Common deviation and regime-dependent dynamics in the index derivatives markets

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Abstract

In this study, we use the high-quality intraday KOSPI 200 futures and options data to examine the common deviation and regime-dependent price dynamics in the index derivatives markets according to reliability of the common deviation. Through this analysis, we find the common deviation in the futures and options markets. In terms of the dynamics of asset prices and trading volumes, the linkage between the derivatives (i.e., futures and options) markets is stronger than the relationship between the underlying stock market and the derivatives markets. Whereas the deviations between the derivatives markets and the stock market exhibit an inverted U-shaped intraday pattern, the pattern of the deviation between the futures and options is relatively flat. The deviations between the derivatives markets and the stock market are tied to trading activities in the same direction. When we identify regimes based on the difference between deviations in derivatives markets, defined as the relative deviation, the common deviation is significantly corrected only when the relative deviation is moderate. Although the stock market does not lead the derivatives markets with a mild level of relative deviation, there is a bi-directional information flow between the derivatives markets and the stock market with an extreme relative deviation. A sudden change in the relative deviation is induced by options trading rather than futures trading.

Keywords: KOSPI 200 futures and options; Mispricing; Price dynamics; Threshold vector error correction model (TVECM)

JEL Classification: G13, G14, G15

1. Introduction

Owing to model specification errors, it is difficult to accurately determine a "fair value" of spots implied by derivatives in practice. This problem has motivated academic researchers to utilize model-free approaches, which are implicit in arbitrage opportunities. If the payoff of an underlying asset can be reproduced with tradable derivatives, then the price of an underlying asset should be matched to the price of the corresponding combination of derivatives. Thus, a deviation can be clearly defined as a difference between the spot price and the price of the synthetic asset comprised of derivatives. Cornell and French (1983) examine the pricing of stock index futures based on the simple arbitrage model. Moreover, Figlewski (1989) considers mispricing in the options market related to an arbitrage strategy using continuous rebalancing. By using the most actively traded derivatives contracts in the markets—futures and options—investors can easily replicate the payoff of the underlying asset. The cost-of-carry model provides the implied prices of spots, which equal the discounted prices of the corresponding futures. Similarly, the put-call parity between the spot and options markets holds under the no-arbitrage assumption (Stoll, 1969). A payoff of underlying assets can be replicated by a long position in a call option, a short position in a put option that has the identical strike price and maturity with those of the call option, and debt contracts. Because a deviation indicates arbitrage profits trading the underlying and the synthetic assets, price dynamics of underlying assets, futures, and options should be closely related to deviation adjustments. There exist a number of studies that evaluate the features of deviation adjustments. For example, by observing the behavior of arbitrage in the S&P 500 futures and spot markets, MacKinlay and Ramaswamy (1988) show that deviation increases with the time to maturity of futures. In addition, Brenner et al. (1989) identify undervaluation in the Nikkei futures market that may be partially attributable to trading restrictions and transaction costs. Furthermore, Chung (1991) uses the cost-of-carry model to test the efficiency of the index futures market. Finucane (1991) suggests a measure of the relative prices of the calls and puts from the put-call parity and shows that the relative prices lead the stock market by 15 minutes.

If trading activities can vary by market conditions, deviation adjustments and price dynamics also can differ on the basis of variant market conditions. Previous works in this domain consider a number of factors to determine the nature of market conditions. Fleming et al. (1996) show that if transaction costs of derivatives are lower than those of spots, then the derivatives market can lead the spot market. Jiang et al. (2001) examine the dynamics between the spot index and the index futures under three types of short-selling restrictions on stocks in Hong Kong. Pan and Poteshman (2006) examine the information content of ratios of put option volume to call option volume as a means to forecast underlying stock price changes. The size of a deviation in and of itself has also been studied. A number of researchers use the threshold vector error correction model (TVECM) framework in this manner. Dwyer et al. (1996) show that a three-regime TVECM on S&P 500 futures and spots provides a better fit than a linear model, and that estimated thresholds are reasonably close to independent estimates of transaction costs. Using a TVECM with five regimes on S&P 500 futures and spot prices, Martens et al. (1998) show that (a) prices react more sensitively when mispricing is substantial and (b) that the effect of futures prices on spot prices is more substantial when the futures are underpriced. Using a three-regime TVECM, Kim et al. (2010) show that indices outside the no-arbitrage band have a mean-reversion property which leads it into the no-arbitrage band, but the series of indices and futures located within the no-arbitrage band are non-stationary. However, most previous work is limited to exploring the relationship between two of three types of markets (i.e., futures, options, and stock markets). These studies do not consider these relationships simultaneously, despite the fact that they are mutually co-dependent and their intraday trades are closely related.

In this study, we use intraday data of both KOSPI 200 futures and options, which are the world-class derivative assets, to investigate deviations in the futures and options markets simultaneously. Through this analysis, we reveal a common movement of price changes in the implied indices from the futures and options. Our data suggest that there is significant undervaluation of both futures and options, which increases in concert with the remaining time-to-maturity. The price changes of the implied index in the futures market are more closely associated with price changes in the options market than with price changes in the spot index. Moreover, the price changes of the implied indices from futures and options, their innovations, and the trading volumes of futures and options often change in similar fashions; however, this tendency is less clear for the price changes, innovations, and trading volumes in the stock and derivatives markets. The pattern of intraday deviation between the futures and options markets is different from the pattern of deviation between the futures and stock markets or the options and stock markets. In addition, the respective effects of trading volumes of stocks, futures, and options on changes in the deviation between the futures and stock markets is nearly equivalent to its effect on the deviation between the options and stock markets. These findings suggest the existence of the common deviation in the derivatives market. We define the sum of the deviations in the futures and options markets as the common deviation in the derivatives markets. As a consequence, the difference between them represents the relative deviation between the derivatives markets. If the futures market deviates from the options market substantially, investors in the derivatives markets will doubt information associated with the common deviation. Therefore, investors become reluctant to correct the common deviation, thereby causing it to sustain for a substantial period of time. Given that prices can respond to deviation only when related trading activity occurs, the common deviation may be adjusted only when the absolute value of the relative deviation is sufficiently small. Thus, we consider the size of the relative deviation between the derivatives markets as a critical factor in determining the adjustments of the common deviation and price dynamics.

This study uses a three-regime TVECM to estimate the regime-dependent pattern of deviation adjustment and price dynamics according to the reliability of the common deviation. We define regimes on the basis of the relative deviation between the derivatives markets. Further, we specify price dynamics in each regime after regime-splitting. The large absolute value of the relative deviation between futures and options in the extreme regimes (regimes 1 and 3) dissuades investors from responding sensitively to the common deviation. On the contrary, the common deviation is significantly adjusted only in the middle regime (regime 2), which indicates a moderate level of relative deviation. There is a general bi-directional lead-lag relationship between the derivatives and stock markets, but the leading effect of the stock market in the middle regime is unclear. In regime 1, which is characterized by substantial positive relative deviation, the relative deviation seems to communicate positive news related to the underlying asset. In testing the aspects around regime switches in our model, we find that options play a leading role in changing the relative deviation compared to futures. To our knowledge, this study represents the first attempt to use intraday data of both KOSPI 200 futures and options to examine regime-dependent price dynamics.

The remainder of this paper is organized into a series of interrelated sections. Section 2 describes the characteristics of the KOSPI 200 futures and options markets. In Section 3, we explain the details of our model specification, as well as our methodology. In Section 4, we describe the data and provide evidence for the common deviation in the index derivatives markets. We discuss the regime-dependent dynamics in the index derivatives markets in Section 5. Finally, we present our conclusions in Section 6.

2. KOSPI 200 futures and options market

The KOSPI 200 futures and options market is one of the most liquid and representative index derivatives markets in the world. Despite their short trading history, KOSPI 200 options have maintained a top-tier position in the global financial market and KOSPI 200 futures have become a major index futures product. Table 1 summarizes information associated with the top ten global futures and options exchanges in terms of their trading volume. This information indicates that the KOSPI 200 futures and options exchange is highest-ranked among all derivatives markets in terms of cumulative trading volume since 2008. Due to the synergistic effect of the combined trading of KOSPI 200 futures and options (Ryu, 2011, 2013, Forthcoming), Korea’s derivatives market remains in a period of sustained growth.

[Insert Table 1]

Unlike derivatives markets of developed countries, the KOSPI 200 future and options markets are dominated by individual investors. Although domestic and foreign institutional investors are heavily represented in more established derivatives markets, trades made by domestic individual investors comprise a substantial portion of the total trading volume in the KOSPI 200 index derivatives markets. Table 2 illustrates trading activities performed by three types of investors (domestic individuals, domestic institutions, and foreign investors) during this study's sample period. As indicated by the table, transactions performed by domestic individuals account for more than one-third of the total trading volume of all derivatives (futures, calls, and puts) between January 3, 2005 and March 10, 2011. In addition, domestic individual investors engage in trading activities in the options market, specifically in the call options market, to a greater degree than the futures market. Considering that domestic individual investors are less-informed and noisy in the Korea's derivatives markets,[1] speculative trading behaviors may be more dominant in the options market than in the futures market. This, in turn, may incite an abnormal pattern in the price dynamics in the options market.

