findings on such a liquid market suggest that the observed violations against the predictions of one-dimensional option pricing models are not

[6] Refer to the official website of the Futures Industry Association (https://fia.org). The top-tier position and importance of the KOSPI 200 options market and the applications of the options product are well-documented in prior studies (Guo, Han, & Ryu, 2013; Lee, Kang, Ryu, 2015; Lee and Ryu, 2013; Ryu, Kang, Suh, 2015).

driven entirely by market frictions related to a lack of liquidity or trading barriers. Rather, we entertain the possibility that the violations are associated with noise trading: the trading of individual investors, who are speculative and noisy, can allow option prices to move against the predictions of one-dimensional option pricing models.

The market microstructure of the KOSPI 200 options market can be described as follows. The options market is classified as a purely order-driven market, where there is no designated market maker. All trades are made via the central electronic limit order book (CLOB) in the options market, which means that all liquidity is provided by limit order traders, and all submitted orders are collected and carried out by the CLOB. Market orders and marketable limit orders are completed immediately upon submission in real time. Limit orders are stored in the CLOB and matched based on the price and time priority rules. In other words, all orders submitted by the KOSPI 200 options traders are transacted fairly and transparently through the limit order book system, and this market structure and trading mechanism ensure the anonymity of all market participants and market transparency.

On a normal trading day, the KOSPI 200 options market opens at 9:00 and closes at 15:15.[7] During the last 10 minutes (from 15:05 to 15:15) and during the hour-long pre-opening session (from 8:00 to 9:00), standing orders are transacted under the uniform pricing rule. During other intraday periods (from 9:00 to 15:05), all submitted orders are immediately traded (for market and marketable limit orders) or consolidated into the CLOB (for other limit others).

Four different options contracts with varying maturities can be traded each trading day. The maturity dates fall on the second Thursdays of three consecutive near-term months and the month nearest to each quarterly cycle (one among March, June, September, or December). The nearest maturity options contracts are usually actively traded, with other, longer-term contracts less actively traded. The basic quoting unit of the KOSPI 200 options market is the "point," corresponding to 500,000 Korean won (KRW). The minimum tick size is set as 0.01 point (i.e., 5,000 KRW) for options priced lower than three points and 0.05 point (i.e., 25,000 KRW) for options more than three points.

3. Violations of model predictions

Previous studies have proposed various option pricing models under the assumption that the underlying asset price follows a one-dimensional diffusion process (Bakshi, Cao, & Chen, 1997, 2000; Bergman, Grundy, & Wiener, 1996; Black & Scholes, 1973; Cox & Ross, 1976; Dumas, Fleming, & Whaley, 1998; Jaganathan, 1984; Merton, 1973; Rubinstein, 1994). In the absence of an arbitrage

[7] There are exceptions. On the maturity dates, the trading session closes 25 minutes earlier than on other normal trading days. The trading begins one hour later (i.e., at 10:00) on the first trading date of each calendar year and on the College Scholastic Ability Test (CSAT) date.

opportunity, all models in the one-dimensional diffusion class predict that an increase in the underlying asset value implies an increase (decrease) in the value of a call (put) option. However, several studies indicate that these predictions are often violated in financial markets. For example, Bakshi, Cao, and Chen (2000) list the one-factor no-arbitrage restrictions and examine the empirical violation frequency. They find that the restrictions are frequently violated and interpret these violations as evidence against one-factor models of option pricing. Lin, Chen, and Tsai (2011) similarly explore violation frequency in the Taiwan market and obtain similar results.

The violations of the one-factor no-arbitrage restrictions may serve as evidence against a one-dimensional diffusion process or market frictions. In an option pricing model with an additional stochastic factor, option prices are not necessarily perfectly correlated with the underlying asset price. Bergman, Grundy, and Wiener (1996) show that, when the process of the underlying asset price is non-Markovian, the prices of call options can decrease with the underlying prices. Buraschi and Jiltsov (2006) show that a model that takes information heterogeneity into account can help explain the no-arbitrage violations implied by one-dimensional diffusion models. Market frictions can also explain these no-arbitrage violations. Bakshi, Cao, and Chen (2000) argue that market microstructural effects can help cause violations. Dennis and Mayhew (2009) find that a significant portion of the violations is due to microstructural noises. The observed violations suggest that a perfect hedge is impossible and hence that an option is not a redundant security.

We thus explore four simple no-arbitrage restrictions of option pricing models that assume a one-factor structure:

Type I violation: $\Delta S \Delta C<0$, $\Delta S \neq 0$, $\Delta C \neq 0$, for calls (or $\Delta S \Delta P>0$, $\Delta S \neq 0$, $\Delta P \neq 0$, for puts)

Type II violation: $\Delta S \Delta C=0$, $\Delta S \neq 0$, $\Delta C=0$, for calls (or $\Delta S \Delta P=0$, $\Delta S \neq 0$, $\Delta P=0$, for puts)

Type III violation: $\Delta S \Delta C=0$, $\Delta S=0$, $\Delta C \neq 0$, for calls (or $\Delta S \Delta P=0$, $\Delta S=0$, $\Delta P \neq 0$, for puts)

Type IV violation: $\Delta C/\Delta S>1$, $\Delta S \neq 0$, for calls (or, $\Delta P/\Delta S<-1$, $\Delta S \neq 0$, for puts),

where S is the underlying price, C is the call option price, and P is the put option price.

4. Sample Data

We analyze the intraday trade and quote data for KOSPI 200 index options from January 2010 through December 2011. Figure 1 shows the time trend of the trading volumes and activities for three investor types—domestic individuals, domestic institutions, and foreigners—from 2003 to 2014, which includes the sample period of this study (2010 and 2011). Due to the Korean government's 2012 market reform, the trading volume decreased dramatically, and the relative portion of individual trades also decreased, while that of foreign participants increased. We analyse the sample period before the regulation that effectively decreased option market liquidity and induced a structural break in the KOSPI 200 options market.[8]

[Figure 1 inserted]

Our data contain a comprehensive time-stamped history of all trades and quotes, including the price, time, volume, and direction of each order as well as the type of investor who submitted it. High-quality information such as the fine timestamp and investor type allows us to accurately identify the trades initiated by individual investors. To alleviate concerns about market microstructural biases, we conduct the following filtering procedure. First, we excludes option quotes time-stamped earlier than 9:10 or later than 14:50 from our sample, to eliminate the effect of uniform pricing rule around the daily opening and closing of the market.[9] Second, we exclude options with a trading volume of less than two contracts during any given day from that day's sample.[10] Third, we eliminate options that matured at a given date, as abnormal and unusual trading due to excessively speculative trading and/or trading to close option positions may govern at the maturity dates. Finally, we remove all options with quoted prices below the minimum tick size to eliminate the effects that may arise through tick size restriction.

