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An Analysis of the Magnet Effect under Price Limits*

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ABSTRACT

Using the Korea Stock Exchange's transaction data and limit order book, we document the accelerating patterns of market activity before limit hits. We confirm the existence of the magnet effect from several key market microstructure variables, using a parsimonious quadratic function of the time until the price limit hit. In addition, this paper is the first to isolate the intraday momentum effect from the magnet effect during the period before stock prices hit daily price limits.

I. INTRODUCTION

A price limit is a market-wide rule that sets the range of individual asset's price change from its previous day's closing prices, i.e. stock prices cannot move below or above certain percentage from its previous day's closing prices. The majority of the Asian and European stock markets use price limit rules to curb excessive price movement, unlike US equity markets which function without the daily limit system. Since the price limit directly affects the price discovery process, its efficacy has been the subject of analyses in early studies, which focus on the days before and after limit hits and conclude that the price limit delays price discovery and does not moderate volatility.[1] This paper focuses on the intraday implications of the price limit rule.

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1 Please refer to Kim and Rhee (1997) and their references to early studies.

The magnet effect has been used interchangeably with the gravitational or self-fulfilling effect, which refers to market participants' herding behavior when the possibility of trading interruption materially arises and, as a consequence, this exact fear leads to the realization of the interruption. It is first noted in circuit-breaker related research. Miller (1991), Greenwald and Stein (1991), Gerety and Mulherin (1992) point out that the possibility of a trading halt after a price change of a fixed percent would make investors generally nervous. As a result, investors make the magnet effect self-fulfilling. Market close shares some similarities with price limit since both curb continuous trading. Slezak (1994) predicts that market closures increase pre-closure trading volume because closures delay the resolution of information uncertainty and impose more risk on informed and uninformed traders.

However, the implications drawn from trading halts and market closures may not be directly applicable to price limits. The former two mechanisms cease trading completely, but price limits allow trading to continue as long as the prices to be executed are within the allowable range. In addition, specialists often call a trading halt at their discretion and this information is not public information, while price limits are rule-based and all market participants observe the current price and its distance from that day's limit prices.

Subrahmanyam (1994) provides the first concrete predictions of the magnet effect based on an intertemporal 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 same idea is reflected in Subrahmanyam (1995), in which it is noted that discretionary closures, such as trading halts can bring more information into the closure decision. Therefore, discretionary trading halts can be less susceptible to the magnet effect than rule-based halts, such as price limits.

Earlier studies have focused on the futures market to investigate the magnet effect of price limits. Kuserk et al. (1989) and Arak and Cook (1997) examine Treasury bond futures contracts and do not find evidence of a magnet effect. Berkman and Steenbeek (1998) investigate Nikkei 225 futures contracts traded in the Osaka Securities Exchange (OSE) and the Singapore International Monetary Exchange (SIMEX) (now a part of the Singapore Exchange) and attribute the lack of the magnet effect to strong arbitrage links between OSE and SIMEX. Hall and Korfman (2001) report that agricultural futures contracts do not exhibit a magnet effect even though they are subject to price limits.

Recent studies have extended the analysis of the magnet effect to equity markets. Ackert et al. (2001) find that market participants accelerate their transactions if a trading interruption is imminent in an experimental setting. Cho et al. (2003) document a tendency for stock prices to accelerate toward the upper bound and weak evidence of acceleration toward the lower bound in the Taiwan stock market. Chan et al. (2005) find that price limits, albeit as wide as

30% in the Bursa Malaysia (previously the Kuala Lumpur Stock Exchange), do not improve information asymmetry, delay the arrival of informed traders, and exacerbate order imbalance before limit hits.

Three major limitations are observed in earlier studies. First, the accelerating nature of the magnet effect and its manifestation in market activities are not examined. Even the existence of the magnet effect has not been established given the mixed empirical findings to date. Second, with the exception of Cho et al. (2003), the possibility of an intraday momentum effect has not been controlled for when examining the magnet effect. Cho et al. (2003) introduce the price change from the opening price as a momentum proxy, but recognize that their efforts to distinguish the momentum and magnet effects might not be effective since the two effects are highly correlated. Third, previous studies do not distinguish between the magnet effects associated with hitting upper versus lower limits.

Our paper addresses the above three limitations using tick data from the Korea Stock Exchange (KRX) market, a market well-known for frequent limit hits. We make four major contributions to the relevant literature. First, acceleration patterns of the magnet effect are illustrated before limit hits. We utilize a time-distanced quadratic function, which is parsimonious, robust and common to all the market microstructure variables examined. This quadratic function is applied to a panel data on limit hit cases and it indicates that trading starts to accelerate on average 20 min before a limit price is hit. This paper is the first systematic demonstration of the accelerating microstructure patterns associated with the magnet effect. Second, we isolate the magnet effect after controlling for intraday momentum effect by comparing actual and quasi-limit hits (characterized by price changes that are large but not large enough to hit a limit). We find that the magnet effect is responsible for approximately over 50% of observed acceleration in the microstructure variables examined, a result which has not been established before. Additionally, we further demonstrate that the magnet effect does not exist on the United States. Nasdaq market where no price limit rule is imposed. Third, we find that the magnet effect is significant and equally applicable to both upper and lower limit hits. Fourth, we examine the impact of firm size on the magnet effect. No consistent differences in acceleration rates are observed across small, medium and large cap stocks, indicating that the magnet effect is not confined to small-cap stocks, although small-cap stocks trigger price limits more frequently than medium- and large-cap stocks.