[Insert Table 2]

Although the active participation of individual investors results in a speculative market, it also makes the market more liquid. These effects illustrate the pros and cons associated with the futures and options market. On one hand, most individual investors are short-term investors and day traders. As such, the trades made by these individuals can largely be characterized as noisy trading. Contrary to the objectives of the government and the Korea Exchange (KRX), which have promoted index futures and options trading, individuals do not use index derivatives as hedging tools or trading vehicles for long-term portfolio management. Their trading tends to make the market more volatile, unstable, and excessively speculative. On the other hand, market participants can enjoy the liquidity provided by individual investors, thereby enabling the KOSPI 200 futures and options exchange to occupy the top position as a world-class index derivatives exchange. Like other derivatives, both KOSPI 200 futures and options can be used as hedging instruments and trading vehicles for broad portfolio management. However, as a result of the dominant role played by noisy, speculative individual investors and a high leverage effect of derivatives trading, KOSPI 200 index derivatives (especially, KOSPI 200 options) trading activities are typically highly speculative in kind.

The KOSPI 200 futures and options markets are classified as purely order-driven markets without designated market maker. All transactions are made by the central electronic limit order book (CLOB). Through the CLOB, the orders submitted by investors are fairly and transparently transacted according to the price and time priority rules. This trading mechanism guarantees the transparency of the market, as well as the anonymity of all market participants. During a continuous trading session of each trading day, all submitted orders are immediately traded or consolidated into the CLOB.[2]

In the course of each trading day, four series of index futures (with respective maturity months of

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[1] See the studies of Ahn et al. (2008, 2010), Kang et al. (2012), Kang and Park (2008), Kim and Ryu (2012), Lee (Forthcoming), Ryu (2012, 2013, Forthcoming), Ryu et al. (Forthcoming) among others.

[2] Detailed trading conventions of the KOSPI 200 futures and options markets are described in Section 4.

March, June, September, and December) are traded. The series of options are also classified by four different maturities; however, their maturity months are three consecutive near-term months and the nearest month from the quarterly cycle (i.e., March, June, September, and December). For example, if today is January 31, the options' maturity months are February, March, April, and June. Maturity dates are set to be the second Thursday of maturity months. The second Thursday in each quarter serves as the maturity date on which futures and options simultaneously expire (which is commonly referred to as the "quadruple witching day").

The "point" is the quoting unit for KOSPI 200 index prices. This unit is also used to represent the futures and options prices, but the value of one point can respectively represent different amounts of money in the futures and options markets. For example, whereas one point is equal to 500,000 Korean Won (KRW) in the futures market, in the options market, one point equals only KRW 100,000. The minimum tick size of futures contracts is 0.05 points (KRW 25,000). For options contracts, the tick size is 0.05 points (KRW 5,000) if the quoted price is at least three points and 0.01 points (KRW 1,000) if it is less than three points.

3. The model and methodology

To specify deviations from no-arbitrage conditions in index derivatives markets, we calculate an implied index from the price series of derivatives using the cost-of-carry relationship and the put-call parity. The implied index is defined as the present value of the synthetic asset which replicates the payoff of the spot index at the maturity.

Let S_t be the price of the spot index at time t, and F_t be the price of the futures contract with the nearest maturity, T, at time t. Using the cost-of-carry relationship, we can calculate the fair price of the spot index implied by the price of futures, S_t^f, which is defined as F_t / (1 + r_t × (T–t) / 365) + $D_{t,T}$, where r_t denotes the 91 Day Certificate of Deposit (CD) interest rate and $D_{t,T}$ denotes the present value of dividends from the spot index between the period from t to T. For the options market, we also consider the synthetic asset with the same price as the spot index. According to put-call parity, the synthetic asset is composed of call and put options with the same strike price and debt contracts. The price of the synthetic asset at t, S_t^o, is calculated as $C_t – P_t + K / (1 + r_t × (T–t) / 365) + D_{t,T}$, where C_t is the call option price at time t , P_t is the put option price at time t, and K denotes their strike price.

When the maturity effect (MacKinlay and Ramaswamy, 1988) is noticeable, the proportional deviations, $lnS_t^f – lnS_t$ and $lnS_t^o – lnS_t$, may be expressed as,

$$
\begin{aligned}
lnS_t^f - lnS_t &= \beta_f(T-t) + e_t^f \\
lnS_t^o - lnS_t &= \beta_o(T-t) + e_t^o
\end{aligned}
\tag{1}
$$

where e_t^f and e_t^o are error terms associated with the proportional deviations of the futures and options, respectively. Given this, deviations from no-arbitrage conditions, Dev_t^f and Dev_t^o, can be defined as the detrended proportional differences between the implied indices and the spot index. This can be expressed as follows:

$$
\begin{aligned}
Dev_t^f &= (lnS_t^f - lnS_t) - \hat{\beta}_f(T-t) \\
Dev_t^o &= (lnS_t^o - lnS_t) - \hat{\beta}_o(T-t)
\end{aligned} \tag{2}
$$

where $\hat{\beta}_f$ and $\hat{\beta}_o$ are the estimates of β_f and β_o in Eq. (1). We define a common deviation in the derivatives markets, Dev_t^c, as the sum of the standardized deviations,

$$
Dev_t^c = Dev_t^f / \text{Std}(Dev_t^f) + Dev_t^o / \text{Std}(Dev_t^o) \tag{3}
$$

where Std(Dev_t^f) and Std(Dev_t^o) are the sample standard deviations of Dev_t^f and Dev_t^o, respectively. Similarly, a relative deviation between the derivatives markets, Dev_t^r, is defined as the difference between the standardized deviations,

$$
Dev_t^r = Dev_t^f / \text{Std}(Dev_t^f) - Dev_t^o / \text{Std}(Dev_t^o) \tag{4}
$$

We use the relative deviation between the index derivatives markets as the threshold variable for the TVECM. A market condition is in regime 1 when the relative deviation is smaller than the lower threshold, τ_L, and in regime 3 when the relative deviation is larger than the upper threshold τ_U. Accordingly, a market condition is in regime 2 when the relative deviation is between the two thresholds, τ_L and τ_U. Given these definitions of the regimes, they can be expressed as follows.

$$
\begin{aligned}
i &= 1 \quad if \quad Dev_{t-1}^r \le \tau_L \\
i &= 2 \quad if \quad \tau_L < Dev_{t-1}^r \le \tau_U \\
i &= 3 \quad if \quad \tau_U < Dev_{t-1}^r
\end{aligned} \tag{5}
$$

In each regime, we specify price dynamics of the spot index and the implied indices using the conventional error correction model with the error correction terms of the common deviation and the relative deviation,

$$
\triangle lnS_t = \alpha_{c,i}^s Dev_{t-1}^c + \alpha_{r,i}^s Dev_{t-1}^r + \sum_{j=1}^{p} \beta_{i,j}^s \triangle lnS_{t-j} + \sum_{j=1}^{p} \gamma_{i,j}^s lnS_{t-j}^f + \sum_{j=1}^{p} \delta_{i,j}^s lnS_{t-j}^o + \varepsilon_t^s \tag{6}
$$

$$\triangle lnS_t^f = \alpha_{c,i}^f Dev_{t-1}^c + \alpha_{r,i}^f Dev_{t-1}^r + \sum_{j=1}^{p} \beta_{i,j}^f \triangle lnS_{t-j} + \sum_{j=1}^{p} \gamma_{i,j}^f lnS_{t-j}^f + \sum_{j=1}^{p} \delta_{i,j}^f lnS_{t-j}^o + \varepsilon_t^f \quad (7)$$

$$\triangle lnS_t^o = \alpha_{c,i}^o Dev_{t-1}^c + \alpha_{r,i}^o Dev_{t-1}^r + \sum_{j=1}^{p} \beta_{i,j}^o \triangle lnS_{t-j} + \sum_{j=1}^{p} \gamma_{i,j}^o lnS_{t-j}^f + \sum_{j=1}^{p} \delta_{i,j}^o lnS_{t-j}^o + \varepsilon_t^o \quad (8)$$

where $\varepsilon_t = [\varepsilon_t^s\ \varepsilon_t^f\ \varepsilon_t^o]^T$ is assumed to be distributed with a multivariate normal distribution of N(0, Ω), and ε_t^s, ε_t^f, and ε_t^o denote errors for log index returns in the stocks, futures, and options markets, respectively. Ω is the covariance matrix of the error vector, and △ denotes a difference operator. Consistent with the past work by Stephan and Whaley (1990), we set the lags of AR terms, *p*, at 6, thereby indicating a delay of 30 minutes.