We use the lead-month KOSPI 200 futures prices as well as the KOSPI 200 index prices to determine price changes in the underlying asset. Spot, futures, and options prices are collected from real-time quote data using a sampling interval of five minutes, 10 minutes, 15 minutes, 30 minutes, one hour, two hours, and three hours.[11] We use futures and options prices that are set to the midpoints of best bid and offer prices.

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[8] The Korean government regulates index derivatives markets (i.e., KOSPI 200 futures and options markets) to discourage the speculative trading and dominant individual trading that have prevailed in them. As a result, the trading environment of the KOSPI 200 options market has changed dramatically since 2012, when government regulation began, with a significant reduction in option market liquidity and option trades by domestic participants.

[9] The KOPSI 200 options market usually opens at 9:00 and closes at 15:15. The uniform pricing rule governs transactions during the last 10 minutes of daily trading and one hour immediately prior to the beginning of the daily session. During these two periods (i.e., from 15:05 to 15:15 and 8:00 to 9:00), all submitted orders are first accumulated in the CLOB and then carried out at a single market price during the last moments of each session. We filter out option quotes time-stamped earlier than 9:10 or later than 14:50 to alleviate concerns that the uniform pricing rule may affect option price movements in nontrivial ways.

[10] We filter out all options with fewer than two transactions in a given day, which excludes less than 5% of the options in our sample. However, our overall conclusions remain unchanged without this filtering process.

[11] The KOSPI 200 spot index is recorded every two seconds.

An option contract is classified as short-term if it has fewer than 30 days to expiration, medium-term if it has between 30 and 60 days to expiration, and long-term if it has more than 60 days to expiration. We define the moneyness of a call (put) as the ratio of the underlying asset price (strike price) to the strike price (underlying asset price). An option is said to be OTM if its moneyness is less than 0.975, ATM if its moneyness is between 0.975 and 1.025, and ITM if its moneyness is greater than 1.025. Table 2 presents the summary statistics for the five-minute sample for calls and puts. First, we confirm that the KOSPI 200 index options are highly liquid and active; short-term OTM options appear to be intensively traded, indicating that market participants in the options market are highly speculative and that most do not use the KOSPI 200 options as hedging or long-term investment tools. As shown in Table 2, the trading volume for short-term OTM options is, on average, 6,523 contracts, more than the combined volume of their ATM and ITM counterparts. Second, OTM options have narrower bid–ask spreads than ATM or ITM options but exhibit wider percentage spreads, presumably due to their lower nominal prices. Specifically, short-term OTM options have an average percentage bid–ask spread of 16.17%, while their ITM counterparts have one of 2.22%.

[Table 2 inserted]

5. Empirical Findings

5.1. Violations of model predictions

Table 3 presents each occurrence frequency of type I, II, III, and IV violations, computed as a percentage of total observations in a given sample. Overall, the basic violation patterns documented by Bakshi, Cao, and Chen (2000) are also observed in the KOSPI 200 index options market, though some patterns across moneyness and maturity differ slightly from each other. Essentially, we confirm that option prices often do not monotonically and perfectly correlate with underlying asset prices. First, we observe that, over our sample period, call prices move in the direction opposite that of the underlying index between 13.42% and 20.07% of the time, depending on sampling time intervals (type I violation). The frequent occurrence of type I violations is clearly inconsistent with the monotonicity and perfect correlation properties of one-dimensional diffusion option pricing models. Moreover, we find no evidence that the occurrence rate of type I violations monotonically varies with the sampling interval, indicating that the frequent occurrence of type I violations is not associated with market microstructural effects.

[Table 3 inserted]

Second, we demonstrate that call or put prices often do not change, even when the underlying asset price changes (type II violation). Notably, the occurrence of type II violations decreases with the sampling interval. For example, based on the cash index, the rate decreases from 22.58% (at the five-minute sampling frequency) to 5.61% (at the three-hour sampling frequency). This monotonic pattern may indicate a relation between type II violations and market microstructural biases. With a nontrivial minimum tick size or bid–ask spread, underlying asset price changes can be too small to incur a change in option prices, producing type II violations.

Third, we find that type III violations—indicating that option prices change despite an absence of change in the underlying index—rarely occur at each sampling frequency. This is not surprising because the KOSPI 200 index and futures prices rarely remain unchanged at a given time interval. The decreasing pattern of type III violations along with the sampling frequency is also consistent with this conjecture.

Finally, we find that absolute changes in option prices are often greater than those in the underlying asset price (type IV violation), occurring as frequently as between 9.91% and 11.65% of the time when the cash index is used as a proxy for the underlying asset. Similar to type II violations, this class of violations can be affected by the tick size restriction or bid–ask spread. For instance, when the option delta is close to one and the implied change in option value is a little lower than the minimum tick size, option investors can either keep their price quotes unchanged or change them by the minimum tick size. The latter may result in type II violations and the former in type IV violations.

Interestingly, type IV violations are more frequent in the KOSPI 200 options market than in the US options market, perhaps reflecting the extent to which market makers and/or liquidity providers over-adjust option quotes in response to a change in the underlying stock price. Even in the KOSPI 200 options market, a purely order-driven market without a designated market maker, some institutional investors can play a role in market making and liquidity providing. Hence, we infer that option prices in the Korean market are more likely to be over-adjusted than are those in the US market, leading to more frequent type IV violations.(만약에 US options market의 결과가 Bakshi, Cao, and Chen (2000)의 결과라면, 현재 2010-2011년의 type IV violations 결과가 Bakshi, Cao, and Chen (2000)의 type IV violations 결과보다 값들이 더 작습니다.)

Collectively, our analyses show that some of the contradictory option price movements documented in Bakshi, Cao, and Chen (2000) are also observed in the Korean options market. During our sample period, the KOSPI 200 options markets are characterized by high liquidity, low transaction costs, no tax on capital gains, and low margins, producing relatively few market frictions. Our empirical results reveal that the confounding findings of Bakshi, Cao, and Chen (2000) are not limited to well-developed markets but also apply to highly liquid leading emerging markets, providing strong evidence against the predictions of one-dimensional diffusion option models.

Table 3 also shows that every violation (except type III) is more frequent when the lead-month futures price is used as a proxy for the underlying asset price than when the cash index price is used. This difference persists across the sampling interval and, more interestingly, is larger for the KOSPI

200 index options than for the S&P 500 index options. Figure 2, presenting the time-series of the occurrence rates for each violation, shows that the occurrence rates for futures prices are persistently lower than those for cash index prices during the sample period, perhaps attributable to the “stale” index prices. Since the index value can be stale while futures and option prices are not, violations are observed more frequently when we use the cash index price than when we use the futures price. Another possible explanation concerns the strong market linkage between the KOSPI 200 index futures and options markets. In addition to the close relationship resulting from the sharing of the same underlying asset (i.e., KOSPI 200 spot index) and information source (i.e., market-wide and macroeconomic information on the Korean market), most professional investors in the Korean market are known to trade both index derivatives simultaneously, which reinforces the market linkage and intraday co-movements (Ryu, 2011, 2015).

