The role of dynamic and static volatility interruption: evidence from the Korean stock markets

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Abstract

We conduct a comprehensive analysis on the sequential introductions of dynamic and static volatility interruption (VI) in the Korean stock markets. The Korea Exchange introduced VIs to improve price formation, and to limit damage to investors from brief periods of abnormal volatility, for individual stocks. We find that dynamic VI is effective in price stabilization discovery, while the effect of static VI is limited. The static VI functions similarly to the pre-existing price-limit system; this accounts for its limited incremental benefit.

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1. Introduction

Volatility interruption (VI) is a sophisticated microstructure mechanism designed to provide cooling-off periods and effective price discovery during brief periods of abnormal volatility for individual stocks. Generally, VI consists of two components: dynamic and static. Dynamic VI is invoked when a price fluctuation due to a single order exceeds a predetermined threshold range, e.g., ±2~6% in the Korea Exchange (KRX). Static VI is activated when the cumulative price fluctuation due to multiple orders and transactions exceeds a predetermined threshold range, e.g., ±10%. If the potential execution price exceeds either the dynamic or static threshold range, all transactions for the individual stock are stopped for a predetermined short period of time, e.g., 2~5 minutes, and trading resumes with a call auction that includes a random-end (RE) trading mechanism.[1]

Since its early days, the KRX has used a price-limit system, limiting price movements for the day to a specified percentage (e.g., ±15% from December 7, 1998 to June 14, 2015). On September 1, 2014, the KRX adopted only the dynamic component of VI, while leaving the price limit unchanged. Then, on June 15, 2015, the exchange added the static component of VI and simultaneously expanded the price limit to ±30%. As the result, the KRX has not only VIs, but also a price-limit system.[2] The KRX documents state that the purpose of VIs is to improve price formation, and to limit damage to investors from brief periods of abnormal volatility, for individual stocks. In this paper, we investigate the separate contributions of the two components of VI to price stabilization and price discovery. In addition, we study the separate contributions of the newly-introduced VIs and the extant price-limit system.

[Figure 1 here]

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[1] An RE trading mechanism is an integral part of a call auction mechanism. The ending time of the call auction is not fixed, but extended under certain circumstances for a brief randomly-chosen span of time less than or equal to a 'maximum duration' such as 30 seconds or one minute. Brugler and Linton (2014) state that the London Stock Exchange (LSE) introduced a RE mechanism "to remove the incentive to enter erroneous orders that would unduly affect price formation towards the end of the auction." We believe they meant "manipulative" or "spoofing" orders, rather than "erroneous" orders; it is hard to see how a random end could correct errors, but easy to see how it discourages manipulative orders.

[2] Generally, VIs are considered as implicit dynamic price-limit systems, compared to the explicit price-limit systems.

To implement these research objectives, we examine the effects of two events, the sequential introductions of dynamic VI and static VI. We focus on 45 trading days before and after each event and investigate the effects of the events, utilizing four different approaches. First, we analyze for the two events the descriptive statistics on dynamic and static VI occurrences and their relationships to firm characteristics. This preliminary analysis shows conditions under which VI is more likely to be invoked. Second, we examine the price stabilization effects of VIs using a binomial distribution analysis of two consecutive price changes; if dynamic (static) VI effectively stabilizes the price, then two price changes, the one between the last execution (last call auction) price and the potential execution price and the other one between the potential execution price and the call auction price, will show a reversal.[3] Third, we evaluate the price-discovery effect using two-step regressions. Fourth, using panel-logit regression analysis, we examine the relation between the occurrences of VI and those of the price-limit hit. Static VI and the price-limit system have similar functionalities. Hence, our analysis focuses on whether the VI occurrences have an effect on the price-limit hits.

In this paper, we analyze 1,791 stocks in 2014 and 1,842 in 2015, which are listed on KOSPI and KOSDAQ markets in the KRX. To be more specific, there are 1,676 common stocks in 2014 and 1,685 in 2015 and the rest are preferred stocks.

The following are our empirical results. First, both dynamic and static VIs are invoked more often in small, low-priced, and highly volatile stocks. Second, we find that the contribution of dynamic VI to price stabilization is very significant, while that of static VI appears to be ineffective. Third, we find that the contribution of dynamic VI to price discovery is substantially larger than that of static VI. Fourth, we find that static VI and the price-limit system are triggered by the same kind of circumstances.

Since the Brady Report (1988), academics have used the terminology, circuit breakers, in a broad sense, encompassing a variety of individual-stock trading halts and price-limit systems in addition to market-wide trading halts.[4] Here, individual trading halts consist of rule-based trading halts, e.g. VIs, as well as discretionary trading halts, e.g., voluntary trading halts occurring when an individual firm requests that trading be suspended before the release of material

[3] In other words, reversal in these two price changes is an indication of stabilization.
[4] By contrast, exchanges and practitioners use the term, circuit breakers, only for market-wide trading halts.

information, or the decision of an exchange to suspend trading in a stock which exhibits extreme order imbalances. Except for market-wide trading halts, all of these circuit breakers—discretionary trading halts, VIs, and price-limit systems—apply to individual stocks. Recently, algorithmic and high-frequency trading has grown to constitute a high proportion of transactions on global stock markets, and liquidity can evaporate quickly as a result (see The Government Office for Science, 2012). As a consequence, VIs have become a very important tool for price stabilization and investor protection. Since the 2007 implementation of the Markets in Financial Instruments Directive (MiFID) in Europe and the 2010 Flash Crash in the U.S., VIs and their variants have been introduced or have substantially replaced pre-existing price-limit system for individual stocks in global stock exchanges. A good example is the U.S., which introduced Limit Up/Limit Down (LULD),[5] a simpler version of the VIs, after the Flash Crash.

Most of the related academic literature, thus far, has focused on market-wide circuit breakers, discretionary trading halts, and price-limit systems, while there has been scant study of VIs.[6] As far as we know, there are only three papers analyzing VIs, and their results are rather mixed. First, Abad and Pascual (2010) examine the static VI on the Spanish Stock Exchange (SSE) SIBE platform

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[5] The LULD applies a rolling price limits to individual stocks, using price bands (5 or 10%) calculated over the previous five minutes trading.