In Eqs. (6), (7), and (8), the coefficients of the error correction terms ($\alpha_{c,i}^s$, $\alpha_{c,i}^f$, $\alpha_{c,i}^o$, $\alpha_{r,i}^s$, $\alpha_{r,i}^f$, $\alpha_{r,i}^o$) indicate the speed of error corrections. If Dev_{t-1}^c is positive (i.e., the implied indices in derivatives markets are greater than the spot index), then investors will take a short position of the synthetic asset composed by derivatives and buy stocks. In this case, the implied indices will decrease and the spot index will increase. In contrast, if a common deviation is negative, the implied indices will increase and the spot index will decrease. In this case, $\alpha_{c,i}^s$ in Eq. (6) are positive and the respective coefficients for $\alpha_{c,i}^f$ and $\alpha_{c,i}^o$ in Eqs. (7) and (8) are negative. However, the relative deviation between the derivatives markets, Dev_{t-1}^r, may not be sensitively corrected in the spot market. We can expect that $\alpha_{r,i}^s$ in Eq. (6) may be insignificant. Conversely, we expect a negative value for $\alpha_{r,i}^f$ and a positive value for $\alpha_{r,i}^o$ in Eq. (7) because a positive (negative) value for Dev_{t-1}^r indicates that implied index in the futures market is higher (lower) than the implied index in the options market.

We also determine the thresholds, τ_L and τ_U, to estimate a three-regime TVECM. For given values of thresholds, the error correction model represented by Eqs. (6), (7), and (8) can be estimated using a conventional maximum likelihood method. We define the log likelihood function as a function of the given thresholds,

$$lnL(\tau_L, \tau_U) = -\frac{n}{2} ln|\Sigma| - \frac{1}{2}\sum_{t=1}^{n} \hat{\varepsilon}_t^T \Sigma^{-1} \hat{\varepsilon}_t \quad (9)$$

where $\hat{\varepsilon}_t = [\hat{\varepsilon}_t^s\ \hat{\varepsilon}_t^f\ \hat{\varepsilon}_t^o]^T$ is the residual vector in Eqs. (6), (7), and (8), and $\Sigma = \frac{1}{n}\sum_{t=1}^{n} \hat{\varepsilon}_t \hat{\varepsilon}_t^T$. Then, we utilize an approach similar to the grid search method to find the thresholds that maximize the log likelihood function. We respectively allow the threshold τ_L to vary from the 15th percentile to the 50th percentile of Dev_t^r, and the threshold τ_U to vary from the 50th percentile to the 85th percentile.

4. Data and common deviation

4.1. Data and summary statistics

In this study, we analyze the intraday transaction prices of KOSPI 200 futures and options and the corresponding underlying index (KOSPI 200 index) from January 3, 2005 to March 10, 2011. Our sample period contains not only the boom period during which speculative trading is prevalent, but also the high-volatility crisis period.[3] The continuous trading sessions differ slightly across markets. The stock market's continuous trading session opens at 9:00 a.m. and closes at 2:50 p.m. The trading sessions in the futures and options markets also open at 9:00 a.m., but close at 3:15 p.m. on non-maturity days.[4] Transactions in the last 10 minutes are executed in accordance with the uniform pricing rule. Trading of futures and options on maturity days ends 25 minutes earlier than on non-maturity days (i.e., 2:50 p.m.). We use only the time series of intraday transaction prices from 9:00 a.m. to 2:50 p.m. as a means of synchronizing the timing of the three markets. We include only the nearest maturity contracts of futures and options in our sample because they are most actively traded. Moreover, our sample includes only near-the-money options, which have a strike price between 97% and 103% of the closing price of the stock market. We do not include deep out-of-the-money options and deep in-the-money options in our sample, as they are traded too infrequently and are characterized by a relatively small trading volume. The sample contains transaction prices at every five minutes to avoid noise derived from infrequent transactions related to the put options. To calculate the implied index in the futures and options markets, we use the 91 Days Certificate of Deposit (CD) interest rates and the sum of daily dividends on the KOSPI 200 index portfolio. To calculate the implied index in the options market, we take the average of the implied indices from the pairs of near-the-money call and put options that share the same strike price. Table 3 summarizes the statistics associated with the variables of interest for this study.

[Insert Table 3]

In Panel A of Table 3, the three logarithms of the index series (lnS_t, lnS_t^f, lnS_t^o), which should be equivalent to each other if there is no arbitrage opportunity, show similar distributions. Overall, their skewness and kurtosis are slightly negative, but they are close to zero. The price changes (ΔlnS_t, ΔlnS_t^f, ΔlnS_t^o), however, are negatively skewed and have extreme tails. The negative values of the mean and median of the deviation between the derivatives markets and the stock market imply overall undervaluation in the derivatives market (see Panel B of Table 3). This phenomenon can be interpreted as limits to arbitrage. Investors in the stock market suffer as a result of the higher

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[3] High levels of volatility in the underlying market may reduce the informational role of an options market (Chakravarty et al., 2004).

[4] There are two exceptions to the opening time. Trading begins at 10:00 a.m. on the first trading day of the year and on the day of Korea's college scholastic aptitude test in November.

transaction costs of selling stocks relative to costs associated with buying stocks. The ban on short sales and asymmetric transaction taxes in the stock market may explain these costs.[5] Ofek et al. (2004) show that violations of the put-call parity relationship are asymmetric and that their magnitudes are strongly related to short-selling constraints. When we adjust the maturity effect, undervaluation in the derivatives markets becomes sharply reduced, but nonetheless remains. The estimated coefficients of the time-to-maturity, $\hat{\beta}_f$ and $\hat{\beta}_o$, are significant and negative (-3.357×10^{-5} and -3.587×10^{-5}), indicating that undervaluation diminishes over the time-to-maturity. Interestingly, index differences between the futures and options markets have much heavier tails than the differences between the spot market and derivatives markets. The distinct distribution of differences between derivatives markets suggests that there may exist a close connection between derivatives markets. The undervaluation seems more prominent in the futures market than in the options market, possibly indicating a longer time-to-maturity among futures contracts (MacKinlay and Ramaswamy, 1988). This tendency remains even following an adjustment of the maturity effect. It is noticeable that kurtosis of the relative deviation is extremely large, but that of the common deviation is small.

4.2. Common deviation in the index derivatives markets

In the absence of market frictions (e.g., trading costs or information asymmetry), new information should affect the spot index and the implied indices identically and contemporaneously. In this case, the correlations between the price changes of the spot index and implied indices might be close to 1. In Panel A of Table 4, it is interesting to note that the price changes of implied indices from futures and options are strongly correlated (0.957), but the correlations between the price changes of the spot index and implied indices from futures and options (0.898 and 0.897, respectively) are much smaller. Furthermore, differences between the implied indices and the spot index, ($lnS_t^f - lnS_t$) and ($lnS_t^o - lnS_t$), are strongly correlated (0.782). The differences between the implied index from futures prices and indices in other markets, ($lnS_t^f - lnS_t$) and ($lnS_t^f - lnS_t^o$), are relatively weakly correlated (0.555). Moreover, the absolute value of the correlation between differences between the options market and other markets, ($lnS_t^o - lnS_t$) and ($lnS_t^f - lnS_t^o$), is smaller still (0.085). Taken together, these results may suggest that there are common movements in the futures and options markets, given that the standard deviations of the index series (lnS_t, lnS_t^f, lnS_t^o) are nearly equivalent (see Table 3).

[Insert Table 4]

If the indices move independently and the deviations are the result of market noise, price changes in one market should not be associated with deviations between other two markets. However, our results

[5] The Korean government imposes a 0.3% transaction tax on selling stocks, but not on buying stocks.

show that the model is only fit for the price changes of the spot index and the differences between the futures and options markets. The price changes of the implied index in the futures market and the differences between the options market and the stock market are correlated to a degree that is statistically different from zero (0.046). This correlation is similar in magnitude to the analogous correlation associated with price changes of the implied index in the options market. This also supports the notion of common movements of the implied index in the futures and options markets.

In addition, we examine whether price changes, innovations from MA(1) price changes, and changes of trading volume in the stock and derivatives markets move in the same direction (i.e., increase or decrease in concert; see Panel B of Table 4). These data show that the implied indices in the derivatives markets simultaneously increase or decrease more frequently (81.64%) than the spot index and the implied index in the options (73.52%) or futures (66.11%) markets. The contemporaneous matching is more evident for the result of innovations. This pattern of results is similar for the trading volumes in the stock market and derivatives markets.

4.3. Intraday patterns of deviations and trading activities

The evidence outlined in the previous section supports the notion that the implied indices in the derivatives markets share common dynamic features. However, this may be caused by unique intraday trading patterns in the stock market. To examine this possibility, and in accordance with the work of Stephan and Whaley (1990), we calculate the respective proportions of each five minute interval to the total daily trading volume for each market. Figure 1 illustrates the average proportions across the sample period. The trading volume patterns concerning stocks and derivatives are relatively similar; the trading volume patterns for derivatives are also close to equivalent. All patterns adopt a U-shape over trading hours. Trading volumes are at their highest at the day's opening, after which the volumes decrease quickly. Following the time of day at which trading volumes are at their lowest (12:15 p.m.), they tend to increase until the closing of the day. In contrast, deviations between derivatives and stock markets adopt an inverted U-shape. Once again, the deviation between the futures and options markets shows a distinct pattern which is slightly negative and flat through the day. The intraday trading volume and deviation patterns also offer evidence related to the common deviation in the derivatives markets.