[Figure 2 inserted]

For further investigation, we examine whether violation occurrences differ across moneyness and maturity. Table 4 presents the occurrence rate of each violation along with that of type I to type IV violations combined for each moneyness and maturity category, where option prices are sampled every five minutes. The occurrence rate is computed as a percentage of total observations in a given moneyness and maturity category. Several interesting observations emerge. First, ITM options have the most frequent type I violations of a given term to expiration; thus, ITM option prices are the most likely to move in the direction opposite that of the underlying asset. Second, within each moneyness class, the type I violation rate monotonically increases with the term to expiration. These patterns remain the same irrespective of whether the cash index or the futures price is used as a surrogate for the underlying asset. Third, for a given term to expiration, OTM (ITM) options have the highest violation rate for type II (type IV) violations. For example, among short-term options, the type II violation rate is as high as 45.52% for OTM options and only 9.20% for ITM options, while the type IV violation rate is as high as 23.19% for ITM options and only 0.17% for OTM options, based on the futures price. These patterns, which are the same with the cash index, may indicate that both type II and type IV violations are affected by market microstructural effects such as the tick size restriction.[12] Since OTM options have the lowest option deltas and hence are least sensitive to price changes in the underlying assets, their prices rarely change despite changes in the underlying prices. By contrast, ITM options have high option delta values (nearly 1) and are thus more likely to be over-adjusted relative to underlying price changes. Consistent with this explanation, Table 4 shows that type II

[12] Dennis and Mayhew (2009) argue that, when option prices are observed with noise, a significant portion of the reported violations may be caused by microstructural biases.

violations are most frequent among OTM options and type IV violations most frequent among ITM options.

[Table 4 inserted]

The findings shown in Table 5 also indicate the market microstructural effects on type II and IV violations. The table reports the occurrence rate of each violation within each subsample constructed by bid–ask spreads, relative bid–ask spreads, and option trading volumes. The occurrence rate is computed as a percentage of total observations in a given subsample. As expected, the type II (type IV) violation rates decrease (increase) with the bid–ask spread, in accordance with our earlier finding that type II (IV) violations are more frequent among OTM (ITM) options, as OTM options tend to have lower bid–ask spreads. Thus, options with lower bid–ask spreads are presumably OTM and therefore lead to more (less) frequent type II (type IV) violations.

[Table 5 inserted]

Interestingly, we observe that type I violations increase with the bid–ask spread and decrease with an option contract's trading volume, which is not observed in the US options market.[13] This evidence is consistent with our earlier finding that of a given term to expiration the ITM call (put) prices are the most likely to move in the direction opposite (same) to the underlying asset (as shown in Table 4), given that ITM options have much higher nominal bid–ask spreads than ATM or OTM options.

5.2. Individual trading proportions

So far, we have shown that the predictions of one-dimensional diffusion models are often violated in the KOSPI 200 options market, the leading and highly liquid emerging options market. In this section, we investigate whether the contradictory option price movements found in the previous section are associated with the demand-pressure effects, as suggested by Gârleanu, Pedersen, and Poteshman (2009).[14] Specifically, we hypothesize that violations are more frequent among options heavily traded

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[13] Bakshi, Cao, and Chen (2000) find no association between the type I violation rates and option moneyness, claiming that type I violations do not occur as a result of market microstructural effects.

[14] Lin, Chen, and Tsai (2011) examine whether tactical trading in a market characterized by price/time priority and moderate liquidity may cause violations of the empirical monotonicity property studied by Bakshi, Cao, and Chen (2000). They claim that the frequent violations of the monotonicity properties are largely attributable to microstructure effects and arise from rational trading tactics.

by individual traders, on the presumption that individual traders are the end-users—and thus have a fundamental need for option exposure—and that options with higher individual trading proportions (ITPs) experience greater demand pressures. Gârleanu, Pedersen, and Poteshman (2009) argue that investors' demand pressures can impact option prices when options are not redundant securities. Specifically, in an economy where competitive investors cannot hedge their positions perfectly, option prices cannot be exclusively determined by no-arbitrage, implying that investors' demands can impact option prices. In light of the findings of Gârleanu, Pedersen, and Poteshman (2009), we test whether option price movements are associated with demand pressures, proxied by the proportion of individual trading. Exploiting the advantages of using a dataset containing high-quality information on who initiates each trade,[15] we compute ITP as the ratio of the number of transactions initiated by individual traders to the total number of transactions during a given time interval for each option and then examine whether ITP has a relation to violations.

We explore the characteristics of options heavily traded by individual investors by, first, examining the relations between ITP and other characteristics. Panel A of Table 6 shows the average correlations calculated using option prices sampled every five minutes. In Panel A of Table 6, *Spread* (*Relative spread*) denotes the (relative) bid–ask spread, and *Tick size* denotes the minimum tick size determined by the corresponding option price. *Volume* denotes the number of transactions during a given interval. *Days* and *Moneyness* refer to the number of calendar days to expiration and moneyness, respectively. Except for *Volume*, all variables are measured at the beginning of the time interval. As expected, moneyness is positively related to the bid–ask spread and the minimum tick size, supporting our earlier conjecture that ITM options tend to have the highest minimum tick sizes and bid–ask spreads. Options with higher moneyness (i.e., ITM options) are the least liquid and have the highest prices.

[Table 6 inserted]

Second, inspired by the conjecture that the prices of options heavily traded by individual investors can be affected by demand pressures, we investigate the relation between ITP and option expensiveness measured by implied volatility. Panel B of Table 6 shows the estimated coefficients in the regressions, where the dependent variables are change in implied volatility (IV), ΔIV, and the explanatory variables are *ITP*. Specifically, IV is the volume-weighted average of the implied volatility computed by option prices sampled every five minutes. Given the interval, we compute IV

[15] Our dataset classifies investors into four types: domestic individuals, domestic institutions, foreign institutions, and other investors. Similarly detailed information on investor type is not provided in the US market.

using all options (models 1 and 2) or using OTM options (models 3 and 4), considering that OTM options are subject to stronger demand pressure (Gârleanu, Pedersen, & Poteshman, 2009). *ITP* is the ratio of the number of contracts initiated by individual investors to the total number of contracts during a given time interval. We use the past change in IV, $\Delta IV_{(-1)}$, as a control variable and also include two dummy variables, D_1 and D_2, to control for the intraday variation of implied volatility. D_1 (D_2) equals 1 if each option corresponds to the time period from 9:00 to 10:00 (from 10:00 to 14:00) and 0 otherwise.