[6] Broadly-defined circuit breakers theoretically lead to the "cooling-off effect" such as "mitigation of information asymmetry (Spiegel and Subrahmanyam, 2000) and reduction in the risk of a market order being executed at an unfavorable price, i.e., 'transactional risk' (Greenwald and Stein, 1991; Kodres and O'Brien, 1994); reduction of counter-party risk in derivatives markets and for leveraged investors (Chowdhry and Nanda, 1998; Brennan, 1986); delay of price discovery (Fama, 1989) and the magnet effect whereby price limits become self-fulling (Subrahmayam, 1994); limitations to the gains from market manipulation (Kim and Park, 2010) and the associated costs of monitoring market manipulation (Deb, Kalev, and Marisetty, 2010); and reduction of volatility and price deviations from fundamentals driven by noise traders (Westerhoff, 2003)" (see Brugler and Linton, 2014). Examples of empirical findings are as follows. For market-wide circuit breakers, Goldstein and Kavajecz (2004) report that traders display behavior consistent with the magnet effect and curtail activity during the market-wide closure. For news-specific, i.e., discretionary, trading halts, Jiang, McInish, and Upson (2009) show that, during the halt period, explicit and implicit trading costs, and trading activity increase in informationally related stocks, which consistent with Spiegel and Subrahmanyam's (2000) theoretical prediction. For price-limit systems, many studies document negative effects caused by price limits such as delayed price discovery, volatility spillover, delayed trading, and the magnet effect (e.g., Kim and Rhee, 1997; Cho, Russell, Tiao, and Tsay, 2003 among many others). Comparing discretionary trading halts with price-limit systems in the Spanish Stock Exchange (SSE), Kim, Yagüe, and Yang (2008) support the hypothesis that "[discretionary] trading halts enable policymakers to bring more information into the system at their discretion, whereas price limits depend solely on the size of the price movement," which is consistent with Subrahmayam (1995).

from June, 2001 to December, 2003. They report that the volatility and trading activity return to normal conditions in 90 minutes after the resumption of post-event trading, and that the adverse-selection cost is largest when the VI is invoked, but then resolves in 30 minutes. More interestingly, they find price continuation during the call auction period and price reversal after the post-event trading. These results imply that in the SSE, the static VI makes the stock price more volatile rather than more stable. Zimmermann (2013) study the price stabilization and discovery effects of VIs on Deutsche Börse (DB) Xetra platform between January 2009 and January 2012. He does not distinguish between dynamic and static VI, but includes the RE session induced by a VI occurrence in his test window and utilizes Xetra midday auctions (13:00 to 13:02 for constituent stocks of DAX 30 index) as a control group.[7] According to his results, VIs play a major role in shaping post-VI occurrence market quality, resolving 36% of the price uncertainty on average. Third, Brugler and Linton (2014) investigate static VI on the London Stock Exchange (LSE) from July, 2011 to August, 2011. They analyze the changes in trading volume and volatility during the trading suspension period to evaluate the effectiveness of static VI, and document that the economic effects of static VI vary depending on the market state. Specifically, they report that static VI can be an effective tool for promoting market-wide stability in falling markets.

This paper makes the following contributions to the existing literature. Above all, the sequential introductions of dynamic and static VIs to the Korean stock markets allow us to separate the effects of these two components of VIs and compare their effectiveness. Moreover, the pre-existing price-limit system on the Korean stock markets allows us separate the effects of price-limit systems and VIs. Next, the sequential introductions of dynamic and static VIs allows us to clearly measure the difference in market state with dynamic VI versus no VI, and with dynamic and static VI versus only dynamic VI. Thus, we avoid one of the main pitfalls of the circuit-breaker literature, the need to control for an artificial counterfactual that well describes what the status of the market would have been if a circuit breaker had not been triggered.

The remainder of the paper is organized as follows. Section 2 briefly describes the VIs in the Korean stock markets. Section 3 discusses the sample period and the data. Section 4 provides the results on the distribution of static and dynamic VIs and their relations with firm characteristics.

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[7] "Within the Xetra market system, midday auctions, likewise open and close auctions, show high similarities to the volatility interruption mechanism concerning the auction duration as well as general submission, cancellation and modification possibilities" (see Zimmermann, 2013).

Sections 5 and 6 present the empirical results on price stabilization and price discovery, respectively. Section 7 examines the relationship between the occurrences of VI and those of price-limit hits. We conclude the paper in Section 8.

2. Volatility Interruptions in the Korean Stock Markets

The purpose of dynamic VI is to alleviate the temporary volatility caused by a sudden imbalance of supply and demand resulting from a single order. In Korea, dynamic VI is invoked when the difference between a stock's most recent execution price and potential execution price exceeds a specified price range (±2~6% of the most recent price). The thresholds for invoking dynamic VI for constituent stocks in the KOSPI 200 index are 2% (closing call auction), 3% (continuous trading); and 4% (closing call auction), 6% (continuous trading) for all other KOSPI- and KOSDAQ-listed stocks. Dynamic VI is effective during the continuous trading session, closing call auction and after-hours trading, but not during the opening call auction.

The purpose of static VI is to mitigate cumulative price movement during a trading day resulting from one or more orders. In Korea, static VI is triggered when the difference between the price at the previous call auction and the potential execution price exceeds ±10%, for all stocks on the KOSPI and KOSDAQ markets. Static VI is effective during the opening and closing call auction and continuous trading session, but not during after-hours trading.[8]

When a dynamic or static VI occurs during a continuous trading session, all transactions in the stock cease and a call auction is triggered, with a random end between 2 minutes and 2 minutes 30 seconds; at the random end, the buy and sell orders are crossed and executed, and the continuous trading session resumes. When a dynamic or static VI occurs during a call auction, the call auction period is extended by a random length of time between 0 and 30 seconds.[9]

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[8] After-hours trading consists of periodic call auctions. VIs are not applied during market-wide circuit breakers or intraday call auctions after a discretionary trading suspension. For penny stocks (stocks priced less than 1,000 KRW), the VI threshold is three ticks (3 KRW), rather than a percentage.

[9] At the introduction of dynamic VI on September 1, 2014, the ending time of the call auction period was fixed rather than random. Beginning with the introduction of static VI on June 15, 2015, RE was applied to the call auction periods arising from both dynamic and static VI (see Figure 1).

The VIs are applicable to products including common stocks, depositary receipts (DRs), beneficiary certificates, and exchange-traded funds (ETFs), but do not apply to products scheduled to be delisted or designated as temporarily overheated.

The introduction of VIs on the KRX differed significantly from that in European countries. The KRX sequentially adopted VIs on top of the pre-existing price-limit system. In contrast, the European systems generally do not utilize price limits, and generally introduced dynamic and static VI simultaneously. The sequential introduction in Korea allows us to separate the effects of dynamic and static VI, as well as the effects of static VI and price-limit systems.

3. Sample Period and Data

In this paper, the overall analysis is based on the two events (the sequential introductions of dynamic and static VIs). Thus, it is very important to control for other possible effects and avoid exogenous shocks when we determine the sample period for our event study. Dynamic VI was introduced on September 1, 2014 while static VI was introduced on June 15 2015. To choose appropriate sample periods for our analyses, we first examine the market movement around these events using the representative market index, the KOSPI 200 index, and the market volatility index known as the V-KOSPI 200 index.

[Figure 2 here]

In Figure 2, Panels A and B show the time-series of the KOSPI 200 index and the V-KOSPI 200 index from January, 2014 to January, 2016, respectively. There were a large drop in the KOSPI 200 index and an abrupt large hike of the V-KOSPI 200 index in the final days of August 2015. The turmoil on the Shanghai Stock Exchange in late August 2015 and the "mini Flash Crash" (related to the LULD (Limit Up/Limit Down) rule) on the New York Stock Exchange (NYSE) on August 24, 2015 may have contributed to the increases in the V-KOSPI 200 index around the end of August, 2015.

To avoid the effects of these exogenous shocks, we chose to end the sample period (hereafter, "post-event period in 2015") for the introduction of static VI on August 21, 2015. Thus, it runs from June 15, 2015 to August 21, 2015, a total of 45 trading days. Accordingly, we chose the "pre-event period in 2015" to include 45 trading days, from April 8, 2015 to June 12, 2015. For consistency, we chose to include 45 trading days before and after the 2014 dynamic VI event in our sample period. Accordingly, the period before the 2014 event (hereafter, "pre-event period in 2014") is from June 27, 2014 to August 29, 2014 and the period after the 2014 event (hereafter, "post-event period in 2014") is from September 1, 2014 to November 7, 2014.

