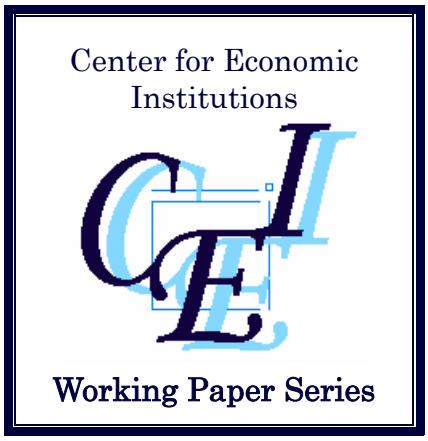
Center for Economic Institutions

Working Paper Series

CEI Working Paper Series, No. 2005-17

"An Anatomy of the Magnet Effect: Evidence from the Korea Stock Exchange High-Frequency Data"

Yan Du
Qianqiu Liu
S. Ghon Rhee



Institute of Economic Research
Hitotsubashi University
2-1 Naka, Kunitachi, Tokyo, 186-8603 JAPAN
Tel: +81-42-580-8405
Fax: +81-42-580-8333
e-mail: cei-info@ier.hit-u.ac.jp

An Anatomy of the Magnet Effect: Evidence from the Korea Stock Exchange High-Frequency Data

Yan Du*
Qianqiu Liu*

and

S. Ghon Rhee*

*All at College of Business Administration
University of Hawai'i at Manoa
2404 Maile Way
Honolulu, HI 96822-2282, USA
Email Addresses:
yand@hawaii.edu
qianqiu@hawaii.edu
rheesg@hawaii.edu

Current Draft: June 2005

JEL Classification: G14; G15; G18

Keywords: Price Limit; Magnet Effect; Rate of Return; Trading Volume; Volatility; Order Flow; Order Type; Price Trajectory; Korea Stock Exchange

An Anatomy of the Magnet Effect: Evidence from the Korea Stock Exchange High-Frequency Data

Abstract

We examine the existence and the forms of the magnet effect using transaction files and limit order book of the Korea Stock Exchange. A significant magnet effect exists in all five market microstructure variables (the rate of return, trading volume, volatility, order flow, and order type) when the limit hit becomes imminent. Specifically, investors place increasingly more orders, choose proportionally more market orders, and frequently reposition existing orders to advance transactions. We also find that: (i) a narrower price limit exhibits higher acceleration rates in all five variables compared to a wider price limit; and (ii) the upper limit hits draw heavier volumes of transactions, order submissions and market orders than the lower limit hits. We confirm that the magnet effect is a phenomenon unique only to markets with daily price limit systems.

Starting from its initiation, a price limit is imposed as a means to curb excessive price movement and prices being carried too far away. Recently price limits have been implemented in a majority of the Asian and European stock markets. The implications of price limits on market liquidity, volatility and price discovery processes have drawn a great deal of attention from market participants, regulators and scholars.[1]

In practice, most stock exchanges have undergone repeated changes in price limit rules. For example, the Taiwan Stock Exchange used eleven different daily price limits since 1962 with its most recent change from 5% to 7% in 1989; the Stock Exchange of Thailand raised the price limit from 10% to 30% at the end of 1997; the Korea Stock Exchange (KRX) raised it from 4.6% to 15% in four phases from 1995 to 1999 and its most recent change from 12% to 15% was implemented on December 7, 1998.

Most of past studies on price limits are limited to the analysis of daily price movements and the primary focus is on the post-limit-hit period, which leaves one important aspect of price limits largely unexplored, i.e., the magnet effect or the gravitational effect. Therefore, the discussions of the magnet effect in earlier studies are mostly conjectural. Miller (1991) states that circuit breakers could be self-fulfilling if traders rush to avoid being locked into their positions when prices come in the range of the trigger point. Greenwald and Stein (1991) note that the magnet effect makes circuit breakers vulnerable to criticism in that the very existence of a circuit breaker might somehow cause large declines to feed on themselves and cause the market to crash.[2] Gerety and Mulherin (1992) also point out that the possibility of a trading halt after a price change of a given percent would make investors generally nervous and prone to leave the market more quickly compared to a situation where a circuit breaker did not exist.

---

[1] The early studies on price limits date back to the 1970s. See, for example, Hieronymus (1971).

[2] The theories on circuit breakers can be applicable to the price limits because of the similarities in their functionality. Both of them curb continuous trading in the entire market and/or for individual stocks. However, circuit breakers close the market completely but price limits allow transactions to continue at the limit prices. In practice, volume quickly dries up when a price limit is triggered. Therefore, price limits function essentially the same way as circuit breakers.

Subrahmanyam (1994) offers the most direct predictions of the magnet effect with his inter-temporal model of circuit breakers. He proposes that price variability, market liquidity, trading volume, and the probability of the price crossing circuit breaker bounds will increase in the period before the limit hit due to suboptimal order submissions. The implications of price limits may also be relevant to the literature on market closure because the trigger of price limit interrupts continuous trading. Slezak (1994), for example, uses a multi-period model on market closure and predicts that market closures increase pre-closure trading volume because closures will delay the resolution of information uncertainty and impose more risk on both informed and uninformed traders. This idea is also reflected in Subrahmanyam (1995), in which he notes that discretionary closures can bring more information into the closure decision and therefore they can be less susceptible to the magnet effect than rule-based halts.

Theoretical studies on circuit breakers and price limits support the existence of the magnet effect but existing empirical evidence is mixed. Studies on derivatives markets tend to report the non-existence of the magnet effect. For example, Kuserk *et al*. (1989) examine the price behavior on limit hit days for Treasury bond and commodity futures contracts but they do not find evidence in support of the magnet effect. In another study, Arak and Cook (1997) examine price behavior in the U.S. Treasury bond futures market in the mornings after large overnight price movements. They conclude that a price reversal after the market open signals calming effects instead of the magnet effect. Berkman and Steenbeek (1998) investigate price, relative trading volume and volatility prior to the limit hits using Nikkei 225 futures contracts traded in the Osaka Securities Exchange (OSE) and the Singapore International Monetary Exchange (SIMEX).[3] They attribute the lack of the magnet effect to strong arbitrage links between the OSE and the SIMEX. Finally, Hall and Korfman (2001) examine five agricultural futures contracts and find that daily price limit in the futures markets has neither any impact on traders' expectations nor some stabilization effect, thus rejecting the gravitational effect.

[3] The SIMEX is now a part of the Singapore Exchange.

Studies on stock markets, however, provide supportive evidence of the magnet effect. McMillan (1990) examines market breaks in the United States on October 13th and 16th of 1987 and finds strong patterns of runs in prices prior to the triggering of the circuit breakers. Ackert *et al.* (2001) find that market participants accelerate their transactions if a trading interruption is imminent under an experimental setting. Cho *et al*. (2003), using high-frequency data from the Taiwan Stock Exchange, document a distinct tendency for stock prices to accelerate toward the upper bound and weak evidence of acceleration toward the lower bound. Chan *et al*. (2005), using transaction data from the Kuala Lumpur Stock Exchange, find that price limits themselves cause order imbalances prior to the limit hits, which is indication of the magnet effect as illustrated in the latter part of this paper.

In general, studies on the magnet effect are far from conclusive or comprehensive, especially for the equity markets. Three weaknesses are noted in earlier studies. First, results drawn from the futures markets may not be generalized to the stock markets. Ma *et al.* (1989) suggest that we need to be cautious when ascribing their results to the equity markets due to the institutional differences between the futures and the equity markets. Second, the existence of the magnet effect can be captured when transaction data and the limit order book rather than daily data are used. Earlier studies have not taken advantage of the tick-by-tick data largely due to the unavailability of such data. Third, earlier studies on the magnet effect focus primarily on the rate of return, leaving out other important market microstructure variables such as trading volume, order flow, quote positions, order types, etc. Cho *et al.* (2003) provide the most rigorous modeling on the magnet effect so far but their focus is solely on the return series. We believe that the return variable alone can not unfold the dynamic process of the magnet effect. For example, if the rising rate of return is not associated with elevated trading volume, the magnet effect should be considered very minimal because only a small number of transactions would respond to the price limit. If investors proactively react to the proximity of the price limit, we would observe that investors use their

discretions to improve order positions in order to advance transactions; this has not been documented in earlier studies.[4]

The main objective of our paper is to delineate the intraday dynamic process of the magnet effect. Our contributions to the current literature are four-fold. First, we apply a multi-variable approach to investigate the magnet effect. Five market microstructure variables, namely, rates of return, trading volume, volatility, order flow, and order type are considered in this study. Second, we introduce a quadratic function to capture the nature of the magnet effect. Earlier studies are quite vague about the forms of the magnet effect; w rather than daily data ords such as self-fulfilling, gravitation, and acceleration are used to define the magnet effect. In our paper, we model the magnet effect by applying a quadratic function to the five market microstructure variables. A convex function is perceived as a strong support of the magnet effect. Third, we address the magnet effect from three dimensions: magnitude, acceleration and persistence. The slope of the convex function measures the acceleration rate while the persistence of the magnet effect is defined as the time-interval between the lowest point of the convex curve to the limit hit. The respective sizes of the five standardized market microstructure variables at ten three-minute intervals indicate the magnitude of the magnet effect. Fourth, we compare the magnet effect between two price limit regimes and between the upper and the lower limit hits from all these three dimensions. To the best of our knowledge, it is the first attempt to examine the magnet effect in a multi-variable and multi-dimensional setting.

The remainder of the paper is organized as follows. Section I presents the institutional background as well as of the relevant summary statistics of the KRX. Section II presents the research methodology. Section III reports the empirical results. We present strong evidence in support of the magnet effect from all five variables. Moreover, a narrower price limit exhibits higher acceleration rates compared to the wider price limit; the upper limit hits draw heavier trading volume, order flow, and market orders compared to the lower limits hits. Section IV presents

[4] One exception is Chan *et al.* (2005).

robustness analysis. We observe that there is no magnet effect for the firm and for the time-of-the-day matched non-limit-hit groups. It is also documented that the magnet effect is robust to momentum effect. We find that there is no magnet effect in the NASDAQ, which is a market without the price limit rule. This finding confirms that the magnet effect is caused by the cap/floor imposed by the price limit rule. Section V concludes the paper.

I. Institutional Background and Summary Statistics

A. Institutional Background

The KRX is one of the most active stock exchanges in the world. In the year of 2004, its annual share turnover ratio is 397% compared with 99% on the New York Stock Exchange (NYSE); its average market capitalization is $375 billion and the average daily trading volume is 305 million shares. At the end of 2004, the KRX had 683 listed companies and 844 listed issues.

The market opens from Monday to Friday and the KRX currently has four trading sessions in each trading day: a pre-hours session 7:30-8:30 A.M., a morning session 9:00 A.M.-12:00 Noon, an afternoon session 1:00-3:00 P.M., and an after-hours session 3:10-4:00 P.M.[5] As in the case of many Asian stock markets, the KRX is an order-driven market, where buy and sell orders compete for the best prices. A call market auction is applied to the morning and afternoon session's open and the market close. Orders are accumulated between 2:50 P.M. and 3:00 P.M and a single auction occurs at 3:00 P.M to determine the closing price. During other time periods of the regular sessions, orders are continuously matched to satisfy both parties in terms of price and time priority. The pre-hours and after-hours sessions are specially designed to facilitate basket trading where paired buy and sell orders are executed at the preceding closing prices.

The KRX fully automated its securities trading on September 1, 1997. It runs an order routing system and the KRX Automated Trading System (KATS). The order routing system receives order inputs through system terminals at member firms' offices and then transmits them to

[5] The pre-hours session was introduced on December 1, 2003. The after-hours session was extended by 20 minutes on October 14, 2002. It was from 3:10-3:40PM in our sample period.

the KATS. The KATS executes orders, transmits information on the transaction to the order routing system and produces the information necessary for clearing and settlement.

The KRX currently sets the daily price limit at 15%; stock prices can not move beyond 15% above or below the previous day's closing price. The KRX believes that the price limit system can moderate excessive price fluctuations and maintains an orderly market. The last change on the price limit was introduced on December 7, 1998 when the price limit was raised from 12% to 15%. We use this event date to divide our study period into two regimes; the pre-regime between September 1, 1998 and December 6, 1998 and the post-regime between December 8, 1998 and March 31, 1999. On the same day, the KRX eliminated Saturday trading and extended its morning session by one hour, from 9:30-11:30 A.M. to 9:00 A.M.-12:00 Noon.

B. Summary Statistics

We use real-time transaction data and the limit order book of the KRX during the study period from September 1, 1998 to March 31, 1999, with 80 trading days in the pre-regime period and 73 trading days in the post-regime period. We select the stocks that had average daily transactions above 100 and traded on each of the 153 trading days in our study period to avoid thin-trading problems.[6] In total, our sample contains 385 stocks, totaling $52.7 billion in capitalization and the average firm size is $137 million as of September 1, 1998. Our sample stocks are from 39 out of the 41 industries in the KRX; they consist of 220 small firms, 77 medium firms and 88 large firms based on the rule set by the KRX.[7]

The daily price limit literally sets the boundaries of allowable prices, $\pm$12% in the pre-regime and $\pm$ 15% in the post-regime from the previous day's closing price. However, prices do not

[6] More stringent sampling criteria are used and the statistical results remain qualitatively similar.