[Insert Figure 1]

Because deviations have intraday patterns that are opposite to those of trading volumes, we can infer that the implied indices may be underpriced when the derivatives markets are liquid. Table 5 summarizes the results of the regression analysis of the deviations and their changes on the proportions of trading volume. The trading volume of futures negatively affects deviations, which implies that futures prices are underpriced in the liquid futures market. Similarly, a large volume of call options reduces the implied index from options prices; the opposite is true with regard to the volume of put options. Given that a put option price is negatively related to the implied index according to the put-call parity, the liquidity of both call and put options may be negatively associated with their option prices. Overall, the liquidity in derivatives markets is a salient factor to the underpricing of derivatives. The relationship between prices and volume in the stock market, however, is reversed. When the stock market is liquid, deviations between the derivatives and stock markets decrease. This indicates that investors in the derivatives markets actively trade when they are concerned about a rapid decline of the spot index. More importantly, the estimated coefficients of volumes are similar for deviations between the derivatives and stock markets except for the call option volume on the deviations between the futures and stock markets. As shown in Table 2, a greater proportion of domestic individual investors are active in the call options market (37.81%) than the put options market (35.86%) or futures market (33.47%). Given that domestic individual investors in the Korean market are less informed than domestic institutions or foreign investors (see footnote 1), the abnormal relationship between call option volume and deviations may be attributable to speculative trades or market disturbances. Futures volume has an influence on the deviations between other markets (i.e., options and stock markets), and options volume vice versa. The evidence consistently supports the notion that common factors affect prices in the futures and options markets.

[Insert Table 5]

5. Price dynamics in the index derivatives markets

5.1. Error correction model

We specify the price dynamics in the index derivatives markets using a regular error correction model (ECM) before investigating regime-dependent price dynamics of spots and derivatives. To apply the ECM, the error correction terms in our model, the common and relative deviations, and price changes should be stationary. Therefore, we carry out the stationarity tests of the index series, the index price changes, and the deviations.

As shown in Panel A of Table 6, we cannot ignore the existence of the unit root for all the index series. In contrast, the changes of the indices and the deviations seem to be stationary. On the other hand, we examine whether the spot index and the implied indices are cointegrated. We also test whether these series are cointegrated with the cointegrating vectors of [1 -1 0], [1 0 -1], and [0 1 -1], which construct the deviations. To perform these cointegration tests, we employ the conventional method proposed by Johansen (1991). Panel B of Table 6 demonstrates that the null hypotheses (i.e., no cointegration), for rank 1 can be rejected at the 5% significance level. However, we are unable to reject the null hypothesis which tests cointegration for rank 2. As expected, the estimated cointegrating vectors with the assumption of cointegration for rank 2 are close to [1 -1 0], [1 0 -1], and [0 1 -1]. Thus, we can consider the common deviation and the relative deviation as error correction terms in an ECM framework.

[Insert Table 6]

The estimated coefficients of the common deviation in the derivatives markets are consistent with our expectations (see Panel C of Table 6). The coefficient estimates are significantly negative in the equations for futures and options, but positive in the equation for the spot index. Therefore, we can confirm that investors generally intend to adjust the common deviation. Also as expected, investors in the stock market insignificantly respond to the relative deviation between the derivatives markets. However, the sign of coefficients of the relative deviation for the futures equation is not consistent with the mean reverting behavior of deviations. Results illustrate that investors react to the common deviation more sensitively than they do to the relative deviation. Generally, the derivatives and stock markets lead each other bi-directionally, meaning that lagged differences in one market have statistically significant effects on the other market. Considering the size of the coefficients, derivatives lead spots more intensively than spots lead derivatives. This result is consistent with results reported by Kawaller et al. (1987) and Stoll and Whaley (1990).

5.2. Regime-dependent dynamics

We show that there is a common movement in the derivatives markets. Given this, the information in the common deviation may be more reliable when the derivatives markets do not deviate substantially from each other. In this case, the response to the common deviation is dependent on the size of the relative deviation between the derivatives markets. To investigate the possibility of nonlinearity in deviation adjustment, we specify a three-regime TVECM in which the threshold variable is defined as the relative deviation between the derivatives markets.

The three-regime TVECM estimation result is shown in Table 7. The two thresholds, τ_L and τ_U, are estimated as $\tau_L = -0.346$ and $\tau_U = 0.282$. The estimated thresholds are slightly asymmetric. According to the estimated thresholds, an excessive overvaluation of futures (i.e., regime 3) occurs more frequently (20.14%) than an excessive undervaluation of futures (i.e., regime 1; 18.69%). This result suggests that investors are somewhat susceptible to overvaluation of futures. This is consistent with the overall undervaluation of futures relative to options as reported in Table 3 and Figure 1.

[Insert Table 7]

The signs of the estimated coefficients of the common deviation are consistent with our expectations. For all regimes, the estimates are negative for the futures and options equations, but positive for the spot index equations. As a result, we can confirm that investors generally intend to modify the common deviation. However, investors respond to the common deviation differently based on the extremity of the relative deviation. In regime 2, which indicates a moderate degree of relative deviation, there is a clear adjustment of the common deviation. In contrast, the coefficients of the common deviations in the regimes 1 and 3 are not statistically significant. This is especially true in the stock market, where the correction of the common deviation is insignificant even at the 10% significance level. This result supports our hypothesis that the common deviation is more reliable when the absolute value of the relative deviation is sufficiently small.

We expect that the relative deviation does not affect price changes of the spot index because it captures the long-run relationship between the derivatives markets, but not the stock market. On the other hand, the relative deviation should be adjusted negatively in the futures markets and positively in the options market for the mean-reversion. Similar to the correction of the common deviation, the relative deviation is adjusted normally in the middle regime. Although the estimate for the relative deviation in the futures equation is not significant, the signs of the estimated coefficients are consistent with our expectations in regime 2. However, all estimates for the relative deviation are positive in regime 3, and are consistently significant in the stocks equation. This finding serves as an indication that the large gap between futures and options is interpreted as positive information about the fundamental price. This “good news” will affect not only the prices of derivatives, but also the spot index. Because the effect of the relative deviation should be modified by the mean-reverting long-run relation, it is amplified in the options market and diluted in the futures market. Alternatively, the price of futures may serve as an anchor of the long-run equilibrium in regime 3. If the price of futures represents the true value of fundamental asset, it does not respond to deviations in the other markets. This effect does not exist in regime 1. Contrary to our original expectation, there is a significant and positive relationship between the relative deviation and price differences of futures in regime 1. The relative deviation has no substantial effect on stocks and options equations. This indicates that the excessive undervaluation of futures and overvaluation of options sustain for a relatively long period of time.

We find the bi-directional lead-lag relationship between stocks and derivatives in the estimation of TVECM as in the result of the traditional VECM. We perform a Granger-type causality test to elucidate and clarify the short-run effect of one market on the other markets (Engle and Granger, 1987). As shown in Table 8, the short-run price effects of futures on other markets are significant regardless of the regimes. Options lead futures and stocks in all regimes, with the exception of futures in regime 1. In addition, the leading effect of stocks on futures in regime 1 is weaker than the effect in regime 3. This result suggests that the futures market plays a critical role in price discovery when futures are excessively undervalued. It is notable that the short-run effect of stocks is confined to regimes 1 and 3. With a mild level of relative deviation, only the derivatives markets lead the stock market. Therefore, the dominant information effect of derivatives on spots (Fleming et al., 1996; Ryu, forthcoming; So and Tse, 2004) is clear when the futures and options markets are closely related.

[Insert Table 8]

When a regime switch occurs, there is a sudden change in the relative deviation. However, it is unclear whether such a sudden change results from futures, options, or both. To address this question, we examine the index changes that result from the regime switches. If futures incite a regime switch, the change of the spot index should be similar to the change of the implied index in the options market (and vice versa). Because a regime is defined by the lagged relative deviation, the implied index in the futures market may move in the opposite direction of the price change of the implied index in the options market prior to a regime switch. Given this, we can determine the leading effect of futures and options by identifying whether the movement of the spot index is associated with the index change in futures or options market. Figure 2 illustrates the average changes in the indices across the sample period from 30 minutes before to 30 minutes after the occurrence of a regime switch. Panel A (Panel D) depicts regime switches from regimes 2 or 3 to regime 1 (regimes 1 or 2 to regime 3). We delineate regime switches from regimes 1 and 3 to regime 2 separately in Panel B and C because the direction of index changes for regime switches from regime 1 to regime 2 will be opposite to that from regime 3 to regime 2. Interestingly, the price changes of the spot index are very similar to index changes in the futures market. Therefore, we conclude that the options market plays a leading role in regime switches. Rapid changes to the implied index in the options market may result from speculative trading or market disturbance. This supports findings produced by past researchers that the price discovery effect is more substantial in the futures market than in the options market (Chang et al., 2013; Hsieh et al., 2008; Ryu, forthcoming; Schlag and Stoll, 2005). The lower proportion of the domestic individuals in the KOSPI 200 futures market relative to the options market may reflect amplified informational role of financial markets when the proportion of private investors (in terms of trading volume) decreases (Bohl et al., 2011).

[Insert Figure 2]

6. Conclusion

This study represents a first attempt to identify the intraday dynamics of common deviation in the index derivatives markets, which is implicit in the model-free approach. Moreover, we investigate the regime-dependent price dynamics in the spot and the derivatives markets using the reliability of the common deviation.