We included all common and preferred stocks[10] listed on the KOSPI and KOSDAQ markets, but excluded (1) DRs, special purpose acquisition companies (SPACs), and real estate investment trusts (REITs), (2) newly-listed and delisted stocks, and instruments that changed listings (e.g. from KOSDAQ to KOSPI) during the sample periods, (3) stocks which traded less than 40 days before or after the event, and (4) ETFs. Consequently, our sample data includes 1,791 securities in 2014 and 1,842 in 2015. More specifically, among them, there are 1,676 common stocks in 2014 and 1,685 in 2015. Others are preferred stocks.

4. Descriptive Statistics on VI occurrences

4.1. Distribution of dynamic and static VI occurrences

In this section, as our preliminary analysis, we investigate the distribution of dynamic and static VI occurrences and their relationships to firm characteristics during the sample period. We examine them in each of three subsamples (post-2014, pre-2015 and post-2015).[11] The results yield implications about the change in the market in response to the sequential introductions of VIs.

[Table 1 here]

Table 1 provides the descriptive statistics on dynamic and static VI occurrences during the sample period. As shown in Panel A, dynamic VI occurred in more stocks in both pre- and post-event periods in 2015 than in 2014. Considering the number of VI occurrences in Panels B and C, however, the pattern is not uniform. Meanwhile, Panels A to C show that dynamic VI was activated significantly more often in the 2015 post-event period than in the 2015 pre-event period

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[10] Preferred stock (non-voting stock), domestically and internationally, differs from its corresponding common stock (voting stock) not only in pricing, but also in determinants of its value (see, e.g., Beiner and Gibson (1999) and Nenova (2003) among many others). For this reason, researchers do not generally include preferred stock unless their focus on preferred stock *per se*. In Korea and many other non-U.S. markets, preferred stock is substantially more volatile than common stock. In this paper, we include preferred stock because VI is specifically designed to curb a large abrupt price movement over a brief time span, which is characteristic of volatile securities. After showing this character of preferred stock in the descriptive statistics, our main analysis focuses on common stock.

[11] Prior to the 2014 event, there were of course no VI occurrences to report.

and this phenomenon is particularly prominent in preferred stocks.

Panels A to C provide evidence that static VIs, newly implemented over the post-event period in 2015, occurred more frequently to both common and preferred stocks than dynamic VIs over the corresponding period. The number of stocks with dynamic VI occurrences is 639, about half the number with static VI occurrences, 1,212. Both the total number of the static VI occurrences and that of VI's per stock are 4.11 times, respectively, larger than those of the dynamic VI occurrences. Both dynamic and static VIs occurred more frequently in preferred stocks than in common stocks.

Panel D of Table 1 presents the distribution of VI occurrences across prices in each subsample period. Regardless of subsample periods, dynamic and static VIs show similar distributional patterns across prices. More specifically, most VIs occur in stocks whose prices are between 1,000 KRW[12] and 50,000 KRW and particularly to stocks with relatively lower prices between 1,000 KRW and 5,000 KRW.[13] The number of the VI occurrences is substantially lower for stocks with extremely low prices, lower than 1,000 KRW, and stocks with prices higher than 50,000 KRW.

The distribution of dynamic VI becomes somewhat flatter after the introduction of static VI. In the 2015 pre-event period before the introduction of static VI, more than 50% of dynamic VI occurred within the price range 1,000 KRW to 5,000 KRW. In the 2015 post-event period, however, the number of dynamic VIs in this price range decreased somewhat while that in all other price ranges consistently increased. Since the highest number of static VI occurrences is observed from the price range 1,000 KRW to 5,000 KRW, this distributional change in dynamic VI occurrences in the 2015 post-event period can be attributed to the introduction of static VI.

4.2. The relationship of VI occurrences with firm characteristics

To understand the relationship of VI occurrences with firm characteristics, we analyze their correlations. For firm characteristics, we employ trading volume in shares (*volume_share*), trading volume in KRW (*volume_value*), firm size measured by market capitalization (*mkt_cap*), and the closing price (*prc*). We also use volatility measured by the standard deviation of daily returns

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[12] At the end of 2014, the KRW/USD rate was 1,088.50 and the exchange rate did not change dramatically during our sample period. According to the exchange rate at the end of 2014, 1,000 KRW is about 0.92 USD.

[13] This is for common stocks. For preferred stocks, VIs occur in stocks with relatively higher prices between 10,000 KRW and 50,000 KRW.

(*std_dev*) and the daily highest and lowest price (*intra_vol*).[14]

[Table 2 here]

Table 2 shows Kendall correlation among firm characteristics and the number of VI occurrences in the 2014 post-event period (Panel A), the 2015 pre-event period (Panel B), and the 2015 post-event period (Panel C). For comparison, we also report the Kendall correlation among firm characteristics in the 2014 pre-event period in the Appendix (Table A1), but the overall results suggest that there is not much change in their relationships. In other words, the introductions of dynamic and static VIs seem to cause no significant changes in the relationships among firm characteristics.[15]

In Table 2, with regard to dynamic VI, the absolute values of correlations of its occurrences with trading volume, firm size, and price generally decrease from the 2014 post-event period to the 2015 post-event period. The size of most of these decreases are small, but the correlation with the price drops notably in the 2015 post-event period when static VI was introduced. For example, the correlation between price and dynamic VI occurrences in the 2015 pre-event period is -0.1060 and it is statistically significant, but it becomes -0.0169 and insignificant in the 2015 post-event period. These results seem to be consistent with the flatter distribution of dynamic VI occurrences during the 2015 post-event period in Panel D of Table 1. On the other hand, the correlation between volatility (measured by *intra_vol*) and dynamic VI occurrences increases from 0.0785 in the 2014 pre-event period to 0.2346 in the 2015 post-event period.

Both dynamic and static VI occurrences are negatively correlated with firm size and price, and positively correlated with volatility. However, the correlation of static VI occurrences with volatility is much larger than that of dynamic VI occurrences with volatility. More interestingly, static VI occurrences are positively correlated with liquidity variables, trading volume in shares and KRW, while dynamic VI occurrences are negatively correlated. The negative relation of dynamic VI occurrences with liquidity variables is rather intuitive: the prices of illiquid stocks tend to fluctuate more, and thus dynamic VI occurs more frequently to those stocks. Meanwhile, the positive relation of static VI occurrences seems to be related to the difference of opinion

[14] The measurement of *intra_vol* is as follows: (daily highest price − daily lowest price) / {(daily highest price + daily lowest price) / 2}.

[15] All the corresponding results from Pearson correlation are qualitatively similar, and available from the authors on request.

among traders, since static VI is associated with cumulative price changes. Trading volume can be a proxy for differing opinion among traders (see Diether et al., 2002; Eom et al, 2017). From this point of view, large trading volume caused by traders with differing opinions may contribute to the occurrence of static VI.