[7] Based on the fact book published by the KRX, companies are defined as small firms with capitalization less than 35 billion won, medium firms with capitalization between 35 billion won and 75 billion won, and large firms with capitalization above 75 billion won. At the current exchange rate, $1 is equivalent to about 1,000 won.

need to reach the actual limit price to effectively trigger the limit due to the existence of tick sizes.[8] For example, if stock k closes at 4,900 won on day t and the ruling price limit is 15%, day t+1's allowable price range is between 4,165 won and 5,635 won. When the stock price reaches 5,630 won, it can not move up further because the minimum price movement is 10 won. As a result, at the price of 5,630 won, stock k effectively triggers the price limit. In our paper, we use this effective price in identifying limit hits.

An upper limit hit is identified when $H_{k,t} > (1+LIMIT)C_{k,t-1} - TICK_{k,t,}$ where $H_{k,t}$ is the stock k's high price on day t, $C_{k,t-1}$ is the stock k's closing price on day t-1, LIMIT is the prevailing percentage price limit, and $TICK_{k,t}$ is the tick size for the stock k at price $H_{k,t}$. A lower limit hit is identified when $L_{k,t} < (1-LIMIT)C_{k,t-1} + TICK_{k,t,}$ where $L_{k,t}$ is the low price on day t. Based on the direction and the limit regime, we classify our sample of limit hits into four groups: (i) the pre-up; (ii) the pre-down; (iii) the post-up; and (iv) the post-down groups with the prefix signifying the regime and the suffix representing the direction of price movement.[9]

The summary statistics of limit hits are presented in Table I. Panel A presents limit hits in various categories. We identify 1,449 upper limit hits and 300 lower limit hits in the pre-regime, 1,219 upper limit hits and 492 lower limit hits in the post-regime. The fact that there are considerably more upper limit hits than lower limit hits is consistent with the market's upward trend. The KOSPI doubled in our study period and it moved up 66% in the pre-regime and another 20% in the post-regime.[10] There are on average 18.1 upper limit hits and 3.8 lower limit hits per trading day in the pre-regime, and 16.5 upper limit hits and 6.6 lower limit hits per trading day in the post-

[8] The tick size rule in the KRX is as follows: it is 5 won if the stock price is lower than 5,000 won; 10 won if the price is within (5,000, 10,000); 50 won if the price is within (10,000, 50,000); 100 won if the price is within (50,000, 100,000); 500 won if the price is within (100,000, 500,000) and 1,000 won if the price is above 500,000 won.

[9] We exclude the days that both upper and lower limit hits occurred and the days that prices moved outside the price boundaries. The KRX may apply a different daily price limit, more likely a wider price limit under the following two cases: (i) the market reopens after long holidays; and (ii) the exchange deems that the application of the daily price limit is extremely difficult due to drastic changes in market conditions.

[10] KOSPI is the Korea composite stock price index. It is a market value weighted index composed of all common and preferred stocks listed on the KRX, except bond-type preferred stocks and newly listed stocks.

regime. Item (3) reports that about 60% of the upper limit hits and 48% of the lower limit hits take place in the morning session. We also observe that there is a spike of limit hits at the market open, which is 17% for the pre-up group, 12% for the post-up group, 14% for the pre-down group and 18% for the post-down group. A high concentration of limit hits at the market open supports the belief that market open exhibits higher volatility and heavier transactions than other time of the day as a result of the overnight non-trading. Figure 1 exhibits the intraday distribution of limit hits.[11]

[Insert Table I and Figure 1]

Item (6) of Table I reports the locked limit hits when prices close at the limit prices. We find that that 66% of the upper limit hits and 50% of the lower limit hits are locked. Items (7) and (8) present the percentage of price continuations and reversals out of the locked limit hit days. If a stock closes at the upper/lower limit and opens at an even higher/lower price on the next non-limit-hit day, it is defined as a price continuation. Similarly, if a stock closes at the upper/lower limit and opens at a lower/higher price on the next non-limit-hit day, it is defined as a reversal. We observe that a high proportion of locked limit hits are followed by price continuation, 78% for the upper limit hits and 62% for the lower limit hits. A high likelihood of price continuation supports the delayed price discovery hypothesis documented in Kim and Rhee (1997) and Kim and Sweeney (2002). If the price discovery process is interrupted before prices reach the equilibrium, it will resume this process when the market reopens, thus continuing the earlier price trend.

There is also evidence that lower limit hits are less likely to close at the limit prices and less likely to be followed by price continuations than upper limit hits. The asymmetry between the upper and the lower limit hits is in line with investors' optimistic sentiment and tendency of overreacting to good news. De Bondt and Thaler (1990) and Butler and Lang (1991) provide evidence that analysts provide systematically overly optimistic forecasts on security prices and

[11] We use a Chi-squared goodness-of-fit test to compare the likelihood of limit hits during each half hour interval. We find that upper limit hits are most likely to occur during the first half hour in the morning session and lower hits are most likely to occur during both the first and the last half hour of the trading day.

earnings. Therefore, it is plausible that investors chase upward trends more persistently and strongly than declining trends.

Panel B of Table I provides the statistics on the frequency of intraday limit hits, limit hit duration and the counts of limit hits by individual stocks. Most stocks trigger price limits repeatedly within a limit hit day: prices hit the limit price, drift away and hit the limit again. In our paper, we count the first time that prices hit the limit as an observation of a limit hit. The limit hit duration is measured from the moment of the first limit hit to the last moment that prices stay at the limit price in the same day. The average limit hit duration varies from 50 minutes for the pre-down group to 93 minutes for the post-down group, higher than the values reported in Cho *et al*. (2003). The maximum number of limit hits by an individual stock varies from 7 for the pre-down group to 21 for the pre-up group.

II. Empirical Design

We choose the half hour pre-hit period as our study window, drawn backward from the moment of the limit hit because the magnet effect is most likely to take effect when the prices reach a certain percentage of the allowable price movements and the limit hit becomes imminent. This approach avoids setting an arbitrary price threshold for the magnet effect which may vary among stocks. We believe that a half hour is long enough to capture the dynamics of the magnet effect and short enough to remain focused. Chordia *et al.* (2005) suggest that the adjustment to the weak form market efficiency is not instantaneous and by thirty minutes, it is well under way. Early studies also suggest that concentrated trading took place within thirty minutes or less prior to the limit hits. Goldstein and Kavajecz (2004) find that investors change their trading behavior during the nine minutes before the market breakdown on October 27-28, 1997.

Next, we assess the magnet effect from the following five market microstructure variables, namely, the rate of return, trading volume, volatility, order flow and order type and from the three dimensions, namely, magnitude, acceleration rate and persistence during the study period. Each variable is measured during the ten three minute intervals of the pre-hit period, denoted by interval

1-interval 10 from the furthest to the closest distance to the moment of the limit hit. All the raw values are standardized by the same stock's mean and standard deviation on non-limit hit days in each regime. The purpose of standardization is to minimize intraday trading patterns, such as the U-shaped volatility and volume pattern.[12] If investors react to the proximity of the price limits by jumping onto the bandwagon, there is likely to be herding prior to the limit hits. The magnet effect is in fact a form of herding where the common signal present in a herding behavior is the proximity to the price limit.

As a result of the magnet effect, we expect to observe a period of concentrated and accelerated transactions prior to the limit hits. The magnitude of the magnet effect is reflected in the standardized market variables during the pre-hit period. We measure the market variables during each interval and across all intervals during the pre-hit period and make comparisons between groups. The acceleration rate and the persistence of the magnet effect are defined by the quadratic function in which the base model is as follows:

$$MarketVariable_{k,t,i} = \alpha + \beta INT_{k,t,i} + \gamma SQINT_{k,t,i} + \varepsilon_{k,t,i} \qquad (1)$$

where the dependent variables are the five standardized market microstructure variables measured for stock k on day t at interval i. INT takes the value of 1 to 10 from the furthest to the closest distance to the limit hit moment, and SQINT is the squared INT. The variable we are most interested in is the SQINT. The coefficient of SQINT, γ measures the acceleration rate of the magnet effect. A positive and significant γ implies that the market variables not only increase but also increase at a rising speed, supporting the magnet effect. Besides the acceleration rate, the quadratic function pinpoints the starting point of an upward trend, i.e. the lowest point of a convex curve. We define the persistence of the magnet effect as the time period from this moment onward to the moment of the limit hits, stated in the number of minutes.

[12] Refer to Wood *et al*. (1985), Jain and Joh (1988), Admati and Pfleiderer (1988) and Chang *et al.* (1993).

We also introduce dummy variables to the base model in order to compare the same direction limit hits between the two regimes, i.e. pre-up vs. post-up, pre-down vs. post-down and the directional limit hits within the same regime, i.e. pre-up vs. pre-down and post-up vs. post-down:

$$MarketVariable_{k,t,i} = \sum_{j=1}^{2} \alpha_j Dummy_j + \sum_{j=1}^{2} \beta_j INT_{k,t,i} + \sum_{j=1}^{2} \gamma_j SQINT_{k,t,i} + \varepsilon_{k,t,i} \qquad (2)$$

where independent variables INT and SQINT are defined the same as before. When we make cross-regime comparisons, $Dummy_1$ takes the value of unity if the observation is from the pre-regime and 0 otherwise and $Dummy_2$ takes the value of unity if the observation is from the post-regime and 0 otherwise. When we make in-regime comparisons, $Dummy_1$ and $Dummy_2$ will represent the upper limit hits and the lower limit hits respectively.[13]

III. Empirical Evidence

A. Rates of Return

In this section, we examine the progression of rates of return prior to the limit hits. Because the price limit rule is benchmarked to the previous day's closing price, we introduce a variable, the distance to the limit, DTL to proxy the rate of return. At any given price, DTL is the percentage distance to the price limit, and ΔDTL (the change of DTL) during a time period fathoms the speed of approaching the price limit.[14] Evidently ΔDTL and the rate of return in the same time period are highly correlated, with a correlation of 0.9 in our sample. The computations are as follows.[15]

---

[13] Equation (2) is equivalent to two individual equations (1) by using regime dummy variables. For example, equation (2) for upper limit hits, where $Dummy_1$ takes the value of unity if it is from the pre-up group and $Dummy_2$ takes the value of unity if it is from the post-up group, is equivalent to two individual equations (1) on the pre-up and post-up groups.

[14] Assuming the prevailing price limit is 15%, on the upper limit hit days, $DTL_{k,t,i} = 1.15\text{-}P_{k,t,i}/CP_{k,t-1}$; $\Delta DTL_{k,t,i} = (1.15\text{-}P_{k,t,i-1}/ CP_{k,t-1})\text{-}(1.15\text{-}P_{k,t,i}/ CP_{k,t-1}) = (P_{k,t,i}\text{-} P_{k,t,i-1})/ CP_{k,t-1}$. On lower limit hit days, $DTL_{k,t,i} = P_{k,t,i}/CP_{k,t-1}\text{-}0.85$; $\Delta DTL_{k,t,i} = (P_{k,t,i-1}/ CP_{k,t-1}\text{-}0.85)\text{-}(P_{k,t,i}/CP_{k,t-1}\text{-}0.85) = (P_{k,t,i-1}\text{-}P_{k,t,i})/ CP_{k,t-1}$. The same formulae hold for the other price limit regime because the range of price limit is cancelled out.

[15] Our standardization is similar to the methodology used in Lee *et al*. (1994), Corwin and Lipson (2000), and Christie *et al.* (2002), where they use the difference between the raw value and the mean value on non-halt days, stated as a percentage of the mean values of non-halt days. We also used the standardization of ΔDTL without demeaning as in Cho *et al.* (2003). Our results remain qualitatively the same using the above methodologies.

Upper Limit Hits: $\Delta DTL_{k,t,i} = (P_{k,t,i} - P_{k,t,i-1}) / CP_{k,t-1}$

Lower Limit Hits: $\Delta DTL_{k,t,i} = (P_{k,t,i-1} - P_{k,t,i}) / CP_{k,t-1}$

$$ST\Delta DTL_{k,t,i} = (\Delta DTL_{t,t,i} - M\Delta DTL_{k,i}) / SD_{k,i} \qquad MST\Delta DTL_i = \sum ST\Delta DTL_{t,t,i} / N_i$$

where $P_{k,t,i}$ is the last transaction price of stock k at interval i on day t; $CP_{k,t-1}$ is the closing price for stock k on day t-1; $ST\Delta DTL_{k,t,i}$ is the standardized ΔDTL for stock k on day t at interval i after the adjustment of the mean $M\Delta DTL_{k,i,}$ and the standard deviation, $SD_{k,I}$ where MΔDTL and SD are computed using non-limit hit day observations; N_i is the number of observations at interval i within each group. $MST\Delta DTL_i$ is the mean standardized ΔDTL at interval i averaged across all the limit hits in each group. Earlier studies by Gerety and Mulherin (1992), Subrahmanyam (1994) and Cho *et al*. (2003) have predicted that investors will rush onto the bandwagon when they observe that price limit is approached.