As conjectured, the regression coefficients on ITP are significant and positive. In model 1, the coefficient estimate on ITP is 0.017, with a statistically significant *p*-value of 0.0052. The positive relation remains unchanged when time dummies are included. We also find that the relation is prominent among OTM options. In models 3 and 4, the coefficients on ITP are more significant and positive than in models 1 and 2, respectively, consistent with our conjecture that individual investors' demand pressure can impact option prices and allows their prices to move in confounding ways.

Table 7 presents the occurrence rates of each violation across individual trading proportions. To examine whether the violation rates differ across the ITP, we compute the violation rates within each ITP and moneyness category, where we sort our samples into terciles by ITP for a given moneyness category and obtain nine classes of ITP and moneyness. Notably, we find that type II violations are the most frequent among OTM options heavily traded by individual traders. The highest ITP tercile of OTM options has the highest type II violation rates of 50.09 % and 43.92% based on the cash index price and the futures price, respectively. Type II violations increase with ITP among OTM options, regardless of the prices (i.e., cash index or futures price) used. This finding supports our hypothesis that the occurrence rate of some violations has a significant relationship with end-users' demand pressures, which are presumably related to the proportion of individual trading. Thus, options heavily traded by individual traders appear more likely to be affected by demand pressures, causing their prices to often move in ways inducing no-arbitrage violations.

[Table 7 inserted]

Table 7 shows that the positive relation between type II violation rates and ITP is the strongest among OTM options. To confirm this result, we run the following regression:

$$V_{i,t}=a_0+a_1Spread+a_2Volume_{i,t}+a_3Days_{i,t}+a_4Moneyness_{i,t}+a_5Call_{i,t}+a_6ITP_{i,t}+a_7(\mathrm{OTM}_{i,t}\times ITP_{i,t})+e_{i,t} \quad (1)$$

where subscripts *t* and *i* indicate the *t*-th time interval and the *i*-th option, respectively. *V* is a discrete variable equal to 1 when the option's price change is characterized by each violation and 0 otherwise. *ITP* denotes the individual trading proportion. *Spread* denotes the bid–ask spread. *Volume* denotes the number of transactions during a given interval. *Days* and *Moneyness* refer to the number of calendar days to expiration and moneyness, respectively. *Call* is equal to 1 if the option is a call option and 0 otherwise. *OTM* is equal to 1 if the option is out-of-the-money and 0 otherwise.

Table 8 presents the results of the regression models examining the relation between ITP and various violation rates. Consistent with the results shown in Table 7, we find that type II violations are more frequent among options with higher individual trading proportions when they are out-of-the-money. Specifically, the regression coefficient on the interaction term between *ITP* and *OTM* (i.e., ITP×OTM) is significantly estimated as 0.312 based on the cash index, indicating that ITP is positively related to type II violation rates among OTM options. OTM options tend to be more heavily traded by individual traders than ITM or ATM options; thus, their prices are the most likely to be affected by demand pressures. If the demand-pressure effect allows option prices to violate the predictions of traditional options pricing models, as we conjecture, the violations will be most frequent among OTM options. In this regard, our results support the role of demand pressure in violation occurrences. In the KOSPI 200 options market, many individual traders tend to consider trading deep-OTM options as buying lotteries, indicating that they are noise traders. Hence, we expect more significant ITP effect to produce more violations among OTM options.

[Table 8 inserted]

6. Conclusion

Using the high-quality TAQ dataset of KOSPI 200 options, we investigate whether the basic properties predicted by the one-dimensional diffusion option pricing model is violated in the leading options market. We find that, first, KOSPI 200 option prices often do not monotonically and perfectly correlate with underlying prices. In 2010 and 2011, call prices move in the direction opposite that of the underlying index 18.78% of the time. Moreover, the underlying index changes but call prices do not 22.58% of the time, with options prices sampled at five-minute intervals. This evidence reveals the limitations of one-dimensional diffusion models to explain option price movements in the KOSPI 200 options market. Second, OTM options heavily traded by individual traders have the most frequent type II violations. The significant relation between individual trading proportions and violation frequencies is consistent with the demand-pressure hypothesis argued by Gârleanu, Pedersen, and Poteshman (2009). Hence, we infer that some violations can result from demand-pressure effects. Finally, overall violation frequencies are higher when we use the KOSPI 200 spot index as a proxy for the underlying asset than when the S&P 500 index is used, perhaps indicating that the KOSPI 200 index is more vulnerable to the stale component than the S&P 500 index.

Our study implies that violations against the predictions of one-dimensional option pricing models may not be limited to a particular market but may instead be universal. We find evidence that the predictions are often violated in a highly liquid emerging market, as they are in developed markets. Emerging Asian options markets (such as the Taiwanese options market) are similar to the Korean options market; for example, the derivatives markets are highly liquid, derivatives trading has a short history (i.e., the markets are immature), speculative short-term trading such as day trading and/or high-frequency trading is prevalent, and trades by individual investors tend to be dominant. Furthermore, most of the investor demand on derivatives contracts is concentrated on index derivatives rather than equity derivatives. Accordingly, we expect that our results would be confirmed in other emerging options markets where high-quality datasets (including information such as investor types) can be obtained.

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TABLE I
Global derivatives exchanges and KOSPI 200 options trading volume by investor type

Panel A. Global top 10 futures and options exchanges

Exchange name	Rank	Trading volume	
		2011	2010
Korea Exchange	1	3,927,956,666	3,748,861,401
National Stock Exchange of India	2	2,200,366,650	1,615,790,692
Eurex	3	2,043,415,593	1,896,916,398
Chicago Mercantile Exchange	4	1,804,312,467	1,656,415,731
Chicago Board Options Exchange	5	1,152,063,397	1,115,491,922
NYSE Liffe Europe	6	1,148,497,743	1,222,556,772
Chicago Board of Trade	7	1,037,747,075	923,593,304
Nasdaq OMX PHLX	8	983,485,204	846,895,365
MCX-SX	9	850,129,060	884,606,842
Bolsa de Valores de São Paulo	10	840,967,001	803,470,201

Panel B. Trading volume of KOSPI 200 options by investor type

	Total		Call options		Put options	
	In contracts	%	In contracts	%	In contracts	%
Individuals	4,634,499,788	32.19%	2,380,617,210	31.85%	2,253,882,578	32.57%
Institutions	4,652,442,931	32.32%	2,662,419,345	35.62%	1,990,023,586	28.76%
Foreigners	5,108,178,927	35.49%	2,432,119,905	32.54%	2,676,059,022	38.67%
Total	14,395,121,646	100%	7,475,156,460	100%	6,919,965,186	100%

Note. Panel A presents the trading volumes of global top-tier derivatives exchanges for 2010 and 2011. The data are sourced from the Futures Industry Association (https://fia.org). The ranks are calculated based on the combined trading volume of futures and options in 2011. Panel B presents the trading volume of KOSPI 200 index options for three investor types—domestic individuals (*Individuals*), domestic institutions (*Institutions*), and foreign investors (*Foreigners*)—for the sample period from January 2010 through December 2011. *Total* denotes the total trading volume of the index options. *Call options* and *Put options* denote the trading volumes of call and put options, respectively. *In contracts* presents the number of contracts and *%* presents the percentage values. The Korea Exchange (KRX; www.krx.co.kr) is our source.