5. Price-Stabilization Effect

Price stabilization was one of KRX's key goals in introducing VIs. To evaluate the price-stabilization effect of VIs, we use the methodology of Eom and Park (2016). According to their binomial distribution analysis, if dynamic (static) VI effectively stabilizes the price, then two consecutive price changes, the one between the last execution (last call auction) price and the potential execution price and the other one between the potential execution price and the call auction price, will tend to show a reversal. Put more specifically, dynamic (static) VI is invoked when the difference between the last execution (last call auction) price and the potential execution price exceeds the pre-determined level. It is based on the assumption that the potential execution price reflects a temporary imbalance of supply and demand.[16] Consequently, if dynamic VI contributes to price stabilization, then the call auction price should become larger (smaller) than the potential execution price if the potential execution price was smaller (larger) than the last execution price. For static VI, the same statement holds provided that the last execution price is replaced by the last call auction price. In other words, reversal in these two price differences, the one between the last call auction price and the potential execution price and the other one between the potential execution price and the call auction price, is an indication of price stabilization.

To test this, we take two steps. First, we compare the number of reversals in price changes (column B in Table 3), which indicate price stabilization, with the number of continuations in price changes (column C in Table 3). If the potential execution price accurately reflects information available to the market, then the probability of reversal should be equal to the probability of continuation.[17] If the proportion of reversals significantly exceeds 0.5, then it

[16] If the last execution (last call auction) price fails to properly reflect the market demand and the potential price is an accurate one, then the transaction should be completed at the potential price, in which the VIs are not required at all.

[17] A trinomial analysis could be considered. In this case, however, an additional assumption would be needed; no new information that might affect the price arrived during the VI session, for which "we cannot separate the effects from the [VI] session and the informational arrival, and in particular cannot assign probabilities to the three possibilities (continuation, reversal, no change). However, there is a natural distribution, 50/50, over two possibilities (continuation

implies that the VIs effectively stabilize the price. We find that the proportion of reversals is indeed significantly greater than 0.5 for dynamic VI, and not for static VI for common stocks during the opening and closing all auctions (column E in Table 3).

[Table 3 here]

Next, we calculate percentage measures of price stabilization and continuation. Each of these is calculated by averaging |(call auction price − potential execution price) × 100 / (potential execution price − last execution or last call auction price)| over the set of reversals and continuations, respectively (columns F and G of Table 3). We also calculate the net price-stabilization effect by averaging −(call auction price − potential execution price) × 100 / (potential execution price − last execution or last call auction price) over the combined set of reversals and continuations (column H of Table 3).

The net price-stabilization effect of dynamic VI is substantially higher in the three subperiods during the continuous session (30.93%; 39.21%; 39.73%) than in the closing call auction (21.91%; 23.46%; 12.65%); the results in the pre- and post-event periods of 2015 are similar (39.21%; 39.73%), indicating that the introductions of static VI and RE, and the expansion of the price-limit system had little effect on the net price-stabilization effect of dynamic VI (Panels A-C of Table 3) during the continuous session, and reduced somewhat the effect during the closing call auction (Panel C of Table 3).[18],[19]

Static VI seems to have a negligible net price-stabilization effect during the continuous session, and a modest effect during the closing call auction (Panel D of Table 3). Even if we consider the effects within specific trading sessions of the day, opening call auction, continuous session, or closing call auction, the stabilization effects of static VI are much weaker than those of dynamic VI. More specifically, the effects during the opening call auction and the continuous

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and reversal), allowing us to use the binomial distribution for the price stabilization effect of [VI] trading mechanism" (see Eom and Park, 2016).

[18] The net price-stabilization effect of dynamic VI during the continuous session is higher in the pre-event period in 2015 than in the post-event period of 2014; since there was no change in the trading rules between those periods, this suggests that the increase reflects some change in market conditions rather than a chance in trading rules.

[19] Over the post-event period in 2015, dynamic VI was modified by the addition of an RE mechanism (see Figure 1). To address potential offsetting effects, we recalculated the price stabilization and continuation, and net price-stabilization effect of dynamic VI using the order book, assuming that the call auction price would be the price exactly 2 minutes after the trigger of dynamic VI. The results are not different from those in Table 3; e.g., for common stock, net price-stabilization effect is 40.26% and 14.47% for continuous session and closing auction, respectively. This indicates that the addition of the RE mechanism to dynamic VI had a negligible effect on the price stabilization and continuation, and net price-stabilization effect. The detailed results are available from the authors on request.

session are less than 3%, indicating that static VI does not provide the intended cooling-off effect. We argue in Section 7 that static VI plays a similar role to the price-limit system.

6. Price-Discovery Effect

The other key goal of the KRX's introduction of VI was to improve price discovery. Following the previous studies (e.g., Chakrabarty et al., 2011; Zimmermann, 2013), we examine price discovery utilizing Corwin and Lipson's (2000) methodology. Specifically, we estimate the following two-step regression model:

$$\text{Step 1: } ln\left(P_{i,post}/P_{i,pre}\right) = \alpha_1 + \beta_1 \times ln\left(P_{i,last}/P_{i,pre}\right) + e_i \quad (1)$$

$$\text{Step 2: } ln\left(P_{i,auction}/P_{i,last}\right) = \alpha_2 + \beta_2 \times e_i + \eta_i \quad (2)$$

where $P_{i,pre}$ ($P_{i,post}$) denotes the reference price before (after) the VI is invoked, which is measured by the mean of the mid-price of the best bid and ask quotes during the ten minutes before the VI is invoked (after the call auction is completed). $P_{i,last}$ and $P_{i,auction}$ denote the last execution price before the VI is invoked and the call auction price, respectively, and e_i and η_i are residuals of each regression model.

In this two-step regression analysis, if the price change over the ten minutes before the VI occurrence perfectly reflects the new equilibrium price over the ten minutes after the resulting call auction, then in the first step $\alpha_1 = 0$, $\beta_1 = 1$, and $R^2 = 1$. Thus, $\beta_1 < 1$ ($\beta_1 > 1$) implies that $P_{i,last}$ overshoots (undershoots) the short-term future equilibrium price and the degree of overshooting (undershooting) is more severe as the magnitude of β_1 deviates further from 1.[20] In the second step, β_2 shows the expected price discovery of the VI. If the VI perfectly resolves the price uncertainty, then $\alpha_2 = 0$, $\beta_2 = 1$, and $R^2 = 1$. For example, if β_2 is positive, then it indicates that VI decreases the price uncertainty, i.e., improves price discovery; moreover, the reduction in uncertainty is greater as β_2 becomes closer to 1. On the other hand, if β_2 is negative,

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[20] Put differently, "$\beta_1 > 1$ suggests that returns exhibit continuations from before to after [($P_{i,last}$)] and $\beta_1 < 1$ suggests that returns exhibit reversals. Barclay and Hendershott (2003) provide an alternative interpretation of the slope coefficient. They note that if [($P_{i,last}$)] is measured with error, the slope coefficient will be reduced. Thus, for $\beta_1 < 1$, the magnitude of the coefficient provides an estimate of the signal-to-noise ratio for [($P_{i,last}$)]" (see Chakravarty et al., 2011).

it indicates that VI results in a deterioration of price discovery. We perform this analysis for dynamic and static VIs separately.