Specifically, we reveal the nature of the co-movement of the implied indices in the KOSPI 200 futures and options markets. Both the implied indices in the futures and options markets are underpriced, but the undervaluation is diminished with the passage of time-to-maturity. Changes in the implied index in the futures and options markets are more strongly correlated than those in the stock and derivatives markets. This tendency is consistent with the correlations between trading volumes of stocks and derivatives. Over the course of a trading session, the patterns of deviation between the derivatives markets and the stock market adopt an inverted U-shape, but the pattern of deviation between the futures and options markets is relatively flat. Deviations in the derivatives markets are tied to trading activities in those markets, which adopt a U-shaped intraday pattern in the same direction.

When we define three regimes on the basis of the relative deviation between the derivatives markets, the common deviation is significantly corrected in a typical direction only when the relative deviation is moderate (i.e., regime 2). In regime 2, the stock market does not lead the derivatives markets in the short-run, but there is bi-directional information flow between the derivatives markets and stock market in the regimes in which there are extreme relative deviations (i.e., regimes 1 and 3). The severe overvaluation of the implied index in the futures market relative to the implied index in the options market seems to have positive information for the fundamental asset price. Options (rather than futures) induce sudden changes in the relative deviation between the derivatives markets. Taken together, the results of this study shed light on the common movement of futures and options and its informational effect. Moreover, this study has meaningful implications for the index derivatives, given the global position of KOSPI 200 index derivatives, which consistently attract a significant number of global investors.

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Table 1
Global top ten futures and options exchanges by cumulative trading volume

	Trading volume			
Exchange name	2008	2009	2010	2011
Korea Exchange	2,865,482,319	3,102,891,777	3,748,861,401	3,927,956,666
Chicago Mercantile Exchange	3,277,630,030	2,589,551,487	3,080,497,016	3,386,986,678
Eurex	3,172,704,773	2,647,406,849	2,642,092,726	2,821,502,018
NYSE Euronext	1,675,791,242	1,729,965,293	2,154,742,282	2,283,472,810
National Stock Exchange of India	601,599,920	918,507,122	1,615,790,692	2,200,366,650
BM&F Bovespa	741,889,113	920,377,678	1,413,753,671	1,500,444,003
NASDAQ OMX	722,107,905	814,639,771	1,099,437,223	1,295,641,151
Chicago Board Options Exchange	1,194,516,467	1,135,920,178	1,123,505,008	1,216,922,087
Multi Commodity Exchange of India	103,049,912	384,730,330	1,081,813,643	1,196,322,051
Russia Trading Systems Stock Exchange	238,220,708	474,440,043	623,992,363	1,082,559,225

This table presents the global top ten futures and options exchanges are ranked by the combined trading volume of futures and options from 2008 to 2011. Reported trading volume is based on the number of contracts traded each year. The exchanges are sorted on the basis of their respective 2011 trading volumes. Source: Futures Industry Association (www.futuresindustry.org).

Table 2
KOSPI 200 trading activity by investor types

		Trading volume (*No. contracts*)	*Percent*	*Trading value* (*mil. KRW*)	*Percent*
Futures	Individuals	270,328,083	34.70	25,836,943,300	33.76
	Institutions	304,845,564	39.13	30,420,923,976	39.75
	Foreigners	203,914,667	26.17	20,274,437,948	26.49
	Total	779,088,314	100.00	76,532,305,225	100.00
Calls	Individuals	6,746,401,891	36.72	538,191,674	37.91
	Institutions	7,499,288,061	40.82	384,243,565	27.06
	Foreigners	4,126,005,874	22.46	497,306,420	35.03
	Total	18,371,695,826	100.00	1,419,741,659	100.00
Puts	Individuals	6,068,776,848	35.79	526,581,771	36.03
	Institutions	6,183,963,676	36.47	354,523,008	24.26
	Foreigners	4,703,541,284	27.74	580,523,286	39.72
	Total	16,956,281,808	100.00	1,461,628,065	100.00

This table presents the trading activity in the Korean derivatives markets (KOSPI 200 futures, KOSPI 200 calls, and KOSPI 200 puts) by three types of investors: *Individuals* denote domestic individual investors. *Institutions* denote domestic institutional investors. *Foreigners* denote foreign investors. *Trading volume* denotes the cumulative number of contracts during the sample period. *Trading value* denotes the cumulative trading value in millions of Korean Won (KRW) during the sample period, which is from January 3, 2005 to March 10, 2011. Source: Korea Exchange (*www.krx.co.kr*).

Table 3
Summary statistics

Panel A: Price variables

	Variables					
	lnS_t	lnS_t^f	lnS_t^o	$\triangle lnS_t$	$\triangle lnS_t^f$	$\triangle lnS_t^o$
N	107574	107574	107574	106034	106034	106034
Mean	5.241	5.239	5.240	7.68E-06	7.69E-06	7.68E-06
Min	4.721	4.717	4.720	-0.064	-0.074	-0.072
Median	5.241	5.241	5.242	0.000	0.000	0.000
Max	5.635	5.632	5.632	0.056	0.059	0.091
Std	0.212	0.213	0.213	0.002	0.002	0.002
Skewness	-0.429	-0.429	-0.431	-1.614	-1.503	-0.883
Kurtosis	-0.594	-0.590	-0.591	122.647	140.845	201.800

Panel B: Deviations

	Variables						
	$lnS_t^f - lnS_t$	Dev_t^f	$lnS_t^o - lnS_t$	Dev_t^o	$lnS_t^f - lnS_t^o$	Dev_t^c	Dev_t^r
Mean	-1.56E-03	-4.97E-05	-5.50E-04	-8.02E-07	-1.01E-03	-0.017	-0.016
Min	-5.01E-02	-4.87E-02	-4.84E-02	-4.78E-02	-4.01E-02	-32.51	-13.29
Median	-1.29E-03	-7.13E-05	-4.67E-04	7.66E-06	-3.82E-04	-0.026	-0.034
Max	2.43E-02	2.59E-02	3.19E-02	3.27E-02	5.92E-02	13.08	22.70
Std	0.003	0.003	0.002	0.002	0.002	1.870	0.570
Skewness	-0.880	-0.512	-0.846	-0.696	-0.381	-0.138	1.771
Kurtosis	12.237	15.022	15.994	16.636	76.437	9.871	148.69

This table reports summary statistics on the index series, price changes, and deviations from KOSPI 200 index, futures, and options. We report the number of observations (*N*) mean (*Mean*), minimum (*Min*), median (*Median*), maximum (*Max*), standard deviation (*Std*), skewness (*Skewness*), and kurtosis (*Kurtosis*) of the log transformation of indices and their changes in Panel A and those statistics of the deviations in Panel B. In Panel B, Dev_t^f and Dev_t^o are the detrended log differences between the implied indices in the futures and options market and the spot index. Dev_t^c is the sum of the standardized deviations, and Dev_t^r is the difference between the standardized deviations.

Table 4

The common movement in the derivatives markets

Panel A: Correlations between price changes and differences between indices

	$\triangle lnS_t$	$\triangle lnS_t^f$	$\triangle lnS_t^o$	$lnS_t^f - lnS_t$	$lnS_t^o - lnS_t$	$lnS_t^f - lnS_t^o$
$\triangle lnS_t$	1					
$\triangle lnS_t^f$	0.898***	1				
$\triangle lnS_t^o$	0.897***	0.957***	1			
$lnS_t^f - lnS_t$	-0.012***	0.054***	0.040***	1		
$lnS_t^o - lnS_t$	-0.016***	0.046***	0.064***	0.782***	1	
$lnS_t^f - lnS_t^o$	0.002	0.024***	-0.021***	0.555***	-0.085***	1

Panel B: The ratios of the same directions

	Stocks & Futures	Stocks & Options	Futures & Options
Price Changes	66.11%	73.52%	81.64%
Innovations - MA(1)	75.79%	76.56%	90.41%
Changes of Trading Volume	65.39%	66.70% (Call) 62.81% (Put)	81.25% (Call) 80.29% (Put)

This table shows the common movement in the KOSPI 200 futures and options markets. In Panel A, S_t, S_t^f, S_t^o denote price indices in stock, futures, and options markets, respectively. Panel A shows the correlation between the price changes of the log transformation of indices ($\triangle lnS_t$, $\triangle lnS_t^f$, $\triangle lnS_t^o$) and differences between the log transformation of indices ($lnS_t^f - lnS_t$, $lnS_t^o - lnS_t$, $lnS_t^f - lnS_t^o$). ***, **, and * denote that correlations in Panel A are significantly different from zero at the 1%, 5%, and 10% significance levels, respectively. Panel B reports the ratios of the same directions for the price changes, innovations for price changes, and changes of trading volume. The innovations for the price changes are the residuals from an MA(1) model fitted to price changes. Values in Panel B represent the percentage of variables in one market with a sign that is equivalent to variables in another market.