Table II summarizes the progression of ΔDTL during the half hour pre-hit period. Panel A reports the magnitude of the average ΔDTL in each interval and across all intervals for the four groups. We observe that all the values are significantly positive, indicating that prices move faster on limit hit days than on non-limit-hit days during the pre-hit period. ΔDTL tapers off as we move away from the limit hit moment, and the interval immediately before the limit hit, interval 10 features the largest price movement for all groups. At the interval 10 of the pre-down group, ΔDTL takes the value of 4.03, followed by 3.3 of the post-down group, 3.2 of the pre-up group and 2.51 of the post-up group. The average three minute return is not significantly different from each other for the four limit-hit groups.

[Insert Table II]

In Panel B, we report the regression results of equation (2), where $Dummy_1$ takes the value of unity if it is from the pre-regime and 0 otherwise and $Dummy_2$ takes the value of unity if it is from the post-regime and 0 otherwise. We observe that the coefficients of SQINT are significantly positive for all four groups, supporting that prices approach the limit at an accelerating speed. The

pre-down group has the highest acceleration rate of 0.087, followed by 0.062 of the pre-up group, 0.055 of the post-down group and 0.038 of the post-up group.[16] We also conclude that the pre-regime has a significantly higher acceleration rate than the post-regime and the lower limit hits have a higher acceleration rate than the upper limit hits in the same regime.

As described earlier, the quadratic function defines the turning point of a convex curve. The computation of the persistence is: $(10+\beta/2\gamma)*3$, where β and γ are the coefficients of INT, SQINT respectively. Following this computation, we infer that the persistence is 19.38 minutes, 20.92 minutes, 17.86 minutes, and 19.77 minutes for the pre-up, the post-up, the pre-down and the post-down groups, respectively. The average persistence is about 19.5 minutes; the pre-up group exhibits a longer persistence than the pre-down group and the difference between the post-up and the post-down groups are insignificant.

In summary, we conclude that the rates of return are significantly higher than non-limit-hit days and prices accelerate to both the upper and the lower limit hits in two regimes. Our results strongly support the existence of the magnet effect. In addition, we observe that the pre-regime features more intensive acceleration in the rate of return than the post-regime and the upper limit hits feature a relatively longer-lived and less intensive acceleration pattern than that of the lower limit hits. The last three minutes prior to the lower limit hits demonstrate the most dramatic price change compared with other intervals or with the upper limit hits.

The differences in the acceleration rate between the two regimes are consistent with our intuition of the magnet effect. A narrower price limit during the pre-regime gives investors less room for continuous trading and implies a higher likelihood of crossing the price limit. The non-execution cost imposed by the limit hit becomes more prominent and investors respond to the limit

[16] Lindley (1957), Leamer (1978) and Connolly (1995) point out the problem related to large sample size in classical test statistics. Hence, the size-adjusted F-test critical value is $[(T-k_1)/P]*[T^{P/T}-1]$, where T is the sample size, k_1 is the number of parameters estimated under the alternative hypothesis, and P is the number of restrictions being tested. The size-adjusted critical t-value is $(T-k)^{0.5}*(T^{1/T}-1)$. We use the 1% level of significance as the rejection criterion and our results are robust to the adjustment.

more frenetically than during a wider price limit regime. Therefore, the acceleration rate in the pre-regime is higher than that in the post-regime.

The differences between the upper and the lower limit hits can be explained by investors' overly optimistic sentiments. If investors believe that an upward trend tends to persist, liquidity buyers will hurry to fulfill their liquidity needs in anticipation of a limit hit and speculators will bid up prices upfront with the expectation of realizing their profits at higher prices. However, when prices are going down, investors tend to believe it is transitory. Liquidity sellers will probably wait for the price reversal until the last chance of execution and speculators will defer locking in their losses as long as possible. As a result, investors jump onto an upward trend at an earlier stage leading to relatively mild acceleration in the rate of return and investors respond to a downward trend at a later stage but in a more concentrated fashion, especially during the last three minutes prior to the limit hits.

B. Trading Volume

In the previous section, we observe high rates of return prior to the limit hits but it may not have any real impact on the cohort of investors if it is caused by some unusual but sporadic transactions and is not associated with heavy trading volume. Therefore, market liquidity is an important aspect when we examine the magnet effect, which will be presented in this section.[17]

Theoretical studies on the magnet effect have predicted heavier trading prior to the limit hits. Subrahmanyam (1994) suggests that investors may sub-optimally advance trades to assure their ability to trade. According to Gerety and Mulherin (1992), skittish investors overreact and leave the market in anticipation of the market close. Slezak (1994) also projects higher pre-closure trading volume in anticipation of a long period of non-execution. Lee *et al*. (1994) and Kim and Rhee (1997) document higher trading activities on the days subsequent to trading halts and limit hits but the lack of transaction data restricts their analyses to a daily basis. Little empirical evidence has been presented on intraday liquidity during the pre-hit period.

[17] Additionally, we used the number of trades and the dollar amount of trades as liquidity measurements. The results are qualitatively similar.

The results on the trading volume are reported in Table III. Panel A summarizes the magnitude of trading volume during the ten three-minute intervals for the four groups. The transactions during the pre-hit period are significantly higher than those on non-limit-hit days. As prices approach the limit price, trading volume rises substantially. For example, the trading volume rises from 0.81 in interval 1 to 5.31 in interval 10 for the pre-up group and same pattern holds for other three groups. We also observe that the upper limit hits demonstrate uniformly higher trading volume than the lower limit hits in all intervals. For example, the average three minute trading volume for the pre-up group is 1.91, which is significantly higher than 1.23 of the pre-down group. Similarly, the average three minute trading volume is 1.96 for the post-up groups, compared with 0.77 for the post-down group. The same relationship holds significantly throughout all ten intervals between the upper and the lower limit hits within the same regime.

[Insert Table III]

Panel B reports the regression results of equation (2) on trading volume for the upper and the lower limit hits. There are significant acceleration patterns for all limit hit groups in that the coefficients of SQINT are positive and significant. It therefore supports the magnet effect and indicates that increasingly more transactions are drawn to the market as prices approach the price limit. Next we compare the acceleration rates between the two regimes. We observe that the coefficient of SQINT for the pre-regime is larger than that for the post-regime in both the upper and the lower limit hits regressions. It indicates that a narrower price limit causes more frenetic transactions in the proximity of price limits as a result of a higher likelihood of crossing the boundaries. The persistence measurement is 18.96 minutes, 18.02 minutes, 21.41 minutes, and 18.59 minutes for the pre-up, the pre-down, the post-up and the post-down group, respectively. However, they are not significantly different from each other.

In summary, a significant magnet effect is exhibited for all four groups in terms of trading volume. Investors respond to the price limit by realizing heavier transactions in anticipation of a price limit hit. The upper limit hits feature heavier transactions volume than the lower limit hits and

the breadth of the price limit rule has a significant impact on the acceleration rates. Besides the overly optimistic sentiment, the lack of short sale infrastructure in the KRX should also contribute to heavier transactions volume of the upper limit hits. Investors can usually materialize their positive expectations by placing more buy orders, but the high costs associated with short sales curb the realization of negative expectations.[18] As a result, investors are restricted from chasing a downward trend and fewer transactions take place prior to the lower limit hits.

C. Volatility

Volatility is a key attribute of the magnet effect because cooling off the market is stated as the primary purpose of a price limit. Earlier studies on volatility focus on the days after limit hits or trading halts and are also limited to a daily time frame. Lee *et al*. (1994) and Corwin and Lipson (2000) state that volatility increases significantly subsequent to trading halts. Kim and Rhee (1997) conclude that the price limit causes higher volatility levels on days subsequent to price limit hits and there is no significant difference in volatility between limit hit days and non-limit-hit days during the pre-hit days. Kim (2001) examines the relationship between price limits and market volatility using the Taiwan Stock Exchange data and finds that narrower price limits do not usually lead to lower volatility.

Empirical evidence on intraday volatility has not been adequately documented, especially during the pre-hit period when the magnet effect is expected to occur. Cho *et al.* (2003) provides the only empirical evidence on intraday volatility using a GARCH model on five minute return series. They conclude that conditional volatility increases as prices move closer to the limits, which increases the probability of prices reaching the price limits. But the volatility was an insignificant portion of their paper and they did not show the growing pattern of the volatility. If the magnet

[18] In the KRX, the proceeds from short sales are held by the securities companies as collateral in the margin account, which is again marked to market on a daily basis. Then the collateral has to be maintained up to a certain ratio of the extended credit to avoid the margin call. Moreover, securities companies raised the initial margin requirement and maintenance requirement after the Financial Supervisory Service relaxed relevant regulations to liberalize the market in March 1998. As a result, the short sales in 1998 and 1999 were at historically low levels.

effect does occur, we expect to observe higher price variability and rising volatility prior to the limit hits, as suggested by Gerety and Mulherin (1992) and Subrahmanyam (1994).

Following Lee *et al.* (1994), Corwin and Lipson (2000) and Christie *et al.* (2002), we use three intraday volatility measures, the absolute return (ABSRETURN), high-low price differences (HLOW) and the number of quote revisions within each three-minute interval (QUOTE REVISIONS). The three measurements capture different aspects of the volatility. The absolute return is a traditional measure of price variation. High-low price differences capture the dispersion of prices. The quote revisions are defined as the number of changes in either bid or ask prices, which can be perceived as an indicator of the investors' eagerness to trade. If investors are nervous about the possibility of non-execution, they are likely to improve their positions frequently to assure execution. We expect to observe positive and rising abnormal volatility statistics prior to the limit hits if there is the magnet effect.

The summary statistics of volatility and the regression results are listed in Table IV. Panels A and B report the magnitude of volatility measurements for the pre-regime and the post-regime respectively. The volatility measures in the pre-hit period are positive and significant, except the quote revision during interval 1 of the post-down group. Significantly positive volatility measurements indicate that price variations during the pre-hit period is significantly higher than those on non-limit-hit days. Next, we compare the average volatility measurement between groups. We observe that the upper limit hits exhibit more frequent quote revisions than the lower limit hits, which is 1.11 and 0.53 for the pre-up and the pre-down group and 0.87 and 0.24 for the post-up and the post-down group. However, the lower limit hits exhibit higher ABSRETURN than the upper limit hits in the same regime. The comparison on HILOW is insignificant. Therefore, we conclude that the comparison on volatility magnitude is contingent on the choice of measurements.

[Insert Table IV]

In Panel C of Table IV, we report the regression results of equation (2) on the three volatility measures. The coefficients of SQINT are positive and significant for all group-

measurements except for the post-down group on quote revisions. Positive coefficients of SQINT support the magnet effect in that volatility rises and accelerates when prices approach the limit prices. Next we make the comparisons between the two regimes. We conclude that the pre-regime has a significantly higher acceleration rate than the post-regime in all volatility measurements. For example, the acceleration rate of ABSRETURN is 0.069 for the pre-up group and it is 0.043 for the post-up group; the acceleration rate of HILOW for the pre-down group is 0.061, compared to 0.031 for the post-down group; the acceleration rate of quote revisions for the pre-up group is 0.022 and it is 0.012 for the post-up group. The persistence measures are reported at the bottom of Panel C and they are not significantly different between groups.

We conclude, in summary, that a strong magnet effect is exhibited in the volatility behavior during the pre-hit period. There is significantly higher volatility during the pre-hit period than on non-limit-hit days. The pre-regime exhibits higher acceleration rates in all volatility measurements than the post-regime, consistent with our earlier findings on the rate of return and the trading volume. The comparisons on the magnitude of volatility are contingent on the measurements. Notably, the last three minutes prior to the lower limit hits feature a huge price variation than other intervals, which could be explained by investors' tendency to jump onto the downward trend at the last minute.

D. Order Flow

In the earlier sections, we have shown that there exists a strong magnet effect in the rate of return, trading volume and volatility. In the following we take a closer look at the investors' trading behavior by examining the limit order book. The limit order book, provided by the KRX records rich information on the order activities in a trading day, e.g. order type, order conditions, order price, order volume and time stamp. We examine order submissions, order imbalances and order revisions in this section and we will examine the choice of order type in the next section.

The predictions on the trading volume can be safely applied to the order flow. If investors become nervous and sub-optimally submit orders to avoid non-execution, we expect to observe

abnormally high order submissions during the pre-hit period. In addition, we expect to observe buy order imbalances prior to the upper limit hits and sell order imbalances prior to the lower limit hits as a result of one directional market herding. We also investigate the revised buy and sell orders during the half hour prior to the limit hits. In the KRX, only limit orders can be later revised to better positions, which means that limit buy orders can only be revised to higher prices and/or higher volumes and limit sell orders can only be revised to lower prices and/or higher volumes. By examining revised orders, we are able to detect the means by which investors advance their orders.

The results on the order flow information are reported in Table V. Panel A reports the share volume and the ratio of regular and revised buy/sell orders for the pre-up and the pre-down groups. In Panel B, we present the same statistics for the post-regime. The ratio of buy/sell orders for the upper/lower limit hits is the percentage of buy/sell orders out of the total amount of buy and sell orders during the same time period. The regular buy/sell order ratios measure the order imbalances prior to the limit hits. A higher regular buy order ratio indicates that there are more buy volumes in the market than the sell volumes.