TABLE II
Summary statistics of the option sample at five-minute intervals

Moneyness		Calls			Puts		
		Term-to-expiration			Term-to-expiration		
		Short	Medium	Long	Short	Medium	Long
ITM	Price	19.516	19.044	22.186	19.085	16.922	19.044
	Bid–ask spread	0.488	0.637	0.992	0.600	0.724	1.103
	Percentage spread (%)	2.218	3.208	4.679	2.479	3.872	5.546
	# of observations	254,611	153,404	92,073	214,345	142,736	103,505
	# of transactions	39	13	11	57	14	11
ATM	Price	4.439	7.292	10.193	4.490	7.193	9.933
	Bid–ask spread	0.048	0.148	0.398	0.048	0.135	0.364
	Percentage spread (%)	1.119	1.850	3.737	1.075	1.747	3.501
	# of observations	151,458	155,189	188,466	151,557	155,928	200,549
	# of transactions	5,988	104	18	4,689	90	20
OTM	Price	0.574	1.851	4.195	0.721	2.104	4.644
	Bid–ask spread	0.013	0.032	0.194	0.013	0.032	0.167
	Percentage spread (%)	16.169	2.938	4.546	11.498	2.262	3.325
	# of observations	248,985	259,910	330,095	353,301	348,011	405,715
	# of transactions	6,523	380	34	4,580	275	33

Note. This table presents the average mid-quote prices (*Price*), the average bid–ask spreads (*Bid-ask spread*), the ratio of average bid–ask spread to option premium (*Percentage spread*), the total number of observations (*# of observations*), and the average number of transactions (*# of transactions*) for each moneyness and maturity category. *Calls* and *Puts* denote call and put options, respectively. An option contract is classified as short-term (*Short*) if it has fewer than 30 days to expiration, medium-term (*Medium*) if it has between 30 and 60 days to expiration, and long-term (*Long*) if it has more than 60 days to expiration. *OTM*, *ATM*, and *ITM* refer to out-of-the-money, at-the-money, and in-the-money, respectively. The sample period is from January 2010 through December 2011.

TABLE III
Violation occurrences

Sampling interval	Number of observations	Underlying asset used	Violations by calls				
			Type I (%)	Type II (%)	Type III (%)	Type IV (%)	Total (%)
5 minutes	1,834,191	Spot index	18.78	22.58	1.60	11.61	54.58
		Index futures	8.01	18.78	6.02	8.05	40.85
10 minutes	912,662	Spot index	16.61	16.81	1.13	11.65	46.20
		Index futures	8.12	14.61	4.60	8.36	35.68
15 minutes	589,121	Spot index	14.99	14.55	0.75	11.27	41.56
		Index futures	7.80	12.75	4.02	8.41	32.97
30 minutes	267,035	Spot index	13.42	11.43	0.69	11.09	36.62
		Index futures	7.44	10.39	3.17	8.27	29.28
1 hour	160,820	Spot index	16.46	8.71	0.60	10.73	36.50
		Index futures	8.25	8.15	2.50	8.92	27.82
2 hours	80,646	Spot index	18.83	6.85	0.48	10.61	36.76
		Index futures	9.05	6.60	1.71	9.13	26.49
3 hours	53,233	Spot index	20.07	5.61	0.55	9.91	36.14
		Index futures	8.65	5.45	1.39	8.41	23.90
			Violations by puts				
5 minutes	2,075,647	Spot index	17.79	24.05	1.62	10.89	54.35
		Index futures	7.40	19.64	6.05	7.47	40.56
10 minutes	1,034,319	Spot index	15.67	17.89	1.16	11.03	45.74
		Index futures	7.44	15.33	4.67	7.81	35.25
15 minutes	668,004	Spot index	14.02	15.40	0.75	10.65	40.82
		Index futures	7.02	13.27	4.15	7.96	32.41
30 minutes	303,290	Spot index	12.52	11.99	0.69	10.63	35.82
		Index futures	6.79	10.62	3.25	7.84	28.50
1 hour	182,729	Spot index	15.76	9.00	0.59	9.93	35.27
		Index futures	7.38	8.35	2.65	8.65	27.03
2 hours	91,326	Spot index	17.54	6.78	0.49	9.89	34.71
		Index futures	7.81	6.53	1.87	8.81	25.03
3 hours	60,539	Spot index	18.70	5.85	0.63	9.37	34.54
		Index futures	8.41	5.68	1.48	8.14	23.71

Note. This table presents the occurrence rates of types I, II, III, and IV violations. Each rate is a percentage of the total violation observations at a given sampling interval. The call and put option prices are obtained by sampling price changes every 5 minutes, 10 minutes, 15 minutes, 30 minutes, one hour, two hours, and three hours. We use the KOSPI 200 spot index prices (*Spot index*) and the lead-month KOSPI 200 index futures prices (*Index futures*) to determine changes in the underlying asset prices, respectively. The sample period is from January 2010 through December 2011.