Table 5
Regressions of the deviations on the proportions of trading volume

	Dependent variables					
	Futures - Stocks		Options - Stocks		Futures - Options	
	Estimates	*t*-value	Estimates	*t*-value	Estimates	*t*-value
Panel A: Deviations						
Constant	0.0000	1.41	0.0001***	5.38	-0.0001***	-5.77
Stocks Volume	0.0013	0.67	-0.0092***	-5.56	0.0105***	9.80
Futures Volume	-0.0203***	-16.13	-0.0032***	-3.00	-0.0170***	-24.40
Calls Volume	0.0056***	3.22	-0.0047***	-3.20	0.0103***	10.74
Puts Volume	0.0076***	4.59	0.0097***	6.78	-0.0020**	-2.20
Panel B: Changes of Deviations						
Constant	0.0000**	2.11	0.0000***	2.57	0.0000	-0.75
Stocks Volume	-0.0028***	-4.82	-0.0028***	-4.70	0.0000	-0.10
Futures Volume	-0.0012***	-3.06	-0.0003	-0.86	-0.0008***	-3.35
Calls Volume	-0.0025***	-4.71	-0.0035***	-6.59	0.0010***	2.99
Puts Volume	0.0053***	10.59	0.0053***	10.29	0.0001	0.26

This table displays the results of the regressions of the detrended deviations and their changes on the proportions of trading volume. ***, **, and * denote that significance of the independent variables can be rejected at the 1%, 5%, and 10% significance levels, respectively. The dependent variable of Panel A shows the detrended deviations between the futures and stock markets, the options and stock markets, and the futures and options markets, respectively. Panel B illustrates the changes of the detrended deviations between the futures and stock markets, the options and stock markets, and the futures and options markets. The estimated coefficients for the explanatory variables (stocks volume, futures volume, call options volume, and put options volume) and their *t*-statistics are reported.

Table 6
Preliminary test results and the VECM estimation result

Panel A: Unit root test results

	lnS_t	lnS_t^f	lnS_t^o	ΔlnS_t	ΔlnS_t^f	ΔlnS_t^o	Dev_t^c	Dev_t^r
ADF	-2.25	-2.33	-2.35	-124.8***	-121.4***	-120.4***	-21.9***	-29.0***
PP	-2.23	-2.3	-2.31	-460.0***	-453.8***	-456.2***	-39.0***	-50.6***

Panel B: Cointegration test results

Rank	Trace	5% Critical Value		Cointegrating vector		
0	1180.57	34.8	lnS_t	1	1	0
1	405.97	19.99	lnS_t^f	-0.9978	0	1
2	5.71	9.13	lnS_t^o	0	-0.9981	-1.0003

Panel C: VECM estimation results

Explanatory Variables	Dependent Variables					
	ΔlnS_t		ΔlnS_t^f		ΔlnS_t^o	
	Coefficients	*t*-value	Coefficients	*t*-value	Coefficients	*t*-value
Constant	3.89E-06	0.94	6.76E-07	0.16	1.59E-06	0.37
Dev_{t-1}^c	5.11E-06**	2.25	-1.17E-05***	-4.88	-1.32E-05***	-5.52
Dev_{t-1}^r	1.17E-05	1.52	1.75E-05**	2.17	1.33E-05	1.64
ΔlnS_{t-1}	-0.4644***	-70.73	0.0238***	3.44	0.0432***	6.24
ΔlnS_{t-2}	-0.2644***	-36.45	0.0312***	4.07	0.0619***	8.09
ΔlnS_{t-3}	-0.1560***	-20.93	0.0414***	5.26	0.0369***	4.70
ΔlnS_{t-4}	-0.1365***	-18.35	-0.0048	-0.61	-0.0224***	-2.86
ΔlnS_{t-5}	-0.1046***	-14.57	-0.0173**	-2.29	-0.0256***	-3.38
ΔlnS_{t-6}	-0.0555***	-8.82	-0.0125*	-1.88	-0.0172***	-2.59
ΔlnS_{t-1}^f	0.4649***	45.89	-0.0626***	-5.86	0.5380***	50.33
ΔlnS_{t-2}^f	0.2961***	25.43	-0.0163	-1.33	0.4370***	35.57
ΔlnS_{t-3}^f	0.2173***	17.78	-0.0038	-0.30	0.3454***	26.79
ΔlnS_{t-4}^f	0.0399***	3.26	-0.0720***	-5.57	0.1298***	10.05
ΔlnS_{t-5}^f	0.0984***	8.50	0.0324***	2.66	0.1135***	9.30
ΔlnS_{t-6}^f	0.0213**	2.13	-0.0050	-0.47	0.0213**	2.03
ΔlnS_{t-1}^o	0.0277***	2.65	0.0351***	3.19	-0.5717***	-51.93
ΔlnS_{t-2}^o	-0.0357***	-2.98	-0.0164	-1.30	-0.4914***	-38.89
ΔlnS_{t-3}^o	-0.0710***	-5.62	-0.0304**	-2.28	-0.3741***	-28.07
ΔlnS_{t-4}^o	0.1016***	8.05	0.0870***	6.54	-0.0900***	-6.76
ΔlnS_{t-5}^o	0.0025	0.21	-0.0113	-0.91	-0.0797***	-6.42
ΔlnS_{t-6}^o	0.0361***	3.60	0.0187*	1.77	0.0045	0.43

This table shows the results for the stationary test and the cointegration test, as well as the results of the estimation of the normal vector error correction model. Panel A presents the statistics for the augmented Dickey-Fuller unit root test and the Phillips–Perron unit root test for the log transformation of the stock, future, options prices indices (lnS_t, lnS_t^f, lnS_t^o), their changes (ΔlnS_t, ΔlnS_t^f, ΔlnS_t^o), the sum of the standardized deviations (Dev_t^c), and the difference of the standardized deviations (Dev_t^r). Panel B shows the results of the Johansen's cointegration trace test based on the traditional vector error correction model, which contains the error correction term as the linear sum of the log transformation of lagged level variables (lnS_{t-1}, lnS_{t-1}^f, lnS_{t-1}^o). The null hypothesis for this test is that the number of cointegration vectors is smaller or equal to the rank. We estimate the cointegrating vectors under the assumption of cointegration of rank 2. We normalize one of the elements of the cointegrating vector and restrict one of the other elements to zero. Panel C reports the estimates of coefficients and their *t*-statistics for the following vector error correction model.

$$\triangle lnS_t = \alpha_c^s Dev_{t-1}^c + \alpha_r^s Dev_{t-1}^r + \sum_{j=1}^{6} \beta_j^s \triangle lnS_{t-j} + \sum_{j=1}^{6} \gamma_j^s lnS_{t-j}^f + \sum_{j=1}^{6} \delta_j^s lnS_{t-j}^o + \varepsilon_t^s$$

$$\triangle lnS_t^f = \alpha_c^f Dev_{t-1}^c + \alpha_r^f Dev_{t-1}^r + \sum_{j=1}^{6} \beta_j^f \triangle lnS_{t-j} + \sum_{j=1}^{6} \gamma_j^f lnS_{t-j}^f + \sum_{j=1}^{6} \delta_j^f lnS_{t-j}^o + \varepsilon_t^f$$

$$\triangle lnS_t^o = \alpha_c^o Dev_{t-1}^c + \alpha_r^o Dev_{t-1}^r + \sum_{j=1}^{6} \beta_j^o \triangle lnS_{t-j} + \sum_{j=1}^{6} \gamma_j^o lnS_{t-j}^f + \sum_{j=1}^{6} \delta_j^o lnS_{t-j}^o + \varepsilon_t^o$$

The sample period is from January 03, 2005 to March 10, 2011. ***, **, and * denote statistical significance at the 1%, 5%, and 10% significance levels, respectively.