From Panel A and B of Table V, we observe that there are considerably more volumes of regular buy/sell orders and higher buy/sell order imbalances than on non-limit hit days throughout the ten intervals prior to the upper/lower limit hits. Investors place substantially more orders to chase the ongoing upward or downward trend, which causes large order imbalance on one side of the market. The results on the revised order volumes are not as robust as the regular orders but they become significantly positive during the last few intervals prior to the limit hits. Weak evidence on the revised orders aligns with our intuition because the most direct way to jump on a bandwagon is to place new orders, rather than revising the stale orders.

[Insert Table V]

Moreover, we observe that the upper limit hits feature significantly higher order flow than the lower limit hits, only with one exception of the regular buy order ratio between the post-up and the post-down groups. For example, the regular buy order volume is 1.17 for the pre-up group,

compared with 0.67 for the regular sell orders of the pre-down group. Similarly, the revised buy order volume for the post-up group is 0.33, higher than -0.01 for the revised sell orders for the post-down group. The difference between the upper and the lower limit hits in order flow is in line with our conjecture of the short sale constraints. Investors are restricted from placing sell orders even in anticipation of a downward trending market.

Panel C of Table V lists the regression results of equation (2) on the share volume of the regular and revised orders for the upper and the lower limit hits respectively. The coefficients of SQINT are significant and positive for all the limit-hit groups. Positive coefficients of SQINT imply that investors place increasingly more orders and make frequent revisions to their existing orders prior to the limit hits from the side of the market that actually leads to the limit hits. Next, we compare the acceleration rates between the two regimes. The pre-regime shows a higher acceleration rate in the regular orders. For example, the regular buy orders for the pre-up group accelerate at 0.038 and it is 0.025 for the post-up group. The acceleration rate of regular sell orders for the pre-down group is 0.038, significantly higher than 0.015 for the post-down group. However, there is no significant difference between the acceleration rates of revised orders between the two regimes. It could be explained that only incumbent investors can choose this option and a lot more investors choose to place new orders to get in the queue of the trend.

Lastly, the persistence measure is 21.9 minutes for the regular orders and 20.9 minutes for the revised orders, averaged across the four limit-hit groups. The persistence comparisons between groups are not significant except that the pre-up group exhibits a significantly slower persistence than the pre-down group on the regular order submissions.

In summary, we conclude that there is strong evidence of the magnet effect on the order flow from the side of the market that ultimately drives the limit hits. It indicates that investors respond to the imminence of the price limit by placing increasingly more orders and repositioning their stale orders to more competitive positions. More specifically, investors place more buy orders and repositioning their stale buy orders when an upper limit hit is imminent; likewise, investors

accelerate sell orders and reposition stale sell orders to jump onto the bandwagon before a lower limit hit is triggered. Additionally, we conclude that the breadth of the price limit has a significant impact on the acceleration rate of the order flow and the direction of the limit hits plays a significant role in the quantity of order submissions and revisions. A narrower price limit features a higher acceleration rate, and the upper limit hits draw heavier regular orders and revised orders than the lower limit hits. These results are consistent with our earlier findings.

E. Order Type

Order type is another important vehicle with which investors have the discretion to advance their transactions. In the KRX, investors can place three types of orders: market orders, limit orders and limit-or-market-on-close-orders. Market and limit orders consist of more than 95% of the total orders; therefore we focus on the choice between limit and market orders. To the best of our knowledge, it will be the first evidence on order type choices in the literature of price limits.

The choice between limit and market orders is contingent on the costs and benefits associated with the order type. Greenwald and Stein (1991) identify two drawbacks of limit orders. First, limit orders carry a risk of non-execution. Therefore limit orders are likely to be avoided by traders with a high demand for immediacy and also by those with valuable but perishable inside information. Second, limit orders are subject to the adverse selection problem. Limit orders leave traders exposed to innovations in fundamentals that could occur between the time an order is placed and the time it is executed. As a result, limit orders are relatively attractive when the variance of fundamentals is low. Bae *et al.* (2003) provide additional evidence of the impact of non-execution on the order type choice. They state that the proportion of limit orders monotonically decreases throughout the trading day because traders are less likely to submit limit orders when there is little time left until the market closes. Verhoeven *et al.* (2004) report that order imbalance is major determinant of the traders' decision to place market and limit orders. A similar point is made by Goldstein and Kavajecz (2004) in their study of circuit breakers on the two-day period of October 27-28, 1997 on the NYSE. They note that the extreme uncertainty concerning the ability to trade

continuously causes market participants to alter their behavior in that sellers use more market orders and less limit orders during the nine minutes before the trading halt.

Price limits share similar characteristics with circuit breakers and the market closure in that it practically closes continuous trading and orders outside the price limit become invalid. The non-execution cost becomes increasingly prominent as prices approach the limit price. And there is no reason to believe that adverse selection problem has improved during the half hour pre-hit period. Therefore, we hypothesize that investors will use more and more market orders as prices approach the limit to avoid the non-execution costs and possible deterioration in the adverse selection. We again focus on the side of the market that ultimately drives the limit hits, which is the buy side for the upper limit hits and the sell side for the lower limit hits.

The results are listed in Table VI.[19] Panels A and B report the magnitude of market buy orders and the ratio of market buy orders out of the total buy orders prior to the upper limit hits and market sell orders and the ratio of market sell orders out of total sell orders prior to the lower limit hits. Investors use considerably more market orders prior to the limit hits than on non-limit-hit days, among both regular order submissions and executed orders. In particular, investors submit increasingly more regular market buy/sell orders prior to the limit hits in both the absolute and the proportion terms, throughout almost all pre-hit intervals. For example, regular market buy orders rise from 0.39 in interval 1 to 3.34 in interval 10 for the pre-up group; the regular market sell orders rise from 0.34 to 2.92 for the pre-down group. The results on the executed market orders are less robust for the lower limit hits but they become significantly positive towards the limit hits.

[Insert Table VI]

We again compare the magnitude of market orders between the upper and the lower limit hits in the same regime. We find that the upper limit hits show significantly heavier use of market orders than the lower limit hits except on the executed market order volume. For example, the average three minute regular buy market order volume is 1.17 for the pre-up group, compared with

[19] We have also used the dollar amount of market orders and the frequency of market orders to conduct the same analysis. The results remain qualitatively similar.

0.89 for the pre-down group. It is 1.19 for the post-up group and significantly higher than 1.08 for the post-down group.

In Panel C of Table VI, we report the regression results of equation (2) on the share volume of the regular and executed market orders. The coefficients of SQINT are positive and significant for all groups, showing that investors choose to use more and more market orders to advance their positions in the order queues and as a result, more market orders are executed than on non-limit-hit days. Next, we observe that the pre-regime features a higher acceleration rate on the regular market orders than the post-regime. To illustrate, the acceleration rate for regular market orders is 0.053 for the pre-up group and it is 0.044 for the post-up group. Regular market sell orders accelerate at 0.050 for the pre-down group, relative to 0.034 of the post-down group. The differences in the acceleration rate of the executed market orders between two regimes are not significant. It can be understood that only the best priced and the timeliest placed orders are executed whereas investors can submit as many orders as they want to. Lastly, the persistence measures are 20.5 minutes for the regular market orders and 19.1 minutes for the executed market orders, averaged across the four groups. The persistence comparison between groups is insignificant.

In summary, we conclude that there exists a strong magnet effect on the order type choice prior to the limit hits. In order to achieve timely execution, investors choose to use increasingly more market orders, i.e. more market buy orders before the upper limit hits and more market sell orders before the lower limit hits. As a result, more market orders are executed than on non-limit-hit days. The choice of market orders reflects investors' eagerness to fulfill the transaction and avoid the cost of non-execution imposed by the price limit. In addition, we find that the pre-regime is characterized by higher acceleration rates than the post-regime and the upper limit hits tend to cause more market orders than the lower limit hits, especially in terms of the regular market orders. We do not observe significant changes in the order type on the opposite side of the limit hits.

IV. Robustness Analysis

A. Analysis of Non-Limit-Hit Days

We have so far concluded that there is a significant magnet effect when the price limit becomes imminent in a market with the price limit rule. We now introduce a control group of stocks matched by the time of the day for the same firm to further verify that the magnet effect is directly caused by the proximity to the price limit. While so doing, we extend the comparison to the half hour post-hit period to examine the behavior of the key variables.

We select the same stock's immediately preceding non-hit day for each limit hit as the control observation. Further, we choose the same time period corresponding to the half hour pre-hit period during the control day. In the end, the pre-up control group has 1399 observations, the post-up control group has 1,173 observations, the pre-down control group has 287 observations and the post-down control group has 484 observations. The post-hit period is defined as the half hour period after the lifting of the price limit on the limit hit days and the corresponding time period on the non-limit-hit days.

For each control group, we conduct the same analysis and compare it with the limit hit groups. Figures 2A, 2B and 2C highlight the differences between the pre-up group and its control group in terms of the trading volume, the quote revisions and the market buy order ratios.[20] From Figure 2, we observe that the standardized trading volume, volatility (as measured by the quote revisions), and the choice of market buy orders on non-limit-hit days are insignificant and there is no systematic pattern. Results on other market microstructure variables are qualitatively similar. Heavier transactions volume is observed during the post-hit period than on non-limit-hit days, but not as heavy as during the pre-hit period. High trading volume during the post-hit period may suggest that smart investors strategically pick on stocks that have hit the price limit, expecting a run-up in the following days, as stated in Seasholes and Wu (2004). We also find that high volatility lingers on for a short period after the limit hits within the same day, consistent with the volatility spillover compiled by Kim and Rhee (1997) using daily data from the Tokyo Stock Exchange.

[20] To conserve space, we present the results on selected variables. The results on other market variables also support that there is no magnet effect in the control groups.

In summary, we find no magnet effect on the firm and the time-of-the-day matched control group and the post-hit period does not exhibit the magnet effect either. Some evidence is found to indicate that the price discovery process is hampered by the limit hits because volatility and transactions volume remain higher during the post-hit period than the non-limit-hit control groups. We conclude that the magnet effect is unique to the time period when the trigger of the price limit becomes imminent. Investors respond to the potential interruption of continuous trading by jumping onto the bandwagon and accelerating their trading activities.

[Insert Figure 2]

B. The Magnet Effect vs. the Market Closure Effect

It is quite possible that the price behavior we observe prior to the limit hits may be the same as the price behavior just before the entire market closes on any trading day. If there is no difference between the two, then one may conclude that price limits represent premature market closures. Naturally, it is important to distinguish between the magnet effect and the market closure effect. We believe that the control group introduced in the previous section can be used to examine the difference between these two effects.

We identified the stocks that hit the limits during the last fifteen minutes of a trading day and compare them with the non-limit-hit group constructed in the same way. We find a significant magnet effect for the limit hit group but not for the control group, thus confirming that the magnet effect is different from the market closure effect.

C. The Magnet Effect vs. the Momentum effect

In the earlier part of the paper, we document that investors respond to the common signal of the proximity to the price limit by placing increasingly more orders, choosing more market orders and repositioning existing orders to advance the transactions, supporting the magnet effect. However, one should be aware that the magnet effect is not the only reason for the accelerated trading; it could be the results of the intraday positive feedback trading as investors purchase stocks that have risen and sell stocks that have declined during the earlier period of the day, as

documented by De Long *et al.* (1990) and Nofsinger and Sias (1999). If investors herd based on the lagged returns, the rate of return and other key variables studied in this study may exhibit momentum even if there is no price limit rule. Unfortunately, the differentiation of the magnet effect from the momentum effect is not an easy exercise, if not impossible.

In order to isolate the magnet effect from the momentum effect, we introduce a notion of "quasi limit hits." We impose a hypothetical 12% price limit to the post-regime limit hit days and identify the quasi limit hits if the stock price hits the hypothetical 12% price limit prior to the actual trigger of 15% price limit. We then compare the progressions of ΔDTL and trading volume between the quasi limit hits and actual limit hits using the same analysis as those introduced in the early part of the paper.[21] If no differences are observed between the two cases, the momentum effect is dominant for the both. However, a higher level of trading volume, a greater fluctuation in prices, and a significantly stronger acceleration pattern observed for the actual limit hit cases than the quasi limit hit cases may be considered as indirect evidence that the magnet effect is not the same as the intraday momentum effect.

Our quasi limit hit sample consists of 257 upper limit hits and 114 lower limit hits. Table VII summarizes the progressions of the change in the distance to limit (ΔDTL) and the standardized trading volume (VOL) during the half hour prior to the quasi limit hits. In Panel A, we report the average ΔDTL and VOL for each interval prior to the limit hits and the average across all intervals. We observe that ΔDTL and VOL are significant but are substantially smaller than the values for the corresponding pre-regime and post-regime limit hits. For example, the average three minute VOL for the quasi upper limit hits is 1.36, significantly smaller than 1.91 for the pre-up and 1.96 for the post-up groups. The differences in the magnitude are attributed to the magnet effect because both the pre-regime and the post-regime limit hits are bounded by the price limit rule, but which is not the fact for the quasi limit hits.

[21] To conserve space, we only report the results of ΔDTL and VOL in this section. All other key market variables exhibit similar results.