TABLE IV
Violation rates across moneyness and maturity

Moneyness	Type of violation	Spot index			Index futures		
		Short	Medium	Long	Short	Medium	Long
ITM	Type I only (%)	21.67	23.10	24.77	7.96	12.11	17.06
	Type II only (%)	12.33	14.42	16.63	9.20	11.56	14.39
	Type III only (%)	1.90	1.88	1.63	7.09	7.46	7.06
	Type IV only (%)	26.21	23.75	22.05	23.19	20.14	19.22
	Total (%)	62.12	63.15	65.08	47.43	51.27	57.74
ATM	Type I only (%)	19.03	18.67	19.35	1.21	3.72	10.24
	Type II only (%)	13.01	14.56	18.98	7.79	10.01	15.38
	Type III only (%)	1.97	1.93	1.69	5.80	6.31	6.70
	Type IV only (%)	13.28	13.18	12.91	5.36	6.06	8.67
	Total (%)	47.29	48.34	52.93	20.16	26.10	40.99
OTM	Type I only (%)	9.24	17.35	19.46	2.01	6.32	11.99
	Type II only (%)	52.29	23.90	21.95	45.52	19.98	18.54
	Type III only (%)	0.85	1.65	1.57	2.58	6.26	6.78
	Type IV only (%)	1.55	3.28	5.71	0.17	0.68	3.09
	Total (%)	63.93	46.18	48.69	50.28	33.25	40.40

Note. This table presents the occurrence rates of types I, II, III, and IV violations for each option in the moneyness and maturity category, respectively. Each violation rate is a percentage of the total observations sampled every five minutes. We use the KOSPI 200 spot index prices (*Spot index*) and the lead-month KOSPI 200 index futures prices (*Index futures*) to determine changes in the underlying asset prices, respectively. An option contract is classified as short-term (*Short*) if it has fewer than 30 days to expiration, medium-term (*Medium*) if it has between 30 and 60 days to expiration, and long-term (*Long*) if it has more than 60 days to expiration. *OTM*, *ATM*, and *ITM* refer to out-of-the-money, at-the-money, and in-the-money, respectively. The sample period is from January 2010 through December 2011.

Table V
Violations across bid–ask spread and option volumes

	Bid–ask spread	Spot index	Index futures	Relative spread (%)	Spot index	Index futures	Option volume	Spot index	Index futures
Type I	<0.01	7.03	1.96	<0.47	21.36	4.15	<3	19.67	9.24
	0.01~0.05	17.92	5.92	0.47~0.78	19.51	4.41	3~15	18.71	7.17
	0.05~0.10	18.41	4.32	0.78~1.06	19.26	6.36	15~56	17.47	5.81
	0.10~0.15	19.52	5.67	1.06~1.64	19.13	9.56	56~230	16.51	4.95
	0.15~0.40	20.12	10.07	1.64~2.86	18.02	11.98	230~2,382	13.97	3.09
	>=0.40	21.84	16.80	>=2.86	12.25	9.62	>=2,382	15.53	2.28
Type II	<0.01	66.84	59.44	<0.47	9.89	6.17	<3	20.63	16.88
	0.01~0.05	25.04	20.45	0.47~0.78	14.79	10.20	3~15	21.22	17.19
	0.05~0.10	16.77	11.87	0.78~1.06	17.69	13.29	15~56	23.54	19.22
	0.10~0.15	16.06	11.78	1.06~1.64	20.63	16.88	56~230	26.64	21.95
	0.15~0.40	15.99	13.11	1.64~2.86	25.82	22.48	230~2,382	31.56	26.06
	>=0.4	18.29	16.50	>=2.86	51.38	46.44	>=2,382	24.59	19.93
Type III	<0.01	0.66	2.43	<0.47	2.11	8.07	<3	1.74	6.89
	0.01~0.05	1.72	6.59	0.47~0.78	1.96	6.88	3~15	1.74	6.75
	0.05~0.10	1.84	6.22	0.78~1.06	1.89	6.90	15~56	1.64	6.31
	0.10~0.15	1.90	6.98	1.06~1.64	1.71	6.64	56~230	1.58	5.72
	0.15~0.40	1.77	6.95	1.64~2.86	1.32	5.24	230~2,382	1.30	4.10
	>=0.4	1.29	5.26	>=2.86	0.66	2.48	>=2,382	1.48	4.64
Type IV	<0.01	1.29	0.10	<0.47	13.34	8.52	<3	13.53	10.11
	0.01~0.05	2.87	0.42	0.47~0.78	13.58	8.78	3~15	11.86	7.92
	0.05~0.10	12.59	6.81	0.78~1.06	11.88	7.32	15~56	9.63	5.53
	0.10~0.15	14.52	9.57	1.06~1.64	10.67	7.21	56~230	7.50	3.70
	0.15~0.40	15.95	12.43	1.64~2.86	9.99	7.67	230~2,382	7.13	3.01
	>=0.40	19.96	17.67	>=2.86	7.92	6.96	>=2,382	3.86	0.44

Note. This table presents the occurrence rates of types I, II, III, and IV violations partitioned according to bid–ask spread (*Bid-ask spread*), relative spread (*Relative spread (%)*), and daily trading volume (*Option volume*), respectively. Each violation rate is a percentage of the total observations sampled every five minutes. We use the KOSPI 200 spot index prices (*Spot index*) and the lead-month KOSPI 200 index futures prices (*Index futures*) to determine changes in the underlying asset prices, respectively. The sample period is from January 2010 through December 2011.

TABLE VI
Relation between implied volatility and ITPs

Panel A. Pair-wise correlations

	Spread	*Relative spread*	*Tick size*	*Volume*	*Days*	*Moneyness*	*ITP*
Spread	1						
Relative spread	0.15	1					
Tick size	0.33	-0.23	1				
Volume	-0.11	-0.01	-0.29	1			
Days	0.15	-0.13	0.29	-0.28	1		
Moneyness	0.48	-0.27	0.65	-0.01	-0.10	1	
ITP	-0.13	0.43	-0.32	0.00	-0.14	-0.34	1

Panel B. Relation between implied volatility and ITPs

	Model 1	Model 2	Model 3	Model 4
	ΔIV_{all}	ΔIV_{all}	ΔIV_{OTM}	ΔIV_{OTM}
Intercept	-0.014***	0.000**	-0.009***	-0.001***
	(<.0001)	(0.0249)	(0.0093)	(0.0013)
$\Delta IV_{(-1)}$	-0.411***	-0.389***	-0.412***	-0.405***
	(<.0001)	(<.0001)	(<.0001)	(<.0001)
ITP	0.017***	0.002**	0.030***	0.004***
	(0.0052)	(0.0227)	(<.0001)	(0.001)
$D_1 \times ITP$		-0.001		-0.001
		(0.1124)		(0.2925)
$D_2 \times ITP$		-0.001		-0.001
		(0.1625)		(0.1239)
Adj. R^2	0.169	0.151	0.170	0.164