[Table 4 here]

Panels A to C of Table 4 show that for dynamic VI, β_1 ranges from 0.4188 to 0.4890, which is positive, but substantially smaller than 1. It indicates that the price greatly overshoots during the ten minutes before dynamic VI. By contrast, β_2 is close to 1. Specifically, it is closest to 1 during the post-event period in 2014 as 0.9017, and 0.6810 during the pre-event period in 2015, and 0.8042 during the post-event period in 2015; all three numbers are significant at the 1% level. These results suggest that dynamic VI resolves a substantial part of price uncertainty. In other words, dynamic VI generates a notable effect in price discovery and price stabilization. Moreover, this beneficial effect is maintained even after the introduction of static VI, showing that both price-discovery and price-stabilization effects of dynamic VI were established at its introduction and were not substantially affected by the introduction of static VI.[21]

In Panel D of Table 5, β_i for i = 1 and 2 are all statistically significant, but their values differ from those for dynamic VI. For dynamic VI, we find that β_2 is much closer to 1 than β_1, but for static VI, β_1 shows the larger value (0.7468) and the R^2 for the first regression model (0.7202) is substantially larger than that for the second one (0.2999). These results indicate that the price change before static VI effectively predicts the short-term future equilibrium price; the price during the ten minutes before static VI overshoots much less than that before dynamic VI. This is an intuitive result; static VI is invoked by the cumulative price change, whereas dynamic VI is invoked by a single order that has a strong price impact. Hence, when dynamic VI is invoked, the price change immediately before its invocation is higher than that before static VI. More importantly, the low value of β_2 indicates that the contribution of static VI in resolving the price uncertainty, i.e., the price discovery is only 0.3787, which is much smaller than the contribution of dynamic VI (0.8042).

7. The Relationship of VIs with Price-Limit System

[21] These effects are not altered by the addition of an RE mechanism to dynamic VI. To address potential offsetting effects, we performed the same two-step regression analysis using the order book, assuming that the call auction price would be the price exactly 2 minutes after the trigger of dynamic VI. The results are not different from those in Table 4; β_1 and β_2 are 0.4520 and 0.7764 with 1% statistical significance, respectively. This indicates that the addition of the RE mechanism to dynamic VI had a negligible effect on the price discovery effect.

In this section, we focus on the post-event sample period in 2015, which is from June 15, 2015 to August 21, 2015, for two reasons. First, the definition of static VI is closely related to the price-limit system, since both rely on the cumulative change in price since the last previous call auction. Dynamic VI does not share this similarity with the price-limit system. Static VI was in force only in the 2015 post-event period in our sample period. Second, the price limit was doubled from ±15% to ±30% in the 2015 event, so we want to control for the effect of this change in order to clearly understand the economic function of static VI with respect to the price-limit system.

To examine the relationship between the occurrences of VI and price-limit hits, we divide the VI occurrences into two groups by the direction of the price change: increasing or decreasing VIs. We define the positive (negative) price change that invoked the VI as "increasing (decreasing) dynamic VI." In other words, when the dynamic VI is invoked with an increase (decrease) of the potential execution price, then we classify it as increasing (decreasing) dynamic VI. "Increasing (decreasing) static VI" is defined in the same way. We also classify price-limit hits into upper and lower price-limit hits.

We use a panel logit regression analysis to examine whether the occurrences of VIs affect the occurrences of price-limit hits. Specifically, we test whether the occurrences of VIs have an effect on the occurrences of price-limit hits using the following equation (3).

$$\Pr(y_{it} = 1) = F(\beta_0 + \beta_1 DVIUP_{it} + \beta_2 DVIDOWN_{it} + \beta_3 SVIUP_{it} + \beta_4 SVIDOWN_{it} + \beta_5 ln(Price_{it}) + \beta_6 Volatility_{it} + \beta_7 Turn_{it} + u_t + \alpha_i + e_{it}) \quad (3)$$

where y_{it} is a binary dependent variable having the value of 1 if the stock i on day t experiences a hit on either upper or lower price-limit, and 0 otherwise. $DVIUP_{it}$ ($DVIDOWN_{it}$) is the number of increasing (decreasing) dynamic VIs that the stock i experiences on day t. $SVIUP_{it}$ ($SVIDOWN_{it}$) is the number of increasing (decreasing) static VIs that the stock i experiences on day t. For control variables, we include the stock price ($ln(Price_{it})$), intraday volatility ($Volatility_{it}$),[22] and turnover ($Turn_{it}$). u_t and α_i capture the time- and fixed-effects, respectively. e_{it} is independently and identically distributed with zero mean and σ_e^2.

[22] $Volatility_{it}$ is computed by $(\text{High} - \text{Low}) \times 2/(\text{High} + \text{Low})$ where 'High' ('Low') indicates the highest (lowest) price on a given day.

We estimate equation (3) separately for the upper and lower price-limits and in each subperiod. Table 5 reports the results.

[Table 5 here]

In Table 5, the results for the upper price-limit hits show consistent patterns of coefficients in the pre-event (Panel A) and post-event (Panel B) periods in 2015. For dynamic VI, the occurrences of increasing dynamic VIs have positive effects on the occurrences of upper price-limit hits (0.2845 at the 10% significance in Panel A and 0.4091 at the 5% significance in Panel B), while the occurrences of decreasing dynamic VIs have negative but insignificant coefficients on the occurrences of upper price-limit hits. For static VI, the results in Panel B show that static VI has much larger and more significant impacts on the upper price-limit hits than dynamic VI. More specifically, the coefficients of upper price-limit hits on increasing and decreasing static VIs are 1.6515 (*t*-statistic = 13.69) and -1.4846 (*t*-statistic = -12.02), respectively, which are much larger and much more statistically significant. These results imply that the occurrences of increasing (decreasing) static VIs increase (decrease) the probability of the occurrences of upper price-limit hits by 0.4129 (0.3711).[23]

In case of the lower price-limit hits, for dynamic VI, the occurrences of dynamic VIs do not have a significant relation with the occurrences of lower price-limit hits in both pre- and post-event periods (Panels A and B). For static VI, the results in Panel B show that the coefficients of lower price-limit hits on increasing and decreasing static VIs are -1.9343 (*t*-statistic = -2.24) and 2.5384 (*t*-statistic = 2.79), respectively, which are statistically significant, and larger magnitudes on the lower price-limit hits than dynamic VI.

Altogether, the occurrences of both dynamic and static VIs are related to the occurrences of price-limit hits only for the same direction of movement: the occurrences of upper-limit hits are positively related to the occurrences of increasing dynamic or static VIs, while the occurrences of lower-limit hits are positively related to the occurrences of decreasing dynamic or static VIs. However, the magnitudes and statistical significances of static VI are much stronger than those of dynamic VI. This indicates that static VI and the price-limit system are triggered by the same

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[23] In a panel logit regression model, the marginal effect of each regressor is $\Lambda(x'\beta)[1-\Lambda(x'\beta)]\beta$, where Λ is the cumulative logistic distribution function. Since the mean of the logit distribution is zero, we set $x'\beta = 0$. Hence, $\Lambda(0)[1-\Lambda(0)] = 0.25$, and the marginal effect of each regressor is 0.25β. Substitute 0.25β for each β coefficient (see Greene (2000), page 817).

kind of circumstances.