Furthermore, we examine the acceleration of ΔDTL and VOL for the quasi limit hit groups, reported in Panel B of Table VII. We document that both the upper and lower quasi limit hits exhibit a significant acceleration pattern as a result of positive feedback trading but the magnitude of the acceleration rate is significantly smaller than the actual limit hits. To illustrate, the acceleration rate of ΔDTL for the quasi upper limit hit group is 0.021 in contrast to 0.038 observed for the post-up group.[22] The acceleration rate of VOL is 0.041 for the quasi upper limit hit group compared with 0.076 for the post-up group.[23] F-tests at the bottom of Panel B, Table VII report the comparison between the quasi limit hits and the actual limit hits in terms of the acceleration rate and they are all significant at 1% level. The persistence comparisons between the quasi limit hits and the actual limit hits are not significant.

[Insert Table VII]

The significant differences in the magnitude and the acceleration rates estimated for ΔDTL and VOL between the quasi and the actual limit hits should be attributed to the magnet effect. As prices approach the limit price, investors react to the signal of reaching the price limit by jumping onto the bandwagon and accelerate their transactions to avoid non-execution costs.

D. A Market without Price Limits

We have attributed the difference between the quasi limit hits and the actual limit hits to the existence of the magnet effect based on the robustness test in the previous section. This is possible because the quasi and actual limit hits are introduced in the market where the price limit system is in place. Another interesting experiment is to conduct a similar test in a market without the price limit rule. In such a market without daily price limits, we may identify two groups of stocks which experience price changes of 12% and 15%, respectively and investigate the progression of key variables introduced in this study. In the absence of the price limit system, we should expect no

[22] The comparable figure for the actual upper limit hit group in the pre-regime period is 0.062 which is significantly greater than those of the quasi and actual limit hit groups in the post-regime period.

[23] The acceleration rate for the actual upper limit hit group in the pre-regime period is 0.102 which is again significantly greater than those of the quasi and actual limit hit groups in the post-regime period.

significant differences between the two groups each with 12% and 15% price changes because no magnet effect should exist and all we may observe is the intraday momentum effect generated by the feedback trading behavior.

We select the NASDAQ market for our experiment because it has more similarities with the KRX-listed stocks in terms of firm size, price level, and investor profiles than the NYSE. We choose the common stocks that traded on each of the trading day in our study period with the average number of daily transactions greater than 100 and with the average price greater than $5. Our NASDAQ sample amounts to 587 stocks whose intraday transaction data are retrieved from the Trade and Quote (TAQ) database. The filters in Bessembinder (2003) are adopted to eliminate the errors in the transaction data. In the absence of price limit rule in the NASDAQ market, we introduce the concept of "pseudo limit hits." To be consistent with our analyses of the KRX-listed stocks, we impose hypothetical 12% (between ±11.5% and ±12.5%) and 15% (between ±14.5% and ±15.5%) daily price limits to identify the pseudo upper and lower limit hits from September 1 to December 31, 1998. As a result, we identify 540 upper limit hits and 367 lower limit hits under the 12% price limit rule and 276 upper limit hits and 143 lower limit hits under the 15% price limit rule.

We are well aware that it is impossible to make cross-country comparisons due to the fundamental differences between the KRX and the NASDAQ. In lieu of cross-country comparisons, we rather examine and compare two pseudo limit hit cases in the same NASDAQ market to confirm that there are no differences between the two cases. This intra-market comparison within NASDAQ allows us to avoid the problem of comparing two markets of very different market microstructure. In the absence of daily price limits, two pseudo limit hit cases should share a common momentum effect and they should not be different from one to another, unlike the quasi and the actual limit hit cases in the KRX market. Hence, no difference between two pseudo limit hit cases on the NASDAQ market should be indirect indication that price discovery on the NASDAQ is not dictated by the magnet effect. Specifically, we expect to observe heavier transactions and an acceleration pattern prior to the pseudo limit hits as the result of intraday

positive feedback trading. However, there should not be any difference between the 12% pseudo limit hits and 15% pseudo limit hits in the absence of the magnet effect. Table VIII reports the regression results of the pseudo limit hit groups.

[Insert Table VIII]

We observe that the coefficients for the SQINT are significant for all regressions but the F-test at the bottom of Table VIII shows that the differences between two hypothetical regimes are uniformly insignificant for both ΔDTL and VOL. The insignificant differences between the 12% and the 15% regimes in the NASDAQ are in contrast with our earlier findings in the KRX in two aspects. First, we document that the pre-regime limit hits have a stronger acceleration pattern than the post-regime limit hits as a result of a narrower price limit rule. Second, we observe a significant difference in the acceleration rates between the quasi limit hits and the actual limit hits in both regimes because the latter incurs the magnet effect while it is absent for the former group.

Moreover, we compare the average ΔDTL and VOL between the hypothetical 12% and 15% regimes for the half hour period prior to the limit this and fail to find any significant differences between regimes or between the upper and the lower limit hits. Consequently, we attribute the lack of the differences between the two regimes in the NASDAQ to the absence of the magnet effect and conclude that the magnet effect is unique to a market with the price limit rule.

V. Conclusions

In this paper, we use the transaction files and the limit order book of the Korea Stock Exchange to examine the existence and the dynamics of the magnet effect. We provide the first comprehensive analysis of the magnet effect from five market variables (rates of return, trading volume, volatility, order flow and order type) and three dimensions (magnitude, acceleration and persistence). We conclude that there exists a strong magnet effect in all variables during on average twenty minutes prior to the limit hits. It is observed that investors alter their trading behavior when the price limit becomes imminent to assure order executions. More specifically, investors place increasingly more buy orders when prices approach upper limit prices and increasingly more sell

orders when prices approach lower limit prices. In addition, investors choose proportionally more market buy orders and constantly bid up stale buy orders when an upper limit hit is imminent. Conversely, investors choose more market sell orders and bid down stale sell orders in face of a potential lower limit hit. As a result, prices approach the limit prices at a progressively rising speed.

In addition, the fact that our dataset covers two price limit regimes enables us to make the comparisons between two regimes and isolate the momentum effect from the magnet effect. We compare the same direction limit hits between the 12% and the 15% price limit regimes and document that the breadth of the price limit has a significant impact on the acceleration rate of the magnet effect. The pre-regime features higher acceleration rates in almost all market variables. A narrower price limit implies a higher likelihood to cross the boundaries, holding all other factors constant, and the tension of non-execution will be built up more quickly and more strongly than in a wider price limit regime. Therefore, investors respond to the proximity of price limit more frantically than in a wider price limit regime.

Moreover, a sufficient number of observations for both the upper and the lower limit hits make it possible to examine the magnet effect under different market conditions. We conclude that the direction of the limit hits has a significant impact on the magnitude of the magnet effect. The upper limit hits feature heavier trading volume, more order submissions, more frequent quote revisions and proportionally more market orders than the lower limit hits during the pre-hit period. Investor psychology and the limited availability of short sales in the KRX may partially explain the differences between the upper and the lower limit hits. Lastly, we observe that the magnet effect sustains on average twenty minutes. The upper limit hits exhibit longer persistence than the lower limit hits but they are not statistically different from each other for most of the variables.

The magnet effect is further confirmed by the robustness tests. We do not find a magnet effect in the firm and the time-of-the-day matched groups. Our results of the magnet effect in the KRX are still robust after taking into account of the intraday momentum effect. We construct quasi limit hits by imposing 12% price limit to the post-regime and conclude that there are significant

differences between the quasi and the actual limit hits. The differences between the quasi and the actual limit hits in terms of the acceleration rate and the magnitude support our hypothesis that there is a magnet effect irrespective of the momentum effect and the proximity to the price limit alters investors' trading behavior to assure execution. Moreover, we document that there is no magnet effect in a market without the price limit rule, e.g. the NASDAQ. The lack of differences between the pseudo 12% limit hits and the 15% limit hits in the NASDAQ reinforces our claim that the magnet effect is driven by the price limit rule and is therefore unique to a market with the price limit rule.

References

Ackert, Lucy F., Bryan Church, and Narayanan Jayaraman, 2001, An experimental study of circuit breakers: the effects of mandated market closures and temporary halts on market behavior, *Journal of Financial Markets* 4, 185-208.

Admati, Anat, and Paul Pfleiderer, 1988, A theory of intraday patterns: volume and price variability, *Review of Financial Studies* 1, 3-40.

Arak, Marcelle, and Richard E. Cook, 1997, Do daily price limits act as magnets? The case of treasury bond futures, *Journal of Financial Services Research* 12:1, 5-20.

Bae, Kee-Hong, Hasung Jang, and Kyung Suh Park, 2003, Traders' choice between limit and market orders: evidence from NYSE stocks, *Journal of Financial Markets* 6, 517-538.

Berkman, Henk, and Onno Steenbeek, 1998, The influence of daily price limits on trading in Nikkei futures, *Journal of Futures Markets* 18, 265-279.

Bessembinder, Hendrik, 2003, Quote-based competition and trade execution costs in NYSE-listed stocks, *Journal of Financial Economics* 70, 385-422.

Butler, Peter A., and Larry H.P. Lang, 1991, The forecast accuracy of individual analysts: evidence of systematic optimism and pessimism, *Journal of Accounting Research* 29, 150-156.

Chan, Soon Huat, Kenneth Kim, and S. Ghon Rhee, 2005, Price limit performance: Evidence from transactions data and the limit order book, *Journal of Empirical Finance 12,* 269-290.

Chang, Rosita P., Toru Fukuda, Makoto Takano, and S. Ghon Rhee, 1993, Intraday behavior of the TOPIX, *Pacific-Basin Finance Journal* 1, 67-95.

Cho, David, Jeffrey Russell, George Tiao, and Ruey Tsay, 2003, The magnet effects of price limits: Evidence from high-frequency data on Taiwan stock exchange, *Journal of Empirical Finance* 10, 133-168.

Chordia, Tarun, Richard Roll, and Avanidhar Subrahmanyam, 2005, Evidence on the speed of convergence to market efficiency, *Journal of Financial Economics* 76, 271-292.

Christie, William G., Shane A. Corwin, and Jeffrey H. Harris, 2002, NASDAQ trading halts: the impact of market mechanisms on prices, trading activity, and execution costs, *Journal of Finance* 3, 1443-1478.

Connolly, Robert A., 1989, An examination of the robustness of the weekend effect, *Journal of Financial and Quantitative Analysis 24*, 133-169.

Corwin, Shane A., and Marc L. Lipson, 2000, Order flow and liquidity around NYSE trading halts, *Journal of Finance* 4, 1771-1801.

De Bondt, Werner F., and Richard H. Thaler, 1990, Do security analysts overreact?' *American Economic Review* 80, 52-57.

De Long, J. Bradford, Andrei Shleifer, Lawrence H. Summers, and Robert J. Waldmann, 1990, Positive feedback investment strategies and destabilizing rational speculation, *Journal of Finance* 45, 379-395.

Gerety, Mason S., and J. Harold Mulherin, 1992, Trading halts and market activity: an analysis of volume at the open and the close, *Journal of Finance* 5, 1765-1784.

Goldstein, Michael, and Kenneth Kavajecz, 2004, Trading strategies during circuit breakers and extreme market movements, *Journal of Financial Markets* 7, 301-333.

Greenwald, Bruce C., and Jeremy C. Stein, 1991, Transactional risk, market crashes, and the role of circuit breakers, *Journal of Business* 64, 443-462.

Hall, Anthony D., and Paul Korfman, 2001, Limits to linear price behavior: futures prices regulated by limits, *Journal of Futures Markets* 21, 463-488.

Hieronymus, Thomas A., 1971, Economics of futures trading (Commodity Research Bureau, New York.

Jain, Prem C., and Gun-Ho Joh, 1988, The dependence between hourly prices and trading volume, *Journal of Financial and Quantitative Analysis* 23, 269-283.

Kim, Kenneth A, and S. Ghon Rhee, 1997, Price limit performance: Evidence from the Tokyo Stock Exchange, *Journal of Finance* 32, 885- 901.

Kim, Kenneth A., 2001, Price limits and stock market volatility, *Economics Letters* 71, 131-136.

Kim, Kenneth A, and Richard Sweeney, 2002, Effects of price limits on information revelation, Working Paper.

Kuserk, Gregory J., Eugene Moriarty, Betsey Kuhn, and J. Douglas Gordon, 1989, An analysis of the effect of price limits on price movements in selected commodity futures markets, CFTC Division of Economic Analysis Research Report.

Leamer, Edward E., 1978, Specification searches: ad-hoc inference with non-experimental data, New York: John Wiley & Sons.

Lee, Charles M.C., Mark J. Ready, and Paul J. Seguin, 1994, Volume, volatility, and New York Stock Exchange trading halts, *Journal of Finance* 49, 183-214.

Lindley, Dennis V., 1957, A statistical paradox, *Biometrika* 44, 187-192.

Ma, Christopher K., Ramesh P. Rao, and R. Stephen Sears, 1989, Volatility, price resolution, and the effectiveness of price limits, *Journal of Financial Services Research* 3, 165-199.