Note. Panel A presents pair-wise correlations between variables sampled every five minutes. *Spread* (*Relative spread*) denotes the (relative) bid–ask spread, and *Tick size* denotes the minimum tick size determined by the corresponding option price. *Days* and *Moneyness* refer to the number of calendar days to expiration and the moneyness, respectively. *Volume* is the number of transactions during a given interval. *ITP* is the ratio of the number of transactions initiated by individual traders to the total number of transactions. Panel B presents estimated coefficients of the following regression models. For models 1 and 3, the regression equation is $\Delta IV_t = a_0 + a_1 \Delta IV_{t-1} + a_2 ITP_t + \varepsilon_t$. For models 2 and 4, the regression equation is $\Delta IV_t = a_0 + a_1 \Delta IV_{t-1} + a_2 ITP_t + (b_0 D_{1t} + b_1 D_{2t}) \times ITP_t + \varepsilon_t$. ΔIV is change in the average implied volatility calculated from option prices sampled every five minutes. $\Delta IV_{(-1)}$ denotes its lagged term. For models 1 and 2, the implied volatilities based on all traded options (i.e., ΔIV_{all}) are used. For models 3 and 4, the implied volatilities based on OTM options (i.e., ΔIV_{OTM}) are used. D_1 (D_2) is a dummy variable that equals 1 if each option corresponds to the time period from 9:00 a.m. to 10:00 a.m. (from 10:00 a.m. to 2:00 p.m.) and 0 otherwise. In Models 1 and 2 (3 and 4), the implied volatility is calculated from the prices of all (OTM) options in our sample. The sample period spans from January 2010 to December 2011. The *p*-values are in parentheses, and *Adj.* R^2 denotes the adjusted *R*-squared value. ***, **, and * indicate statistical significances at the 1%, 5%, and 10% levels, respectively.

TABLE VII
Violations across individual trading proportions

		Low ITP	2	High ITP	Low ITP	2	High ITP	Low ITP	2	High ITP
		ITM			ATM			OTM		
ITP		0.000	0.001	0.332	0.002	0.112	0.359	0.016	0.193	0.701
Type I (%)	Spot index	22.81	22.17	20.10	19.32	18.7	18.44	18.10	16.25	10.79
	Index futures	8.93	7.78	4.40	5.35	1.47	1.91	8.59	5.00	4.47
Type II (%)	Spot index	10.01	8.95	7.81	14.37	14.00	13.63	24.15	24.73	50.09
	Index futures	7.10	6.24	4.70	10.29	8.78	8.56	20.39	20.35	43.92
Type III (%)	Spot index	1.87	1.96	1.87	1.92	1.90	1.91	1.59	1.5	1.00
	Index futures	7.72	7.33	6.92	6.75	5.65	6.00	6.45	5.43	3.66
Type IV (%)	Spot index	25.6	26.91	27.01	13.51	13.88	11.71	4.13	2.79	1.89
	Index futures	22.48	22.42	20.77	7.01	5.88	4.23	1.51	0.44	0.46
Total (%)	Spot index	60.30	59.98	56.80	49.11	48.48	45.68	47.98	45.27	63.77
	Index futures	46.23	43.77	36.79	29.39	21.78	20.69	36.95	31.21	52.52

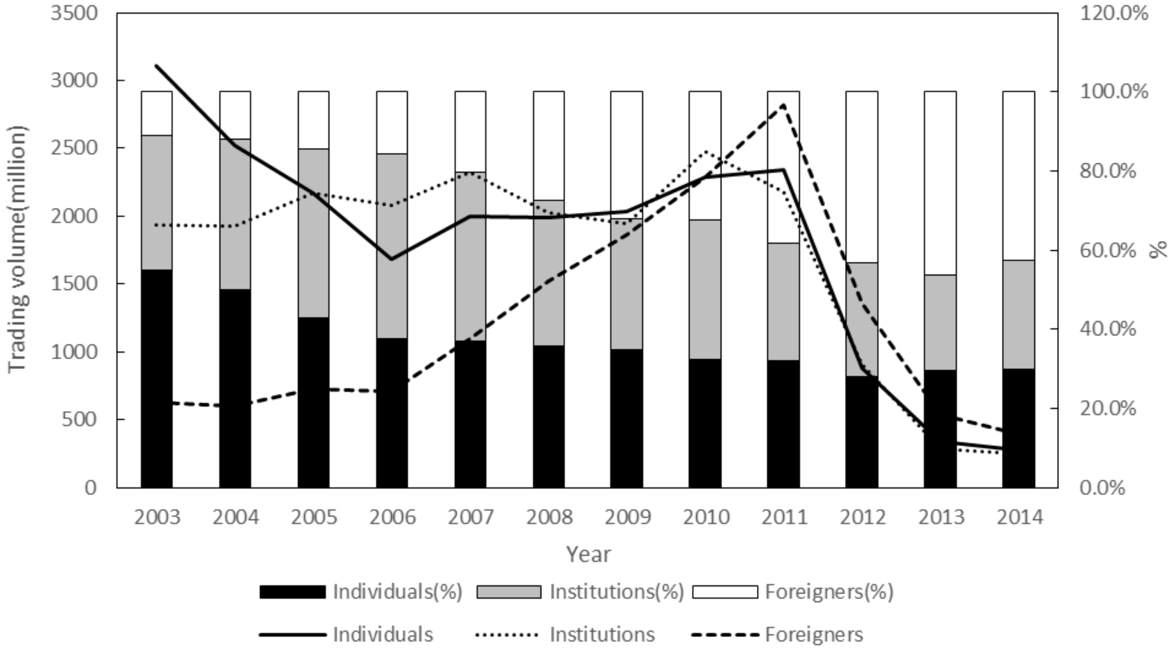
Note. This table presents the occurrence rates of types I, II, III, and IV violations partitioned according to moneyness and individual trading proportion, respectively. Each violation rate is a percentage of total observations sampled every five minutes. We use the KOSPI 200 spot index prices (*Spot index*) and the lead-month KOSPI 200 index futures prices (*Index futures*) to determine changes in the underlying asset prices, respectively. *OTM*, *ATM*, and *ITM* refer to out-of-the-money, at-the-money, and in-the-money, respectively. *ITP* denotes the average of individual trading proportion for given moneyness category. The sample period is from January 2010 through December 2011.