Intraday volatility has a positive coefficient regardless of periods and price limits, except for the lower-price limit hits in the 2015 post-event period. The price shows a negative relation with the upper price-limit hits, but a positive and statically significant relation with the lower price-limit hits. Lastly, the turnover shows a significant relation with the upper price-limit hits, but it appears to be insignificantly related to the lower price-limit hits. This asymmetric relation can be attributed to the stylized fact that the trading volume in the Korean stock markets does not increase a lot when the price decreases (see Kim, Kim, and Doh, 1999).

8. Concluding Remarks

The KRX's sequential introductions of dynamic and static VIs were intended to improve price formation, and to limit damage to investors from brief periods of abnormal volatility, for individual stocks. In the Korean stock markets, the VI system was built on top of a pre-existing price-limit system that was intended to serve similar purposes.

The sequential introductions of dynamic and static VIs to the Korean stock markets allowed us to separate the effects of these two types of VIs and compare their effectiveness. Moreover, the pre-existing price-limit system on the Korean stock markets allowed us to separate the effects of price-limit systems and VIs.

We used intraday transaction data of 1,791 securities in 2014 and 1,842 in 2015. We found the following results. First, both VIs are invoked more often in small, low-priced, and highly volatile stocks. Second, dynamic VI significantly contributes to stabilizing stock prices while static VI does not. Third, in terms of the price discovery effect, the larger benefits arise from dynamic VI than from static VI. We also find that the limited effects of static VI come from its similar functionality to the existing price-limit system.

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Table 1. Descriptive statistics on VI occurrences

This table presents the descriptive statistics on dynamic and static VI occurrences during the sample period. In this table, the results for the pre-event (post-event) period in 2015, which is from April 8, 2015 to June 12, 2015 (June 15, 2015 to August 21, 2015), is denoted as '2015' and 'Pre' ('Post'). The results for the post-event period in 2014, which is from September 1, 2014 to November 7, 2014, is denoted as '2014' and 'Post'. The columns assigned as 'Dynamic' and 'Static' indicate the descriptive statistics on dynamic and static VI occurrences, respectively.

	2014	2015		
	Post	Pre	Post	
	Dynamic	Dynamic	Dynamic	Static
Panel A. Number of stocks with at least one VI occurrence				
Common	435	525	550	1,119
Preferred	68	74	89	93
Total	503	599	639	1,212
Panel B. Total number of VI occurrences				
Common	1,069	958	1,113	5,796
Preferred	384	410	898	2,475
Total	1,453	1,368	2,011	8,271
Panel C. Number of VI occurrences per stock				
Common	0.64	0.57	0.66	3.44
Preferred	3.34	3.60	7.88	21.71
Total	0.81	0.76	1.12	4.60

Panel D. Total number of VI occurrences based on the last execution price prior to the occurrence

	2014		2015					
	Post		Pre		Post			
Price	Dynamic		Dynamic		Dynamic		Static	
(Korean won, KRW)	Common	Preferred	Common	Preferred	Common	Preferred	Common	Preferred
<1,000	155	22	53	13	66	0	422	1
1,000≤ and <5,000	568	162	452	116	438	116	2,043	384
5,000≤ and <10,000	156	56	188	59	214	149	1,034	500
10,000≤ and <50,000	142	124	189	197	234	531	1,680	1,236
50,000≤ and <100,000	16	3	39	5	58	73	271	267
100,000≤	32	17	37	20	103	29	346	87

Table 2. Kendall correlation

This table shows Kendall correlation among firm characteristics and the number of VI occurrences in the post-event period in 2014 (Panel A), the pre-event period in 2015 (Panel B), and the post-event period in 2015 (Panel C), separately. *volume_share* (*volume_value*) indicates trading volume in shares (in KRW) and *mkt_cap* is market capitalization. *prc* is the closing price and for volatility measure, *std_dev* is the standard deviation of daily returns, and *intra_vol* is the intraday volatility measured by the daily highest and lowest price. *** denotes 1% statistical significance.

Panel A. Post-event in 2014

	volume_share	*volume_value*	*mkt_cap*	*prc*	*Volatility*	
					std_dev	*intra_vol*
Number of dynamic VI occurrences	-0.1837***	-0.2817***	-0.2854***	-0.1226***	0.1707***	0.0785***
volume_share	1.0000	0.5309***	0.1428***	-0.2354***	0.3457***	0.4212***
volume_value		1.0000	0.5157***	0.2335***	0.2076***	0.3137***
mkt_cap			1.0000	0.4845***	-0.1376***	-0.0449***
prc				1.0000	-0.1914***	-0.1320***
std_dev					1.0000	0.7277***

Panel B. Pre-event period in 2015

	volume_share	*volume_value*	*mkt_cap*	*prc*	*Volatility*	
					std_dev	*intra_vol*
Number of dynamic VI occurrences	-0.0820***	-0.1789***	-0.2604***	-0.1060***	0.2341***	0.1768***
volume_share	1.0000	0.4973***	0.1315***	-0.2631***	0.3126***	0.3477***
volume_value		1.0000	0.5290***	0.2394***	0.2166***	0.2861***
mkt_cap			1.0000	0.4707***	-0.1151***	-0.0553***
prc				1.0000	-0.1327***	-0.0873***
std_dev					1.0000	0.7646

Panel C. Post-event period in 2015

	Number of static VI occurrences	*volume_share*	*volume_value*	*mkt_cap*	*Prc*	*Volatility*	
						std_dev	*intra_vol*
Number of dynamic VI occurrences	0.3122***	-0.1113***	-0.1175***	-0.2361***	-0.0169	0.2946***	0.2346***
Number of static VI	1.0000	0.2325***	0.1834***	-0.1862***	-0.0676***	0.7330***	0.6979***

occurrences						
volume_share	1.0000	0.4861***	0.1146***	-0.2620***	0.2730***	0.3242***
volume_value		1.0000	0.4768***	0.2515***	0.2391***	0.3233***
mkt_cap			1.0000	0.4593***	-0.1441***	-0.0690***
prc				1.0000	-0.0554***	-0.0096
std_dev					1.0000	0.7674***

Table 3. Price-stabilization effect of VIs

This table describes the results from the binomial distribution analysis to evaluate the price-stabilization effect of VIs. Panels A to C present the results on dynamic VI during the post-event period in 2014, pre-event period in 2015, and post-event period in 2015, respectively, while Panel D presents the results on static VI during the post-event period in 2015. [a] denotes a percentage measure of reversals of price changes, and [b] denotes a percentage measure of continuations of price changes; both [a] and [b] are calculated by averaging |(call auction price - potential execution price)×100/(potential execution price – last execution or last call auction price)| over the set of reversals and continuations, respectively. [c] denotes a percentage measure of net price stabilization, which is calculated by averaging -(call auction price - potential execution price)×100/(potential execution price – last execution or last call auction price) over the combined set of reversals and continuations. *** denotes 1% statistical significance under the hypothesis that the probabilities of reversals and continuations of price changes are equal.