McMillan, Henry, 1990, The effects of the S&P 500 futures market circuit breakers on liquidity and price discovery, Office of Economic Analysis, U.S. Securities and Exchange Commission, June.

Miller, Merton H., 1991, Volatility, episodic volatility and coordinated circuit-breakers, in S. Ghon Rhee and Rosita P. Chang ed.: *Pacific-Basin Capital Markets Research* Volume II, 23-47.

Nofsinger, John, and Richard W. Sias, 1999, Herding and feedback trading by institutional and individual investors, *Journal of Finance*, 2263-2295.

Seasholes, Mark, and Guojun Wu, 2004, Profiting from predictability: smart investors, daily price limits, and investor attention, Working Paper.

Slezak, Steve, 1994, A theory of the dynamics of security returns around market closures, *Journal of Finance* 49, 1163-1211.

Subrahmanyam, Avanidhar, 1994, Circuit breakers and market volatility: a theoretical perspective, *Journal of Finance* 49, 237-254.

Subrahmanyam, Avanidhar, 1995, On rules versus discretion in procedures to halt trade, *Journal of Economics and Business* 47, 1-16.

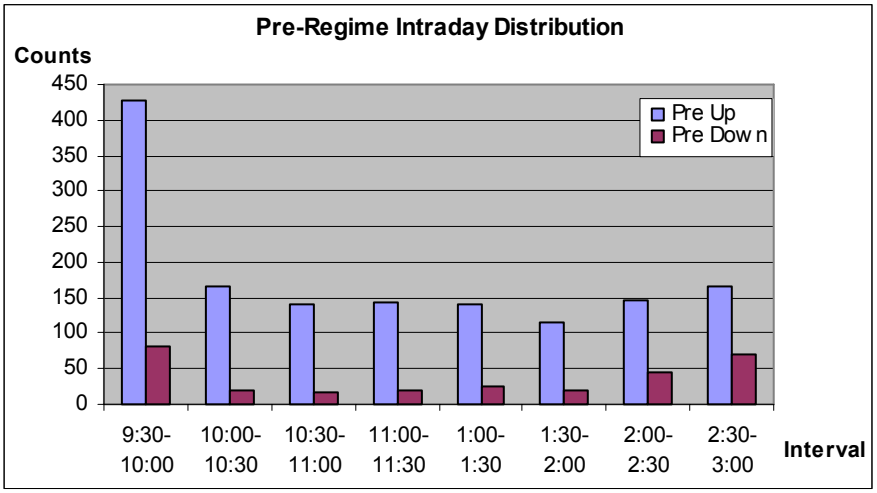
Verhoevena, Peter, Simon Ching, Hock Guan Ng, 2004, Determinants of the decision to submit market or limit orders on the ASX, *Pacific-Basin Finance Journal* 12, 1-18.

Wood, Robert A., Thomas H. McInish, and J. Keith Ord, 1985, An investigation of transaction data for NYSE stocks, *Journal of Finance* 40, 723-741.

Figure 1
Intraday Distribution of Price Limit Hits

Figure I plots the distribution of price limit hits during each half hour period in the trading day. Our sample of price limit hits is categorized into four groups: pre-up, post-up, pre-down and post-down groups based on the direction of limit hits and the price limit regime. The morning trading session in the pre-regime is 9:30AM - 11:30AM and it is 9:00AM - 12:00Noon in the post- regime. The afternoon trading session is 1:00PM - 3:00PM in both regimes.

(a) Pre-Regime



(b) Post-Regime

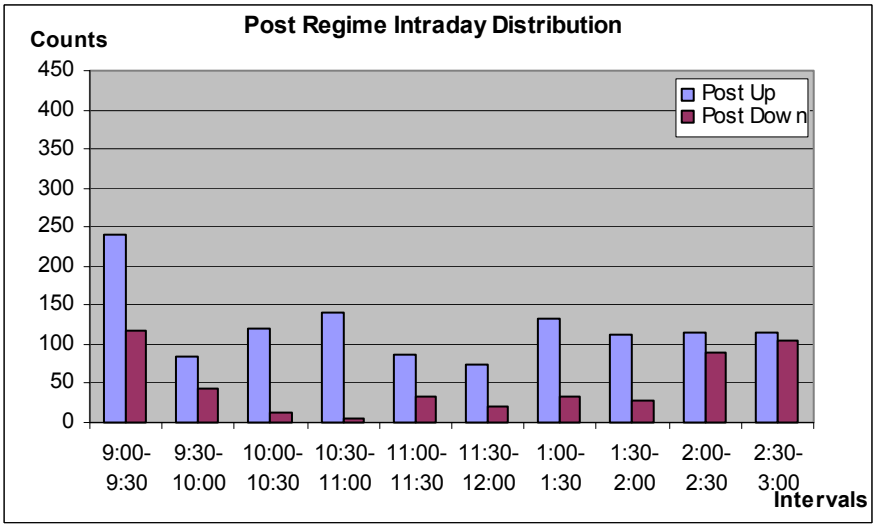
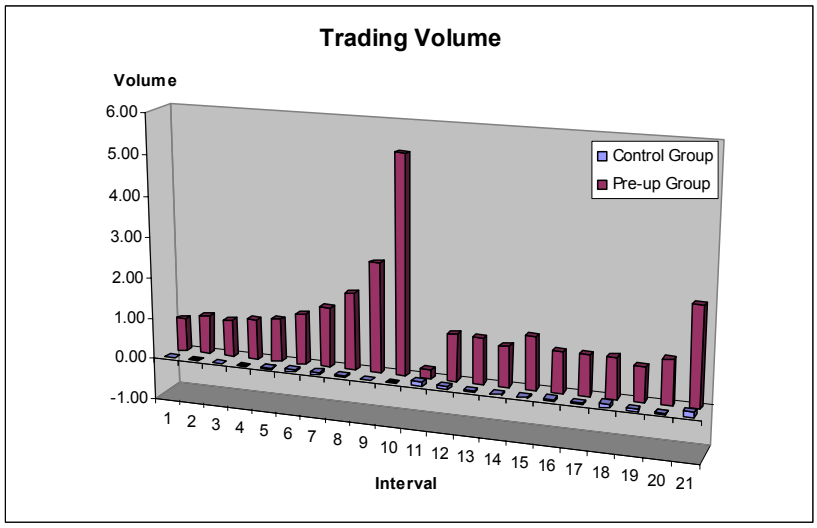


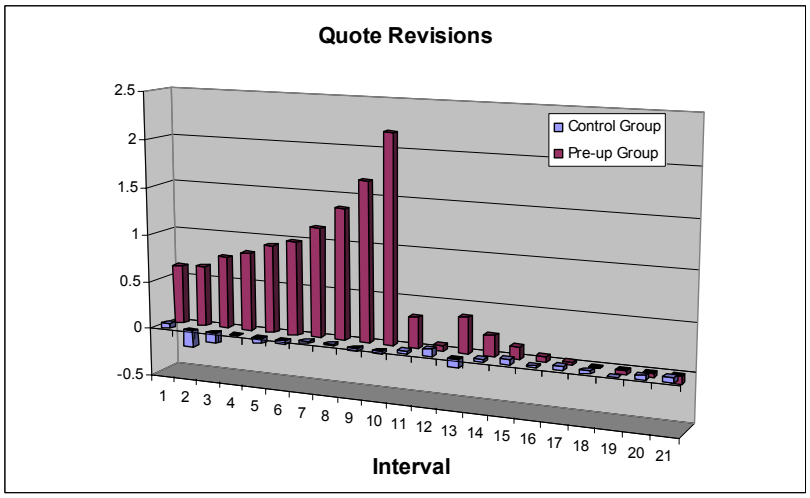
Figure 2
Non-Limit Hit Comparison

Figure 2 illustrates the differences between the pre-up group and its matched group. To conserve space, we only present the differences in trading volume, quote revisions and the ratio of market buy orders out of the trading volume. The control group consists of the days that are the closest previous non-limit-hit days relative to each limit hit day. We measure the market variables during the half hour pre-hit period and the half hour post-hit period for both the limit hit group and its control group. Interval 1 to interval 10 represents the ten three minute intervals prior to the first moment of limit hits. Interval 12 to interval 21 represents the ten three minute intervals after the lifting of the price limits. Interval 11 represent the time period from the first moment of the limit hit to the moment that the price limit is lifted. All the values are standardized by the mean and stated in terms of the standard deviation on the non-limit-hit days.

(a) Trading Volume



(b) Quote Revisions



(C) Market Buy Order Ratio

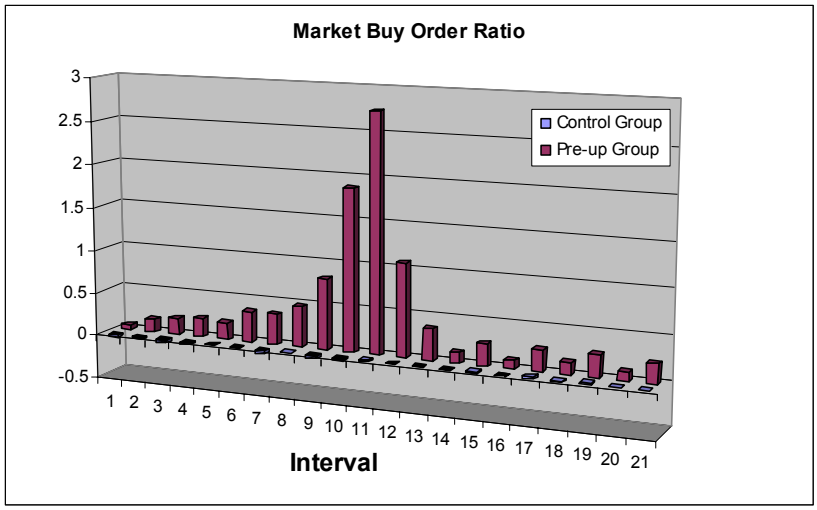


Table I
Summary Statistics of Limit Hits

Our sample includes all the limit hits from September 1, 1998 to March 31, 1999, excluding the days that both upper and lower limit hits occurred. Daily price limit was raised from 12% to 15% on December 7, 1998, which divides our study period into two regimes, the pre-regime, September 1-December 6, 1998 and the post-regime, December 8, 1998-March 31, 1999. Our sample is further classified into four groups based on the direction of the limit hits and the regime. They are: the pre-up, the pre-down, the post-up, the post-down groups, with the prefix signifying the regime and the suffix representing the direction of limit hits.

Panel A presents the following eight variables: (i) total number of limit hits; (ii) average number of limit hits per trading day; (iii) number of limit hits that occurred in the morning trading session; (iv) number of limit hits that occurred in the afternoon trading session; (v) number of limit hits that occurred at the market open; (vi) number of limit hits that closed at the limit prices; (vii) number of price continuations; and (viii) number of price reversals. If the stock closes at the upper/lower limit price on the limit-hit day and the following first non-limit-hit day opens at a higher/lower price, we define it as a price continuation. Likewise, if the stock closes at the upper/lower limit price on the limit-hit day and the following first non-limit-hit day opens at a lower/higher price, we define it as a price reversal. The values in the parentheses of item (3), (4), (5) and (6) are the ratios of this item to item (1). The values in the parentheses of (7) and (8) are the ratios of each item to item (6).

Panel B presents the mean, the median and the maximum values of the following three variables: 1) intraday multiple limit hits, which is the number of intraday limit hits on limit-hit days; 2) limit hit duration, which is the time lapse from the moment of the first limit hit to the last moment that prices stay at limit prices in a limit-hit day; 3) number of limit hits by an individual stock, which is the number of limit hits by an individual stock. Medians are reported in the parentheses and the maximums are reported in the brackets.

Panel A:

		PRE-UP		POST-UP		PRE-DOWN		POST-DOWN	
(1)	Total Number of Limit Hits	1449		1219		300		492	
(2)	Average Daily Limit Hit	18.1		16.5		3.8		6.6	
(3)	Morning Limit Hits	870	(60%)	744	(61%)	140	(47%)	234	(48%)
(4)	Afternoon Limit Hits	579	(40%)	475	(39%)	160	(53%)	258	(52%)
(5)	Limit Hits at Market Open	244	(17%)	148	(12%)	42	(14%)	91	(18%)
(6)	Close at Limit Prices	975	(67%)	794	(65%)	139	(46%)	267	(54%)
(7)	Price Continuation	776	(80%)	610	(77%)	73	(53%)	177	(66%)
(8)	Price Reversal	118	(12%)	115	(14%)	46	(33%)	73	(27%)

Panel B:

	PRE-UP	POST-UP	PRE-DOWN	POST-DOWN
Intraday Limit Hits	5.4	8.4	5.1	5.2
	(4)	(5)	(2)	(3)
	[94]	[288]	[90]	[75]
Limit Hit Duration (Minutes)	82	62	50	93
	(57)	(30	(11)	(32)
	[242]	[300]	[240]	[302]
Limit Hits by Individual Stocks	5.2	4.1	2.4	2.3
	(4)	(3)	(2)	(2)
	[21]	[14]	[7]	[11]

Table II
Rate of Return Progression

Table II reports the return progression during the half hour pre-hit period. The thirty minutes pre-hit period is measured backward from the first moment of limit hits on a limit hit day. It is further divided into ten three minute intervals, denoted by Interval 1 - Interval 10 from the furthest to the closest distance to the moment of limit hits. Distance to the limit, DTL, is the percentage distance at a given price to the upper price boundary on the upper limit hit days and to the lower price boundary on the lower limit hit days. $\Delta DTL_{k,t,,i,}$ the change in DTL for stock k on day t at interval i measures the rate of return. ΔDTL is standardized by the mean on non-limit-hit days, stated in terms of the standard deviation.