TABLE VIII
Regression coefficients

	Spot index				Index futures			
	Type I	Type II	Type III	Type IV	Type I	Type II	Type III	Type IV
Intercept	0.199***	0.141***	0.018***	0.125***	0.075***	0.1018***	0.067***	0.078***
	(0.0005)	(0.0007)	(0.0002)	(0.0005)	(0.0004)	(0.0006)	(0.0003)	(0.0004)
Spread	-0.008***	0.062***	-0.006***	0.008***	0.054***	0.0747***	-0.022***	0.028***
	(0.0008)	(0.0011)	(0.0002)	(0.0008)	(0.0009)	(0.0012)	(0.0004)	(0.0009)
Volume	-0.001***	-0.020***	-0.000***	-0.015***	-0.000	-0.016***	-0.002***	-0.014***
	(0.0002)	(0.0004)	(0.0001)	(0.0002)	(0.0001)	(0.0003)	(0.0001)	(0.0001)
Days	0.030***	-0.084***	0.003***	-0.002***	0.035***	-0.074***	0.016***	-0.004***
	(0.0004)	(0.0006)	(0.0001)	(0.0003)	(0.0003)	(0.0005)	(0.0002)	(0.0002)
Moneyness	0.031***	-0.123***	0.008***	0.086***	-0.012***	-0.123***	0.017***	0.066***
	(0.0004)	(0.0006)	(0.0001)	(0.0003)	(0.0003)	(0.0006)	(0.0002)	(0.0003)
Call	-0.002***	0.020***	-0.002***	-0.014***	0.060***	0.027***	-0.006***	-0.011***
	(0.0005)	(0.0007)	(0.0002)	(0.0004)	(0.0003)	(0.0007)	(0.0003)	(0.0003)
ITP	-0.001	0.015***	0.001***	0.005***	-0.007***	0.006***	0.001***	-0.002***
	(0.0006)	(0.0006)	(0.0002)	(0.0005)	(0.0003)	(0.0005)	(0.0004)	(0.0005)
OTM×ITP	-0.072***	0.312***	-0.008***	-0.034***	0.004***	0.302***	-0.019***	0.012***
	(0.0019)	(0.0023)	(0.0007)	(0.0017)	(0.0012)	(0.002)	(0.0012)	(0.0015)
Adj. R^2	0.015	0.183	0.002	0.081	0.032	0.183	0.007	0.087

Note. This table presents the estimated coefficients of the following regression:
$V_{i,t}=a_0+a_1Spread_{i,t}+a_2Volume_{i,t}+a_3Days_{i,t}+a_4Moneyness_{i,t}+a_5Call_i+a_6ITP_{i,t}+a_7(OTM_{i,t}\times ITP_{i,t})+e_{i,t}$.
Subscripts t and i indicate the t-th time interval and the i-th option, respectively. $V_{i,t}$ is a discrete variable equal to one when the i-th option price change during Δt (from t-1 to t) is characterized by each violation and zero otherwise. *Spread* denotes the bid–ask spread. *Volume* is the number of transactions during a given interval. *Days* and *Moneyness* refer to the number of calendar days to expiration and the option moneyness, respectively. *OTM* is equal to one if the option is out-the-money and zero otherwise. *Call* is equal to one for a call option, and zero for a put option. *ITP* denotes the individual trading proportion. *OTM×ITP* denotes the interaction term. Each violation rate is a percentage of total observations sampled every five minutes. We use the KOSPI 200 spot index prices (*Spot index*) and the lead-month KOSPI 200 index futures prices (*Index futures*) to determine changes in the underlying asset prices, respectively. Newey–West standard errors are in parentheses, and *Adj.* R^2 denotes the adjusted R-square. The sample period is from January 2010 through December 2011. Finally, ***, **, and * indicate statistical significances at the 1%, 5%, and 10% levels, respectively.

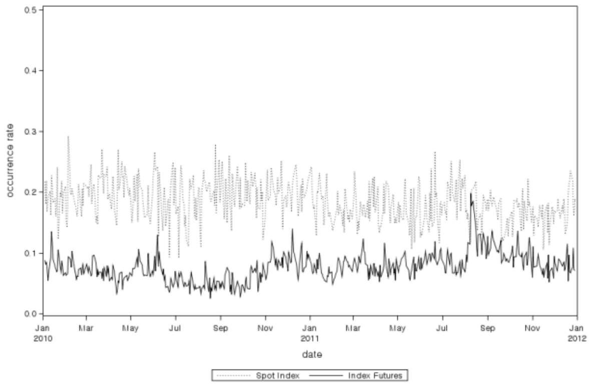
FIGURE I
Time trends of trading volume by investor



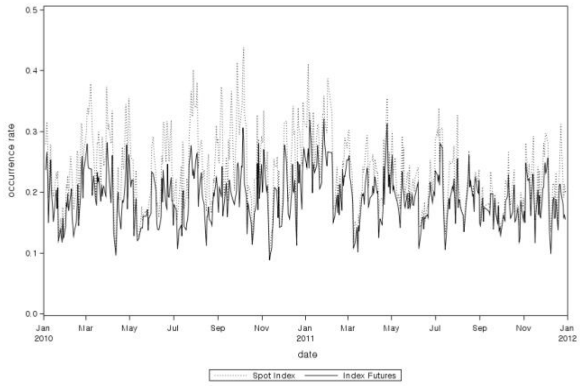
Note. This figure shows the time trend of the trading volume of KOSPI 200 index options for three investor types—domestic individuals (*Individuals*), domestic institutions (*Institutions*), and foreign investors (*Foreigners*)—from January 2003 through December 2014. The solid and dotted lines represent the trading volume of KOSPI 200 index options by investor type. The bar graph shows the trading volume proportions by investor type. The Korea Exchange (KRX; www.krx.co.kr) is our source.

FIGURE II
Time trends of violation occurrences

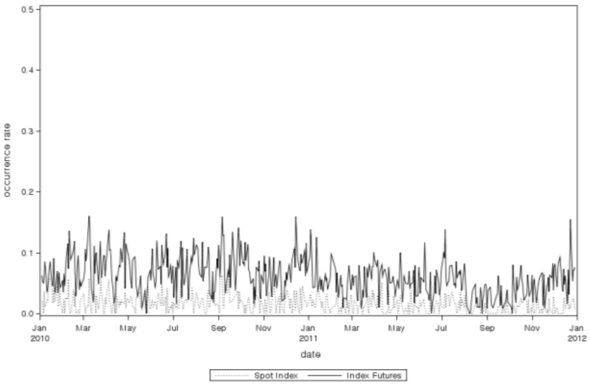
Panel A: Type I violation



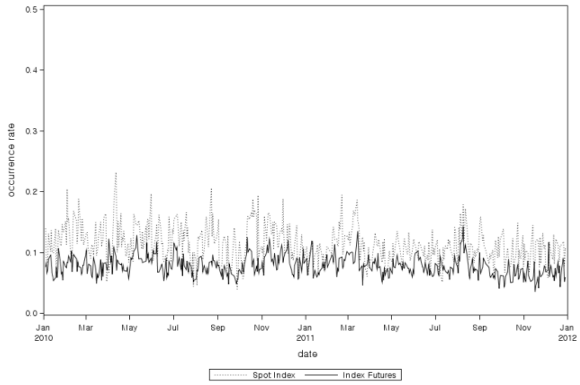
Panel B: Type II violation



Panel C: Type III violation



Panel D: Type IV violation



Note. This figure shows the occurrence rate of each violation when the KOSPI 200 spot index price (*Spot index*) and the lead-month KOSPI 200 index futures price (*Index futures*) are used as a stand-in for the underlying asset. Panels A, B, C, and D show the time trends of type I, II, III, and IV violations, respectively. The KOSPI 200 call and put options prices are obtained by sampling price changes every five minutes. The sample period is from January 2010 through December 2011.