		No. of unchanged prices (A)	No. of cases where no transactions occurred during the VI call auction	No. of reversals of price changes (B)	No. of continuations of price changes (C)	Total no. of VI occurrences (D)	Stabilization ratio (%) (E)	Price stabilization effect (%)[a] (F)	Price continuation effect (%)[b] (G)	Net price stabilization effect (%)[c] (H)
Panel A. Dynamic VI: Post-event period in 2014										
Continuous session	Common	85	2	698	136	921	83.7***	44.33	36.35	31.18
	Preferred	60	5	230	54	349	81.0***	42.50	22.06	30.22
	Total	145	7	928	190	1,270	83.0***	43.88	32.29	30.93
Closing call auction	Common	66		65	17	148	79.3***	31.97	17.96	21.62
	Preferred	21		14		35	100.0***	23.64		23.64
	Total	87	0	79	17	183	82.3***	30.49	17.96	21.91
Total		232	7	1,007	207	1,453	82.9***	42.83	31.11	30.22
Panel B. Dynamic VI: Pre-event period in 2015										
Continuous session	Common	38	3	712	85	838	89.3***	53.49	43.36	43.16
	Preferred	60	4	257	65	386	79.8***	42.06	20.55	29.42
	Total	98	7	969	150	1,224	86.6***	50.46	33.47	39.21
Closing call auction	Common	44		67	9	120	88.2***	27.98	10.22	23.45
	Preferred	10		13	1	24	92.9***	26.30	13.33	23.47
	Total	54	0	80	10	144	88.9***	27.70	10.53	23.46
Total		152	7	1,049	160	1,368	86.8***	48.72	32.04	38.03

Panel C. Dynamic VI: Post-event period in 2015											
Continuous session	Common	61	6	819	110	996	88.2***	53.04	56.54	40.07
	Preferred	38	5	665	132	840	83.4***	53.37	31.42	39.33
	Total	99	11	1,484	242	1,836	86.0***	53.19	42.84	39.73
Closing call auction	Common	61		41	15	117	73.2***	26.25	17.73	14.47
	Preferred	14		30	14	58	68.2***	24.17	19.29	10.34
	Total	75	0	71	29	175	71.0***	25.37	18.48	12.65
Total		174	11	1,555	271	2,011	85.2***	51.92	40.23	38.24
Panel D. Static VI: Post-event period in 2015											
Opening call auction	Common	26		86	89	201	49.1	30.90	15.88	7.11
	Preferred	23		53	70	146	43.1	21.85	24.02	-4.25
	Total	49	0	139	159	347	46.6	27.45	19.46	2.42
Continuous session	Common	849	37	2,776	1,842	5,504	60.1***	11.03	11.94	1.87
	Preferred	247	16	1,231	810	2,304	60.3***	16.77	14.75	4.26
	Total	1,096	53	4,007	2,652	7,808	60.2***	12.80	12.80	2.60
Closing call auction	Common	45		26	20	91	56.5	16.21	7.30	5.99
	Preferred	10		13	2	25	86.7***	26.73	11.25	21.67
	Total	55	0	39	22	116	63.9***	19.72	7.66	9.84
Total		1,200	53	4,185	2,833	8,271	59.6***	13.35	13.13	2.66

Table 4. Price-discovery effect

This table provides the estimation results of the following two-step regressions, performed the analyses for dynamic and static VIs separately over the respective subperiods. * and *** denote the 10% and 1% statistical significances, respectively.

$$\text{Step 1: } ln(P_{i,post}/P_{i,pre}) = \alpha_1 + \beta_1 \times ln(P_{i,last}/P_{i,pre}) + e_i$$

$$\text{Step 2: } ln(P_{i,auction}/P_{i,last}) = \alpha_2 + \beta_2 \times e_i + \eta_i$$

where $P_{i,pre}$ ($P_{i,post}$) denotes the reference price before (after) the VI is invoked, which is measured by the mean of the mid-price of the best bid and ask quotes during the ten minutes before the VI is invoked (after the call auction is completed). $P_{i,last}$ and $P_{i,auction}$ denote the last execution price before the VI is invoked and the call auction price, respectively, and e_i and η_i are residuals of each regression model. *** denotes 1% statistical significance.

	α_i	β_i	$adj\ R^2$	No. of observations	Prob. > F
Panel A. Post-event period in 2014: Dynamic VI					
First-step	-0.0020* (-1.90)	0.4890*** (27.77)	0.5730	575	< 2.2e-16
Second-step	0.0042*** (3.70)	0.9017*** (19.88)	0.4073	575	< 2.2e-16
Panel B. Pre-event period in 2015: Dynamic VI					
First-step	0.0083*** (6.55)	0.4188*** (23.57)	0.4663	636	< 2.2e-16
Second-step	0.0131*** (10.53)	0.6810*** (14.73)	0.2539	636	< 2.2e-16
Panel C. Post-event period in 2015: Dynamic VI					
First-step	0.0069*** (7.57)	0.4480*** (30.93)	0.5223	875	< 2.2e-16
Second-step	0.0157*** (17.00)	0.8042*** (20.19)	0.3175	875	< 2.2e-16
Panel D. Post-event period in 2015: Static VI					
First-step	0. 0099*** (33.28)	0. 7468*** (124.94)	0.7202	6065	< 2.2e-16
Second-step	0.0025*** (15.21)	0.3787*** (50.98)	0.2999	6065	< 2.2e-16

Table 5. Panel logit analysis

This table provides estimation results for a panel logit regression model (Equation (3)). Panels A and B show the results for the pre- and post-event periods in 2015, respectively. Dependents variables are either upper or price-limit hits, which are the binary variable having the value of 1 if the stock i at time t experiences a hit on either upper or lower price-limit, or 0 otherwise. $DVIUP_{it}$ ($DVIDOWN_{it}$) is the number of increasing (decreasing) dynamic VIs that the stock i experiences at time t. $SVIUP_{it}$ ($SVIDOWN_{it}$) is the number of increasing (decreasing) static VIs that the stock i experiences at time t. For control variables, we include the stock price ($ln(Price_{it})$), intraday volatility ($Volatility_{it}$), and turnover ($Turn_{it}$). *, **, and *** denote 10%, 5%, and 1% statistical significance, respectively.

Variable	Upper price-limit hits		Lower price-limit hits	
	Coefficient	z	Coefficient	z
Panel A. Pre-event period in 2015				
$DVIUP$	0.2845*	1.67	0.1765	0.56
$DVIDOWN$	-0.0690	-0.50	-0.1025	-0.36
$ln(Price)$	-3.2042***	-15.46	3.8409***	10.17
$Volatility$	29.8301***	36.14	29.2505***	17.33
$Turn$	4.8411***	10.34	-0.0753	-0.14
Panel B. Post-event period in 2015				
$DVIUP$	0.4091**	2.32	-0.4365	-0.25
$DVIDOWN$	-0.1340	-0.91	4.6256**	2.57
$SVIUP$	1.6515***	13.69	-1.9343**	-2.24
$SVIDOWN$	-1.4846***	-12.02	2.5384***	2.79
$ln(Price)$	-2.5835***	-5.65	-0.6591	-0.44
$Volatility$	12.4968***	9.65	23.7837**	2.22
$Turn$	2.7873***	7.08	1.5809	0.51