Panel A reports the standardized ΔDTL for each interval prior to the limit hits and the average three-minute ΔDTL across all intervals. Panel B reports the regression results of equation (2) in the main text for the upper and lower limit hits respectively, where the dependent variable is ΔDTL. INT takes the value of 1 to 10. SQINT is the squared INT. For the regression on upper/lower limit hits, $Dummy_1$ takes the value of unity if the observation belongs to the pre-up/pre-down group and 0 if it belongs to the post-up/post-down group; vice versa for $Dummy_2$. F-test reports the comparison of the coefficients of SQINT between two regimes. P value is bracketed. The values in the parentheses are the standard errors. All values are significant at 1% level. Persistence at the bottom of Panel B is equal to $3*(10+\beta/2\gamma)$ in number of minutes for the pre-up, post-up, pre-down and post-down groups respectively. ** and * next to the persistence measure indicate that the upper limit hits persistence is slower than that for the lower limit hits in the same regime at 1% and 5% level respectively.

Panel A: Magnitude of ΔDTL

INTERVAL	PRE-UP	PRE-DOWN	POST-UP	POST-DOWN
1	0.33	0.42	0.25	0.31
2	0.30	0.15	0.30	0.13
3	0.33	0.36	0.37	0.34
4	0.50	0.14	0.45	0.38
5	0.36	0.53	0.46	0.60
6	0.51	0.33	0.69	0.58
7	0.75	0.37	0.78	0.80
8	1.11	0.78	0.98	0.99
9	1.61	1.03	1.31	1.11
10	3.20	4.03	2.51	3.30
AVERAGE	0.90	0.81	0.81	0.85

Panel B: Regression Results

	UPPER LIMIT HITS		LOWER LIMIT HITS	
$DUMMY_1$	0.935	(0.063)	1.349	(0.158)
$DUMMY_2$	0.599	(0.063)	0.794	(0.116)
$DUMMY_1$*INT	-0.439	(0.026)	-0.704	(0.066)
$DUMMY_2$*INT	-0.23	(0.026)	-0.375	(0.049)
$DUMMY_1$* SQINT	0.062	(0.002)	0.087	(0.006)
$DUMMY_2$* SQINT	0.038	(0.002)	0.055	(0.004)
ADJUSTED R-SQUARE	0.347		0.313	
F-TEST	50.93	[<0.0001]	18.85	[<0.0001]
PERSISTENCE (Minutes)	19.38 ** (Pre-Up)	20.92 * (Post-Up)	17.86 (Pre-Down)	19.77 (Post-Down)

Table III
Trading Volume Progression

Table III reports the progression of trading volume during the half hour pre-hit period. The thirty minute pre-hit period is measured backward from the first moment of the limit hits within a limit hit day, which is further divided into ten three minute intervals, denoted by Interval 1 - Interval 10 from the furthest to the closest distance to the moment of limit hits. Raw trading volume is measured in each three minute interval and standardized by the mean share volume on the non-limit-hit days, stated in terms of the standard deviation.

Panel A reports the average trading volume for each interval prior to the limit hits and the average three minute trading volume across all intervals. ** next to the Average indicates that the average three minute trading volume for the upper limit hits are significantly higher than those of the lower limit hits in the same regime at 1% level. Panel B reports the regression results of equation (2) in the main text, where the dependent variable is trading volume. INT takes the value of 1 to 10. SQINT is the squared INT. For the regression on upper/lower limit hits, $Dummy_1$ takes the value of unity if the observation belongs to the pre-up/pre-down group and 0 if it belongs to the post-up/post-down group; vice versa for $Dummy_2$. All values are significant at 1% level. F-test reports the coefficient comparison of SQINT between two regimes. P value is bracketed. The values in the parentheses are the standard errors. The last row of Panel B reports the persistence measure for the pre-up, post-up, pre-down and post-down groups respectively.

Panel A: Magnitude of Trading Volume

INTERVAL	PRE-UP	PRE-DOWN	POST-UP	POST-DOWN
1	0.81	0.28	0.88	0.20
2	0.95	0.35	0.95	0.17
3	0.90	0.52	0.97	0.29
4	0.97	0.84	1.07	0.26
5	1.06	0.30	1.33	0.26
6	1.24	0.44	1.36	0.39
7	1.47	0.62	1.72	0.55
8	1.88	1.01	2.02	0.71
9	2.68	1.47	3.43	0.81
10	5.31	4.28	4.09	2.71
AVERAGE	1.91 **	1.23	1.96 **	0.77

Panel B: Regression Results

	UPPER LIMIT HITS		LOWER LIMIT HITS	
$DUMMY_1$	1.954	(0.237)	1.523	(0.291)
$DUMMY_2$	1.569	(0.245)	0.852	(0.222)
$DUMMY_1$*INT	-0.751	(0.095)	-0.767	(0.117)
$DUMMY_2$*INT	-0.486	(0.100)	-0.441	(0.090)
$DUMMY_1$* SQINT	0.102	(0.008)	0.096	(0.010)
$DUMMY_2$* SQINT	0.076	(0.009)	0.058	(0.008)
ADJUSTED R-SQUARE	0.128		0.151	
F-TEST	4.58	[0.032]	9.16	[0.003]
PERSISTENCE (Minutes)	18.96 (Pre-Up)	21.41 (Post-Up)	18.02 (Pre-Down)	18.59 (Post-Down)

Table IV
Volatility Progression

This table reports the progression of volatility during the half hour pre-hit period. Three volatility measured as applied. ABSRETURN is the absolute rate of return from the last transaction price of the previous interval to the last transaction price of the current three minute interval. HLOW is the difference between the high and the low prices during each interval. Quote revisions are the number of bid or ask price changes during each interval. All the measurements are standardized by the mean on non-limit-hit days, stated in terms of the standard deviation.

Panel A and B report the three volatility measurements for the pre-regime and the post-regime respectively. The average volatility for each interval and across all intervals are reported in Panel A and B. ** next to the Average indicates that the average three minute volatility measurement during the pre-hit period for this group is significantly higher than those for the comparison group in the same regime at 1% level. Panel C reports the regression results of equation (2) in the main text. For the regression on the upper/lower limit hits, $Dummy_1$ takes the value of unity if the observation belongs to the pre-up/pre-down group and 0 if it belongs to the post-up/post-down group; vice versa for $Dummy_2$. F-test reports the coefficient comparison for SQINT between two regimes. P value is bracketed. The values in the parentheses are standard errors. All other values are significant at 1% level unless crossed. + indicates that the value is not significant. ++ indicates that the value is significant at 5% level. The last row of Panel C reports the persistence measure, $3*(10+\beta/2\gamma)$, for the four limit-hit groups, stated in the number of minutes.

Panel A: Magnitude for Pre-Regime

	PRE-UP			PRE-DOWN		
INTERVAL	ABSRETURN	HILOW	QUOTE REVISIONS	ABSRETURN	HILOW	QUOTE REVISIONS
1	0.46	0.51	0.62	0.42	0.57	0.26
2	0.41	0.48	0.64	0.37	0.51	0.21
3	0.42	0.52	0.76	0.58	0.55	0.32
4	0.43	0.58	0.82	0.60	0.60	0.44
5	0.43	0.51	0.93	0.68	0.38	0.50
6	0.44	0.58	0.98	0.50	0.57	0.45
7	0.53	0.73	1.15	0.38	0.44	0.53
8	0.81	0.89	1.37	0.64	0.75	0.59
9	1.30	1.37	1.67	1.13	1.08	0.71
10	3.21	2.07	2.18	6.14	2.70	1.28
AVERAGE	0.85	0.88	1.11 **	1.15 **	0.91	0.53

Panel B: Magnitude for Post-Regime

	POST-UP			POST-DOWN		
INTERVAL	ABSRETURN	HILOW	QUOTE REVISIONS	ABSRETURN	HILOW	QUOTE REVISIONS
1	0.09	0.53	0.48	0.34	0.56	0.07 $^{+}$
2	0.23	0.54	0.51	0.39	0.60	0.11 $^{++}$
3	0.28	0.52	0.59	0.55	0.74	0.13 $^{++}$
4	0.33	0.54	0.66	0.43	0.73	0.24
5	0.38	0.66	0.73	0.69	0.85	0.22
6	0.44	0.72	0.86	0.96	0.93	0.25
7	0.61	0.77	0.96	0.93	1.14	0.24
8	0.72	0.93	1.08	1.02	1.07	0.34
9	0.98	1.23	1.31	1.15	1.19	0.36
10	2.56	1.67	1.59	5.26	2.47	0.43
AVERAGE	0.66	0.85	0.87 **	1.17 **	1.10 **	0.24

Panel C: Regression Results

		UPPER LIMIT HITS			LOWER LIMIT HITS		
		ABSRETURN	HILOW	QUOTE REVISIONS	ABSRETURN	HILOW	QUOTE REVISIONS
$DUMMY_1$		1.260	0.894	0.746	2.145	1.327	0.339
		(0.066)	(0.054)	(0.049)	(0.228)	(0.160)	(0.092)
$DUMMY_2$		0.595	0.716	0.504	1.448	0.877	0.049 $^{+}$
		(0.068)	(0.055)	(0.054)	(0.175)	(0.122)	(0.072)
$DUMMY_1$*INT		-0.560	-0.276	-0.086	-1.105	-0.518	-0.056 $^{+}$
		(0.027)	(0.022)	(0.021)	(0.094)	(0.064)	(0.038)
$DUMMY_2$*INT		-0.291	-0.143	-0.016^{+}	-0.711	-0.188	0.030 $^{+}$
		(0.028)	(0.023)	(0.022)	(0.073)	(0.050)	(0.030)
$DUMMY_1$* SQINT		0.069	0.038	0.022	0.132	0.061	0.013
		(0.002)	(0.002)	(0.002)	(0.008)	(0.006)	(0.003)
$DUMMY_2$* SQINT		0.043	0.023	0.012	0.095	0.031	0.001 $^{+}$
		(0.002)	(0.002)	(0.002)	(0.006)	(0.004)	(0.003)
ADJUSTED R-SQUARE		0.262	0.334	0.322	0.277	0.309	0.087
F-TEST		57.49 [<0.0001]	29.56 [<0.0001]	13.38 [0.0003]	12.82 [0.0003]	18.10 [<0.0001]	15.05 [0.004]
PERSISTENCE (Minutes)	Pre	17.83	19.11	24.14	17.44	17.26	23.54
	Post	19.85	20.67	28.00	18.77	20.90	N/A

Table V
Order Flow Progression

Table V reports the progression of order flow during the half hour pre-hit period. We focus on the side of the market that leads to the limit hits, buy side for the upper limit hits and sell side for the lower limit hits. Panel A reports the volume and the ratio of regular and revised buy/sell orders for the pre-up/pre-down group. The average order flow in each interval and across all intervals is reported. Panel B presents similar statistics, only for the post-regime. ** next to the Average indicate that the average three minute order flow measurement during the pre-hit period for this group is significantly higher than those for the comparison group in the same regime at 1% level.

Panel C reports the regression results of equation (2) in the main text on the share volume of regular and revised buy/sell orders for the upper/lower limit hits. INT takes the value of 1 to 10. SQINT is the interval squared. For the regression on the upper/lower limit hits, $Dummy_1$ takes the value of unity if the observation belongs to the pre-up/pre-down group and 0 if it belongs to the post-up/post-down group; vice versa for $Dummy_2$. F-test reports the coefficient comparison for SQINT between two regimes. P value is bracketed. Values in the parentheses are standard errors. All values are significant at 1% level unless crossed. + indicates that the value is not significant. ++ indicates that the value is significant at 5% level. The bottom of Panel C reports the persistence for each limit-hit group. ** next to the persistence indicates that this persistence measure is slower than that for the comparison group in the same regime at 1% level.