Table 7
Three-regime TVECM estimation result

Explanatory Variables	Dependent Variables					
	$\triangle lnS_t$		$\triangle lnS_t^f$		$\triangle lnS_t^o$	
	Coefficients	*t*-value	Coefficients	*t*-value	Coefficients	*t*-value
Panel A: Regime 1 ≡ $Dev_{t-1}^r \leq \tau_L$ = –0.346 (18.69%)						
Constant	9.63E-06	0.74	4.42E-05***	3.21	5.66E-06	0.42
Dev_{t-1}^c	3.35E-06	0.88	-7.42E-06*	-1.84	-9.92E-06**	-2.52
Dev_{t-1}^r	6.17E-06	0.37	4.80E-05***	2.71	-2.13E-06	-0.12
$\triangle lnS_{t-1}$	-0.4520***	-33.77	0.0401***	2.83	0.0533***	3.87
$\triangle lnS_{t-2}$	-0.2833***	-18.98	0.0213	1.35	0.0054	0.35
$\triangle lnS_{t-3}$	-0.1959***	-12.74	0.0102	0.62	-0.0169	-1.07
$\triangle lnS_{t-4}$	-0.1321***	-8.58	-0.0086	-0.53	-0.0279*	-1.76
$\triangle lnS_{t-5}$	-0.0803***	-5.38	0.0243	1.54	0.0048	0.31
$\triangle lnS_{t-6}$	-0.0396***	-2.99	0.0089	0.63	0.0072	0.53
$\triangle lnS_{t-1}^f$	0.4251***	27.19	-0.0494***	-2.99	0.6392***	39.73
$\triangle lnS_{t-2}^f$	0.1187***	4.62	-0.0242	-0.89	0.2579***	9.76
$\triangle lnS_{t-3}^f$	0.0688**	2.52	-0.0178	-0.62	0.0483*	1.72
$\triangle lnS_{t-4}^f$	-0.0268	-0.99	0.0173	0.60	-0.1273***	-4.58
$\triangle lnS_{t-5}^f$	-0.0271	-1.03	0.0421	1.52	-0.0515*	-1.91
$\triangle lnS_{t-6}^f$	-0.0032	-0.13	0.042	1.64	0.0223	0.89
$\triangle lnS_{t-1}^o$	0.0843***	5.29	0.0139	0.83	-0.6902***	-42.11
$\triangle lnS_{t-2}^o$	0.1524***	5.29	-0.0073	-0.24	-0.2659***	-8.98
$\triangle lnS_{t-3}^o$	0.1159***	3.79	0.0121	0.37	-0.0182	-0.58
$\triangle lnS_{t-4}^o$	0.1794***	5.94	0.0134	0.42	0.1999***	6.44
$\triangle lnS_{t-5}^o$	0.1017***	3.42	-0.0455	-1.45	0.0598*	1.96
$\triangle lnS_{t-6}^o$	0.0315	1.16	-0.0491*	-1.70	-0.0248	-0.88
Panel B: Regime 2 ≡ –0.346 = τ_L < $Dev_{t-1}^r \leq \tau_U$ = 0.282 (61.17%)						
Constant	8.69E-07	0.18	-1.92E-06	-0.37	2.18E-06	0.43
Dev_{t-1}^c	8.46E-06***	2.78	-1.12E-05***	-3.45	-9.38E-06***	-3.00
Dev_{t-1}^r	8.05E-06	0.25	-1.04E-05	-0.30	8.51E-05***	2.58
$\triangle lnS_{t-1}$	-0.4853***	-58.32	0.0131	1.48	-0.0048	-0.56
$\triangle lnS_{t-2}$	-0.3062***	-33.45	0.0196**	2.01	0.0060	0.64
$\triangle lnS_{t-3}$	-0.1933***	-20.55	0.0316***	3.16	0.0174*	1.80
$\triangle lnS_{t-4}$	-0.1240***	-13.25	0.0220**	2.21	0.0119	1.24
$\triangle lnS_{t-5}$	-0.0776***	-8.61	0.0225**	2.35	0.0161*	1.75
$\triangle lnS_{t-6}$	-0.0404***	-5.12	0.0059	0.70	0.0036	0.45
$\triangle lnS_{t-1}^f$	0.4289***	20.92	-0.2852***	-13.06	0.2856***	13.58
$\triangle lnS_{t-2}^f$	0.2655***	11.73	-0.2134***	-8.85	0.1438***	6.19
$\triangle lnS_{t-3}^f$	0.2151***	9.43	-0.1105***	-4.55	0.1182***	5.05
$\triangle lnS_{t-4}^f$	0.1696***	7.57	-0.0682***	-2.85	0.0857***	3.73
$\triangle lnS_{t-5}^f$	0.1381***	6.42	0.0166	0.73	0.1034***	4.69
$\triangle lnS_{t-6}^f$	0.0423**	2.31	-0.0263	-1.35	0.0216	1.15
$\triangle lnS_{t-1}^o$	0.0853***	3.83	0.2633***	11.10	-0.2852***	-12.48
$\triangle lnS_{t-2}^o$	0.0290	1.21	0.1852***	7.26	-0.1516***	-6.17
$\triangle lnS_{t-3}^o$	-0.0301	-1.26	0.0776***	3.06	-0.1318***	-5.39
$\triangle lnS_{t-4}^o$	-0.0352	-1.50	0.0639**	2.56	-0.0727***	-3.03
$\triangle lnS_{t-5}^o$	-0.0615***	-2.73	-0.0369	-1.54	-0.1140***	-4.93

ΔlnS^{o}_{t-6}	0.0128	0.65	0.0322	1.54	-0.0087	-0.43
Panel C: Regime 3 ≡ 0.282 = $\tau_U <$ Dev^{r}_{t-1} (20.14%)						
Constant	-3.46E-05*	-1.84	-2.66E-05	-1.36	-4.20E-05**	-2.05
Dev^{c}_{t-1}	9.21E-06	1.43	-1.62E-05**	-2.43	-1.17E-05*	-1.66
Dev^{r}_{t-1}	5.57E-05***	2.66	2.78E-05	1.28	7.91E-05***	3.46
ΔlnS_{t-1}	-0.4345***	-25.95	0.0195	1.12	0.0599***	3.28
ΔlnS_{t-2}	-0.1889***	-10.32	0.0532***	2.80	0.1542***	7.73
ΔlnS_{t-3}	-0.0809***	-4.32	0.0713***	3.66	0.0788***	3.86
ΔlnS_{t-4}	-0.1480***	-7.89	-0.0386**	-1.98	-0.0998***	-4.89
ΔlnS_{t-5}	-0.1967***	-10.80	-0.1277***	-6.75	-0.1701***	-8.57
ΔlnS_{t-6}	-0.1028***	-6.37	-0.0635***	-3.79	-0.0925***	-5.26
ΔlnS^{f}_{t-1}	0.4792***	19.39	0.0485*	1.89	0.3233***	12.00
ΔlnS^{f}_{t-2}	0.3289***	14.16	0.0567**	2.35	0.4364***	17.24
ΔlnS^{f}_{t-3}	0.2204***	9.47	0.0156	0.65	0.4939***	19.48
ΔlnS^{f}_{t-4}	0.0144	0.61	-0.1016***	-4.11	0.3245***	12.52
ΔlnS^{f}_{t-5}	0.1670***	7.32	0.0789***	3.33	0.3533***	14.20
ΔlnS^{f}_{t-6}	0.0349*	1.75	-0.0102	-0.49	0.1437***	6.61
ΔlnS^{o}_{t-1}	-0.0280	-1.12	-0.0567**	-2.18	-0.3402***	-12.48
ΔlnS^{o}_{t-2}	-0.1224***	-5.48	-0.0890***	-3.84	-0.5549***	-22.78
ΔlnS^{o}_{t-3}	-0.1453***	-6.33	-0.0635***	-2.66	-0.5565***	-22.25
ΔlnS^{o}_{t-4}	0.1175***	5.04	0.1280***	5.29	-0.2389***	-9.41
ΔlnS^{o}_{t-5}	0.0208	0.97	0.0444**	2.01	-0.1854***	-7.99
ΔlnS^{o}_{t-6}	0.0533***	3.06	0.0552***	3.06	-0.0618***	-3.26

This table reports the estimation result for the following three-regime threshold vector error correction model with the error correction terms of the sum of the sum of the standardized deviations (Dev^{c}_{t}) and the difference of the standardized deviations (Dev^{r}_{t}).

$$\Delta lnS_t = \alpha^{s}_{c,i} Dev^{c}_{t-1} + \alpha^{s}_{r,i} Dev^{r}_{t-1} + \sum_{j=1}^{p} \beta^{s}_{i,j} \Delta lnS_{t-j} + \sum_{j=1}^{p} \gamma^{s}_{i,j} lnS^{f}_{t-j} + \sum_{j=1}^{p} \delta^{s}_{i,j} lnS^{o}_{t-j} + \varepsilon^{s}_{t}$$

$$\Delta lnS^{f}_t = \alpha^{f}_{c,i} Dev^{c}_{t-1} + \alpha^{f}_{r,i} Dev^{r}_{t-1} + \sum_{j=1}^{p} \beta^{f}_{i,j} \Delta lnS_{t-j} + \sum_{j=1}^{p} \gamma^{f}_{i,j} lnS^{f}_{t-j} + \sum_{j=1}^{p} \delta^{f}_{i,j} lnS^{o}_{t-j} + \varepsilon^{f}_{t}$$

$$\Delta lnS^{o}_t = \alpha^{o}_{c,i} Dev^{c}_{t-1} + \alpha^{o}_{r,i} Dev^{r}_{t-1} + \sum_{j=1}^{p} \beta^{o}_{i,j} \Delta lnS_{t-j} + \sum_{j=1}^{p} \gamma^{o}_{i,j} lnS^{f}_{t-j} + \sum_{j=1}^{p} \delta^{o}_{i,j} lnS^{o}_{t-j} + \varepsilon^{o}_{t}$$

Panel A, Panel B, and Panel C show the estimated coefficients and their *t*-statistics in regime 1 ($Dev^{r}_{t-1} \leq -0.346$), regime 2 ($-0.346 < Dev^{r}_{t-1} \leq 0.282$), and regime 3 ($0.282 < Dev^{r}_{t-1}$), respectively. The sample period is January 03, 2005 to March 10, 2011. ***, **, and * denote statistical significance at the 1%, 5%, and 10% significance levels, respectively.