Figure 1. Time line in the KRX

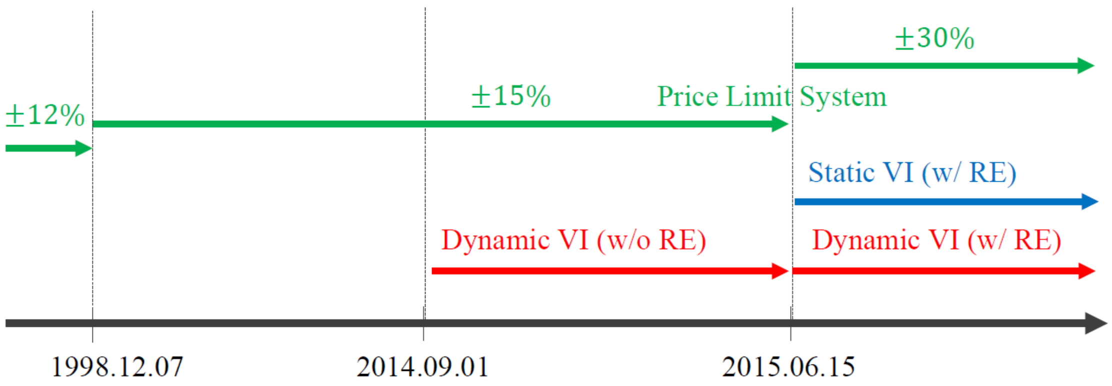
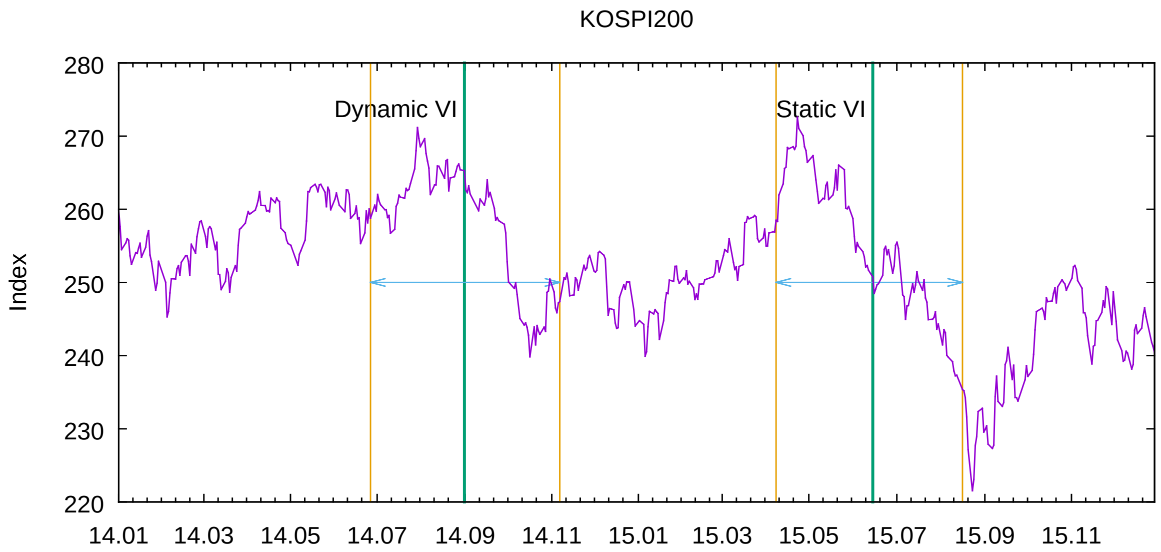
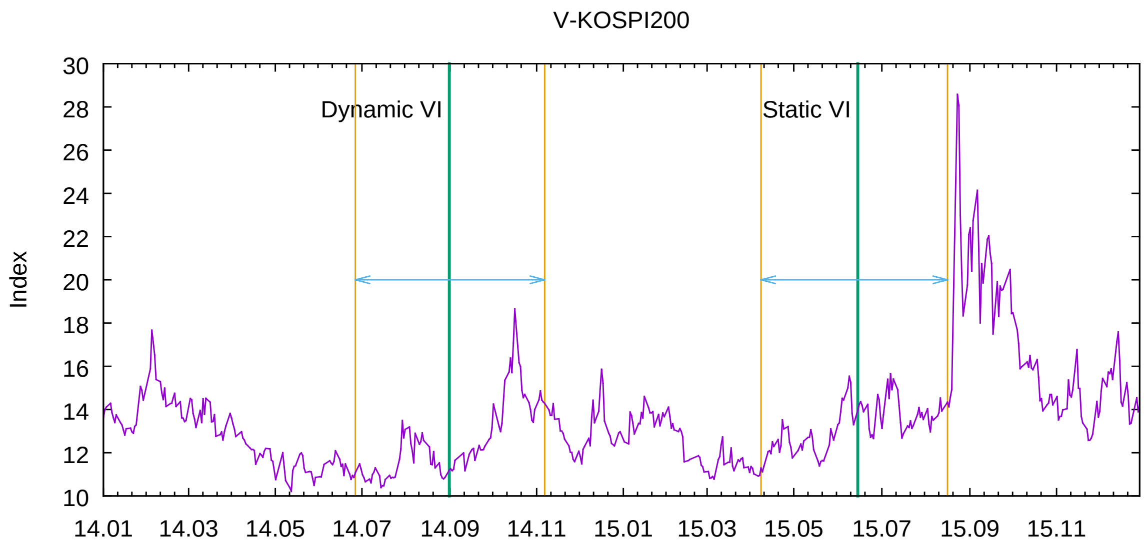


Figure 2. Time-series of the KOSPI 200 index and the V-KOSPI 200 index

Figure 2 depicts the stock market movement from January 2014 to January 2016. Panel A and Panel B show the time-series of a market index (KOSPI200) and a market volatility index (V-KOSPI200), respectively.



Panel A. KOSPI 200 index



Panel B. V-KOSPI 200 index

Table A1. Kendall correlation in the pre-event period in 2014

This table shows Kendall correlation among firm characteristics in the pre-event period in 2014, which is from June 27, 2014 to August 29, 2014. *volume_share* (*volume_value*) indicates trading volume in shares (in KRW) and *mkt_cap* is market capitalization. *prc* is the closing price and for volatility measure, *std_dev* is the standard deviation of daily returns and *intra_vol* is the intraday volatility measured by the daily highest and lowest price.

	volume_value	*mkt_cap*	*Prc*	*volatility*	
				std_dev	*intra_vol*
volume_share	0.5109***	0.1320***	-0.2491***	0.2710***	0.3371***
volume_value	1.0000	0.5158***	0.2399***	0.1292***	0.2393***
mkt_cap		1.0000	0.4794***	-0.1872***	-0.0909***
prc			1.0000	-0.1914***	-0.1226***
std_dev				1.0000	0.7191***

Table A2. Panel logit analysis in the post-event period in 2014

This table shows estimation results for the panel logit regression model (Equation (3)) for the post-event period in 2014.

Variable	Upper price-limit hits		Lower price-limit hits	
	Coefficient	*z*	Coefficient	*z*
DVIUP	0.1392	0.65	0.3771	1.22
DVIDOWN	-0.8278***	-3.41	0.1151	0.44
ln(*Price*)	1.7841***	6.19	-0.1448	-0.38
Volatility	30.3011***	28.20	29.1296***	17.95
Turn	4.6842***	8.51	1.1134	1.37