Panel A: Magnitude for Pre-Regime

	PRE-UP				PRE-DOWN			
	REGULAR BUY		REVISED BUY		REGULAR SELL		REVISED SELL	
INTERVAL	VOLUME	RATIO	VOLUME	RATIO	VOLUME	RATIO	VOLUME	RATIO
1	0.49	0.39	-0.01 +	0.25	0.24	0.17	-0.28	0.20 ++
2	0.52	0.31	-0.06 +	0.24	0.23	0.23	-0.30	0.13 +
3	0.56	0.33	-0.03 +	0.25	0.29	0.18	-0.20	0.34
4	0.74	0.36	0.08 +	0.34	0.34	0.17	-0.12 +	0.26
5	0.77	0.40	0.05 +	0.36	0.52	0.33	-0.17	0.20
6	0.98	0.47	0.09	0.39	0.40	0.27	-0.20	0.20
7	1.21	0.54	0.27	0.51	0.53	0.33	-0.09 +	0.47
8	1.57	0.62	0.55	0.66	0.80	0.50	0.13 +	0.49
9	2.05	0.70	0.86	0.77	1.10	0.62	0.29	0.50
10	2.76	0.72	1.29	0.91	2.28	0.84	0.80	0.59
AVERAGE	1.17 **	0.49**	0.33 **	0.50**	0.67	0.35	0.03	0.36

Panel B: Magnitude for Post-Regime

	POST-UP				POST-DOWN			
	REGULAR BUY		REVISED BUY		REGULAR SELL		REVISED SELL	
INTERVAL	VOLUME	RATIO	VOLUME	RATIO	VOLUME	RATIO	VOLUME	RATIO
1	0.39	0.25	-0.03 $^{+}$	0.31	0.31	0.26	-0.35	0.27
2	0.50	0.30	-0.04 $^{+}$	0.38	0.31	0.34	-0.32	0.28
3	0.58	0.36	-0.03 $^{+}$	0.43	0.32	0.35	-0.19	0.33
4	0.63	0.37	0.02 $^{+}$	0.41	0.36	0.35	-0.18	0.34
5	0.77	0.44	0.12 $^{+}$	0.46	0.44	0.51	-0.07 $^{+}$	0.51 $^{++}$
6	0.92	0.47	0.18 $^{+}$	0.55	0.59	0.53	-0.09 $^{+}$	0.42
7	1.06	0.49	0.36	0.64	0.59	0.53	-0.13	0.44
8	1.33	0.59	0.49	0.76	0.72	0.57	0.06 $^{+}$	0.51
9	1.68	0.58	0.70	0.85	0.73	0.68	0.19	0.61
10	2.24	0.57	1.15	1.05	1.33	0.70	0.46	0.68
AVERAGE	1.01 **	0.45	0.33 **	0.59**	0.57	0.48	-0.01	0.45

Panel C: Regression Results

		UPPER LIMIT HITS		LOWER LIMIT HITS	
		REGULAR BUY	REVISED BUY	REGULAR SELL	REVISED SELL
		VOLUME	VOLUME	VOLUME	VOLUME
$DUMMY_1$		0.887	0.776	0.838	0.550
		(0.061)	(0.074)	(0.129)	(0.150)
$DUMMY_2$		0.695	0.671	0.593	0.480
		(0.066)	(0.080)	(0.097)	(0.118)
$DUMMY_1$*INT		-0.195	-0.194	-0.269	-0.173
		(0.025)	(0.029)	(0.053)	(0.059)
$DUMMY_2$*INT		-0.095	-0.130	-0.083 $^{++}$	-0.087 $^{+}$
		(0.027)	(0.032)	(0.040)	(0.047)
$DUMMY_1$* SQINT		0.038	0.030	0.038	0.025
		(0.002)	(0.003)	(0.005)	(0.005)
$DUMMY_2$* SQINT		0.025	0.025	0.015	0.015
		(0.002)	(0.003)	(0.004)	(0.004)
ADJUSTED R-SQUARE		0.383	0.298	0.217	0.205
F-TEST		15.26 [<0.0001]	1.86 [0.17]	21.27 [<0.0001]	2.23 [0.14]
PERSISTENCE (Minutes)	Pre	22.30 **	20.30	19.38	19.62
	Post	24.30	22.20	21.70	21.30

Table VI
Order Type Progression

This table reports the progression of order compositions during the half hour pre-hit period. We focus on the market order from the side of the market that leads to the limit hits. Panel A reports the share volume and the ratio of regular and executed market buy/sell orders for the pre-up/pre-down groups. Panel B reports the same statistics, only for the post-regime. The three minute average for each interval and across all ten intervals are reported in Panel A and B. ** next to the Average indicate that the three minute average during the pre-hit period for this group is significantly higher than those for the comparison group in the same regime at 1% level.

Panel C reports the regression results of equation (2) in the main text on the share volume of market orders. INT takes the value of 1 to 10. SQINT is the INT squared. For the regression on the upper/lower limit hits, $Dummy_1$ takes the value of unity if the observation belongs to the pre-up/pre-down group and 0 if it belongs to the post-up/post-down group; vice versa for $Dummy_2$. The values in the parentheses are the standard errors. F-test reports the coefficient comparison for SQINT between two regimes. P value is bracketed. All other values are significant at 1% level unless crossed. + indicates that the value is not significant. ++ indicates that the value is significant at 5% level. Persistence is reported at the bottom of Panel C.

Panel A: Magnitude for Pre-Regime

	PRE-UP				PRE-DOWN			
	REGULAR MKT BUY		EXECUTED MKT BUY		REGULAR MKT SELL		EXECUTED MKT SELL	
INTERVAL	VOLUME	RATIO	VOLUME	R ATIO	VOLUME	RATIO	VOLUME	R ATIO
1	0.39	0.22	0.25	0.06	0.34	0.10 +	0.16 +	0.13 +
2	0.60	0.38	0.30	0.15	0.45	0.26	0.49 ++	0.28
3	0.55	0.28	0.13 +	0.19	0.58	0.28	0.49	0.12 +
4	0.69	0.41	0.22	0.22	0.46	0.24	0.93	0.25 ++
5	0.67	0.35	0.37	0.20	0.58	0.36	0.09 +	0.16 +
6	1.00	0.54	0.38	0.35	0.53	0.25	0.54 +	0.06 +
7	1.01	0.57	0.31	0.36	0.71	0.35	0.33*	0.12 ++
8	1.39	0.72	0.48	0.47	1.00	0.49	0.55	0.45
9	1.91	0.96	0.69	0.82	1.25	0.62	0.65	0.35
10	3.34	1.77	1.32	1.87	2.92	1.78	1.30	1.43
AVERAGE	1.17 **	0.65**	0.68	0.48**	0.89	0.46	0.77	0.33

Panel B: Magnitude for Post-Regime

	POST-UP				POST-DOWN			
	REGULAR MKT BUY		EXECUTED MKT BUY		REGULAR MKT SELL		EXECUTED MKT SELL	
INTERVAL	VOLUME	RATIO	VOLUME	RATIO	VOLUME	RATIO	VOLUME	RATIO
1	0.54	0.31	0.37	0.30	0.57	0.19	0.31 $^{++}$	0.34
2	0.48	0.26	0.39	0.24	0.68	0.32	0.23 $^{++}$	0.39
3	0.64	0.36	0.35	0.36	0.71	0.36	0.14 $^{+}$	0.30
4	0.76	0.41	0.43	0.40	0.74	0.32	0.48	0.33
5	0.82	0.47	0.43	0.36	0.78	0.42	0.33	0.37
6	1.02	0.51	0.51	0.52	1.02	0.48	0.72	0.5
7	1.15	0.61	0.60	0.56	1.11	0.59	0.77	0.69
8	1.45	0.75	0.71	0.83	1.22	0.66	0.66	0.62
9	1.81	0.85	1.00	1.06	1.28	0.68	0.88	0.64
10	3.12	1.58	1.45	2.16	2.65	1.41	1.67	1.66
AVERAGE	1.19 **	0.62**	0.79	0.70**	1.08	0.53	0.84	0.59

Panel C: Regression Results

		UPPER LIMIT HITS		LOWER LIMIT HITS	
		REGULAR MKT BUY VOLUME	EXECUTED MKT BUY VOLUME	REGULAR MKT SELL VOLUME	EXECUTED MKT SELL VOLUME
$DUMMY_1$		1.003	0.628	1.070	0.731
		(0.081)	(0.106)	(0.176)	(0.263)
$DUMMY_2$		0.951	0.627	1.037	0.475
		(0.087)	(0.095)	(0.133)	(0.158)
$DUMMY_1$*INT		-0.331	-0.248	-0.365	-0.209*
		(0.033)	(0.039)	(0.073)	(0.100)
$DUMMY_2$*INT		-0.249	-0.178	-0.205	-0.156
		(0.036)	(0.036)	(0.055)	(0.061)
$DUMMY_1$* SQINT		0.053	0.031	0.050	0.026
		(0.003)	(0.003)	(0.006)	(0.008)
$DUMMY_2$* SQINT		0.044	0.025	0.034	0.026
		(0.003)	(0.003)	(0.005)	(0.005)
ADJUSTED R-SQUARE		0.289	0.304	0.247	0.318
F-TEST		3.81 [0.05]	1.61 [0.21]	6.63 [0.01]	0.01 [0.93]
PERSISTENCE (Minutes)	Pre	20.63	18.00	19.05	17.94
	Post	21.50	19.32	20.96	21.00

Table VII
Quasi Limit Hits

This table presents the progression of ΔDTL, the change in the distance to the limit and the standardized trading volume (VOL) during the half hour prior to the quasi limit hits under the post-regime. We define the quasi limit hits as the cases that prices trigger hypothetically imposed 12% price limit rule before actually triggering the limit hits during the post regime. The sample includes 257 quasi upper limit hits and 114 quasi lower limit hits.

Panel A reports the average ΔDTL and VOL for each interval and across all intervals during the half hour pre-hit period. Panel B reports the regression results of equation (2) in the main text on ΔDTL and VOL for the quasi upper and lower limit hit groups. The values in the parentheses are the standard errors. The bottom two rows in Panel B highlight the coefficients of SQINT for the actual limit hit groups and the F-test reports the comparisons of the coefficients of SQINT between the quasi limit hit groups and the actual limit hit groups. F values are bracketed. All the values and comparisons are significant at 1% level.

Panel A: Magnitude

	QUASI UPPER LIMIT HITS		QUASI LOWER LIMIT HITS	
INTERVAL	ΔDTL	VOL	ΔDTL	VOL
1	0.16	0.80	0.27	0.28
2	0.17	0.95	0.31	0.19
3	0.13	0.88	0.00	0.11
4	0.14	0.97	0.66	0.49
5	0.14	1.07	0.42	0.30
6	0.21	1.15	0.54	0.33
7	0.31	1.34	0.85	0.48
8	0.34	1.52	0.74	0.55
9	0.55	1.94	1.12	0.60
10	1.03	3.01	2.26	1.01
AVERAGE	0.32	1.36	0.72	0.43

Panel B: Regression Results

	QUASI UPPER LIMIT HITS		QUASI LOWER LIMIT HITS	
	ΔDTL	VOL	ΔDTL	VOL
INTERCEPT	0.371	1.214	0.546	0.32
	(0.065)	(0.10)	(0.233)	(0.134)
INT	-0.155	-0.259	-0.21	-0.067
	(0.027)	(0.040)	(0.095)	(0.055)
SQINT	0.021	0.041	0.035	0.013
	(0.002)	(0.004)	(0.008)	(0.005)
ADJUSTED R-SQUARE	0.052	0.113	0.100	0.040
F-TEST				
Pre-Regime Limit Hits	0.062 [132.90]	0.102 [77.55]	0.087 [24.11]	0.096 [23.39]
Post-Regime Limit Hits	0.038 [24.55]	0.076 [4.80]	0.055 [4.62]	0.058 [15.57]

Table VIII
A Market without the Price Limit: NASDAQ

This table reports the regression results on ΔDTL and VOL for the pseudo limit hits in the NASDAQ when the 12% and the 15% price limit rules are hypothetically imposed. Our sample consists of 540 upper limit hits and 367 lower limit hits under the 12% price limit rule and 276 upper limit hits and 143 lower limit hits under the 15% price limit rule. All the variables are defined the same as in the Korea Stock Exchange. $Dummy_1$ takes the value of unity if the observation is from the 12% price limit rule and 0 otherwise. $Dummy_2$ takes the value of unity if the observation is from the 15% price limit rule and 0 otherwise. The values in the parentheses are the standard errors. The comparison of the coefficients of SQINT between the 12% and 15% price limit regimes are reported at the bottom as the F-test. The p-value of the F-test is bracketed. All the coefficients are significant at 1% level unless marked. + indicates it is not significant. ++ indicates that it is significant at 5% level.

Regression Results

	UPPER 12% vs. UPPER 15%		LOWER 12% vs. LOWER 15%	
	ΔDTL	VOL	ΔDTL	VOL
$DUMMY_1$	3.440	6.409	4.385	3.491
	(0.428)	(1.640)	(0.520)	(0.769)
$DUMMY_2$	4.457	4.293 $^{+}$	6.120	4.847
	(0.600)	(2.294)	(0.835)	(1.231)
$DUMMY_1$*INT	-1.809	-1.450 $^{++}$	-2.176	-0.786 $^{++}$
	(0.178)	(0.685)	(0.216)	(0.321)
$DUMMY_2$*INT	-2.101	-0.585 $^{+}$	-2.701	-1.301 $^{++}$
	(0.249)	(0.958)	(0.347)	(0.514)
$DUMMY_1$* SQINT	0.235	0.159	0.262	0.109
	(0.016)	(0.061)	(0.019)	(0.028)
$DUMMY_2$* SQINT	0.263	0.106 $^{+}$	0.312	0.154
	(0.022)	(0.085)	(0.031)	(0.046)
ADJUSTED R-SQUARE	0.183	0.023	0.185	0.080
F- TEST	1.050 $^{+}$ [0.31]	0.250 $^{+}$ [0.62]	1.890 $^{+}$ [0.17]	0.700 $^{+}$ [0.40]