Table 8
Short-run causality test results

	Regime 1		Regime 2		Regime 3	
	Wald Stat.	*p*-value	Wald Stat.	*p*-value	Wald Stat.	*p*-value
Stocks → Futures	2.19**	0.0408	2.09*	0.0513	13.54***	0.0000
Stocks → Options	4.15***	0.0004	1.06	0.3821	30.19***	0.0000
Futures → Stocks	162.99***	0.0000	75.74***	0.0000	84.57***	0.0000
Futures → Options	377.57***	0.0000	33.52***	0.0000	14.24***	0.0000
Options → Stocks	8.88***	0.0000	5.53**	0.0000	42.67***	0.0000
Options → Futures	1.08	0.3744	24.68***	0.0000	21.15***	0.0000

This table presents the results of the short-run causality tests for regime 1 ($Dev_{t-1}^{r} \leq -0.346$), regime 2 ($-0.346 < Dev_{t-1}^{r} \leq 0.282$), and regime 3 ($0.282 < Dev_{t-1}^{r}$). The null hypothesis for each test indicates that index or implied index in one market (stocks, futures, options) does not Granger-cause the index or the implied index in the other markets. We report the Wald statistics (Wald Stat.) of the causality test and their *p*-values. ***, **, and * represent statistical significance at the 1%, 5%, and 10% significance levels, respectively.

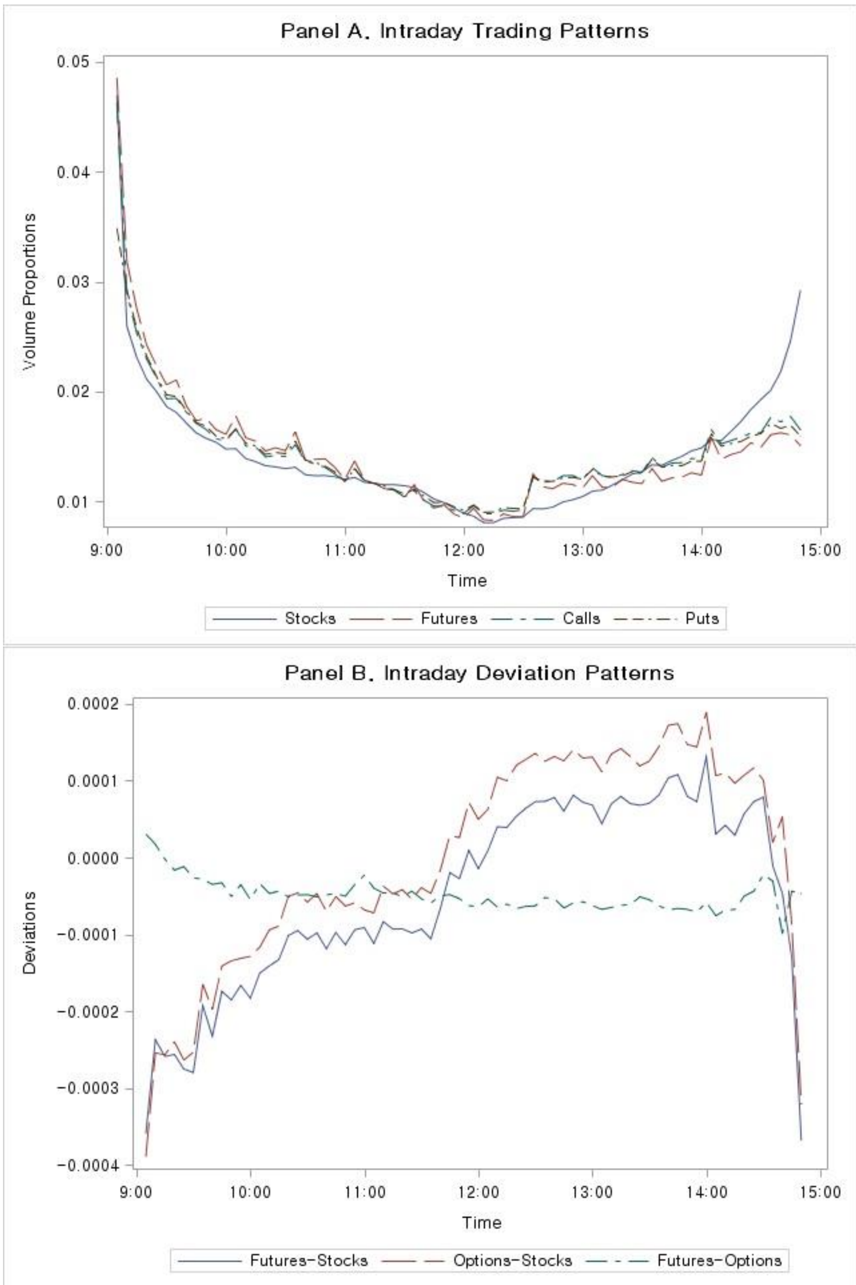

Fig. 1. Intraday trading and deviation patterns.

This figure shows the intraday trading volume and deviation patterns. The x-axis denotes intraday trading time from 9:00 a.m. to 2:50 p.m. Panel A shows the average trading volume proportions across the sample days. The solid line, the dashed line, the dash-dotted line, and the double dash-dotted line respectively represent the trading volume proportions of stocks, futures, call options, and put options. Panel B illustrates the average deviations across the sample days. The solid line, the dashed line, and the dash-dotted line respectively denote the deviations between the futures and stock markets, the options and stock markets, and the futures and options markets.

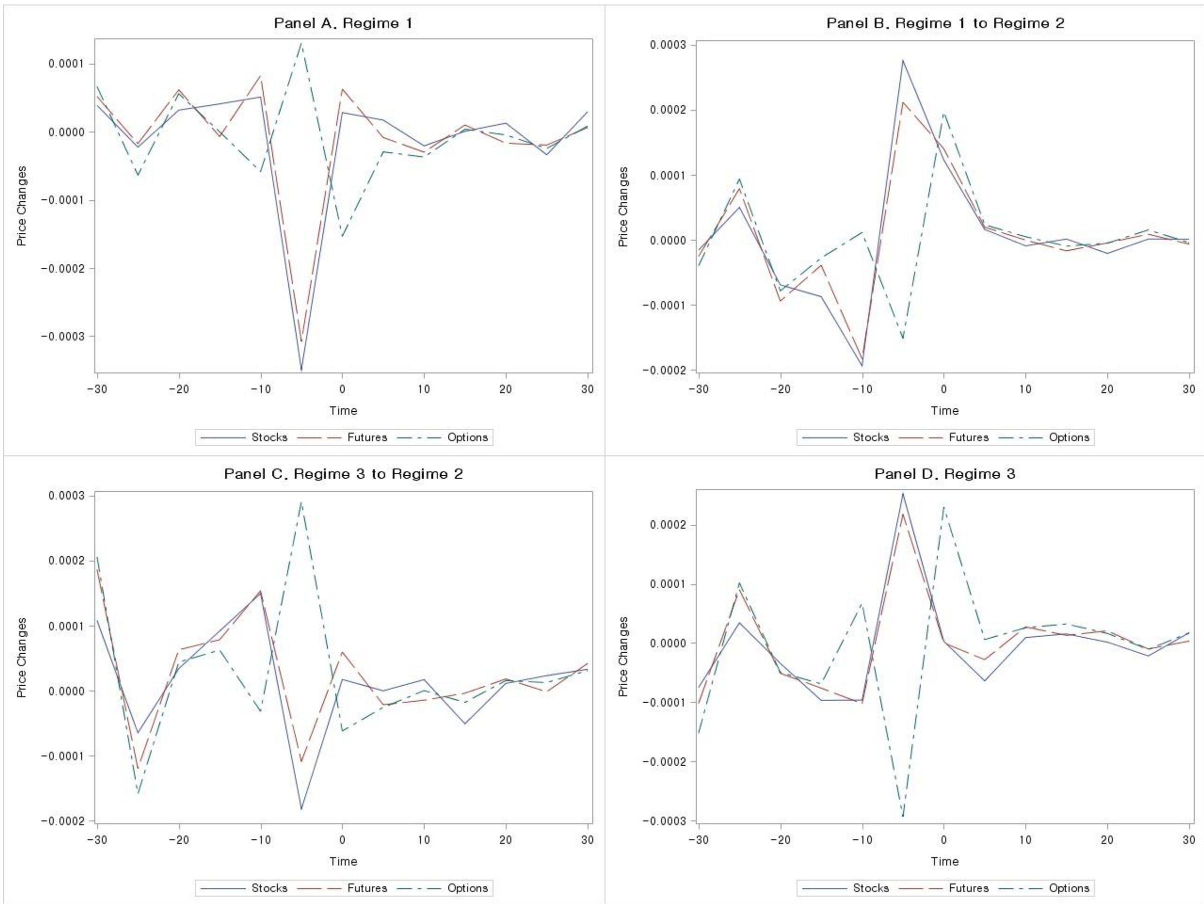

Fig. 2. The patterns of index changes around regime switches.

This figure shows the average index changes around regime switches across the sample days. The relative deviation, Dev_{t-1}^{r}, is smaller than or equal to –0.346 in regime 1, larger than –0.346 and smaller than or equal to 0.282 in regime 2, and larger than 0.282 in regime 3. The time window, which is presented on the horizontal axis, ranges from 30-minutes-before to 30-minutes-after the regime switch. The solid line, the dashed line, and the dash-dotted line respectively indicate the average index changes in the stock market, the futures market, and the options market. Panel A, Panel B, Panel C, and Panel D respectively illustrate price changes associated with regime switches from regime 2 or regime 3 to regime 1, from regime 1 to regime 2, from regime 3 to regime 2, and from regime 1 or regime 2 to regime 3.