The remainder of this paper is organized as follows: Section II presents the institutional background of the KRX market and summary statistics of limit hits. Section III contains a detailed discussion of the methodology. In Section IV, we characterize the magnet effect using five market microstructure variables in three dimensions of magnitude, acceleration rates and duration. Section V investigates the distinction between the magnet effect and the intrady momentum effect. Section VI reports the impact of firm size on the magnet effect and Section VII concludes the paper.

II. INSTITUTIONAL BACKGROUND AND SUMMARY STATISTICS

A. Institutional background

The KRX is one of the most active stock exchanges in the world. At the end of 2006, the KRX had 731 listed companies and the total market capitalization is $705 billion. The average monthly share turnover is 22%. The KRX is an order-driven market, where buy and sell orders compete for the best prices. A call market method, where a batch of buy and sell orders are accumulated and executed at one single price, is used to determine the morning and afternoon open prices and the closing price. The rest of the regular trading hours rely on a continuous auction method. Trading outside the regular trading hours is subject to different trading rules, and this paper only examines transactions during regular trading hours in our sample period.[2] Price limit is a long standing trading rule in KRX. The current price limit is 15%, raised from 12% on December 7, 1998. Quotes and orders with prices outside this range are invalidated for transactions. Different from trading halts or other types of circuit breakers, price limit rules allow investors to continue trading as long as the prices are within the specified ranges.

B. Summary statistics

This paper uses KRX tick-by-tick data of 3 months before and after December 7, 1998, on which the price limit was raised from 12% to 15%.[3] This event date divides our sample into two regimes: the pre-regime, from September 1 to December 6, 1998 and the post-regime, from December 8, 1998 to March 31, 1999. To minimize complications associated with illiquidity, our sample includes only common stocks that had at least 100 average daily trades during the sample period. Our sample has 385 stocks, totaling US$52.7 billion in capitalization and the average firm size is US$137 million as of September 1, 1998. Using the same sorting standards as the KRX fact book, our sample has 220 small-cap firms, 77 medium-cap firms, and 88 large-cap firms and they cover 39 out of the 41 industries.[4] Three hundred and fifty-four out of these 385 stocks have at least one instance of limit hit during our study period.

2 The pre-hours and after-hours have different trading rules and the design is to give investors more opportunities to trade outside regular trading hours. During pre-open hours, from 7:30 to 8:30 A.M., transactions can take place at previous day's closing price. During after hours, 15:10 to 15:30 P.M., trading can be executed at the closing price of the day. Additionally, during 15:30–18:00 P.M., periodic call auction takes place every 30 minutes and prices are subject to daily price limit rules and ± 5% of the closing price of the day.

3 On the same day, the KRX closed Saturday trading and extended its morning session by 1 h, from 9:30–11:30 a.m. to 9:00 a.m.–12:00 noon.

4 KRX Factbook (2005) uses the following cut-off points to sort stocks into three size categories: small-cap stocks, market capitalization below 35 billion won; medium-cap stocks, between 35 billion won and 75 billion won; large-cap stocks, above 75 billion won.

An upper limit hit is identified when $P_{k,t} > (1+\text{LIMIT})\text{CP}_{k,t-1} - \text{TICK}_{k,t}$, where $P_{k,t}$ is an execution price of stock k on day t; $\text{CP}_{k,t-1}$ is stock k's closing price on day $t-1$; LIMIT is daily price limit, 12% in the pre-regime and 15% in the post-regime; $\text{TICK}_{k,t}$ is the tick size for stock k at $P_{k,t}$. A lower limit hit is identified when $P_{k,t} < (1-\text{LIMIT})\text{CP}_{k,t-1} + \text{TICK}_{k,t}$.[5] Since price limit does not prohibit trading completely, it is possible that multiple limit hits occur on the same day for the same stock. To mitigate any confounding effect from multiple hits, we only include the first time limit hit of a stock on a given day as an observation. In addition, we include only limit hits that occur before 14:50 because trading stops during the last 10-min period in preparation for the closing call auction. Four price limit sub-groups are formed: pre-up; pre-down; post-up; and post-down with the prefix representing the regime and the suffix representing the direction of limit hits. Figure 1 plots the intraday distribution of limit hits.

The most limit hits are clustered in the first half-hour of the morning trading session and the number of limit hits levels off during mid-day trading but rises before the market close. This is consistent with the well-documented pattern that market open and market close feature higher volatility and heavier trading activities. However, the market open in the afternoon session does not show significant differences from other mid-day trading.

Table 1 presents more detailed statistics of price limit hits. Panel A lists the number of limit hits in the four groups of limit hits. Our sample includes a total of 1,449 (pre-up), 300 (pre-down), 1,219 (post-up), and 492 (post-down) limit hits, respectively. The average daily upper limit hits are 18.1 and 16.5 and lower limit hits are 3.8 and 6.6 in the pre- and the post- regimes, respectively. There are much more upper limit hits than lower limit hits in the sample, which is consistent with an upward market trend during the study period. Korea's major market index, Korea composite stock price index increased 66% in the pre-regime and an additional 20% in the post-regime.

In addition, market open in the morning accounts for 17% (12%) of upper limit hits and 14% (18%) of lower limit hits in the pre- (post-) regime. Around 65% of upper limit hits and 50% of lower limit hits close at limit prices, which are labeled as locked limit hits. Subsequent to locked limit hits, considerably more price continuations are observed rather than price reversals at the next day's open. For example, on average 78% of locked upper limit hits and 62% of locked lower limit hits are followed by price continuation, much higher than the equal probability of 50%. A high likelihood of price continuation is consistent with the delayed price discovery hypothesis tested by Kim and Rhee (1997): if the price discovery process is interrupted by limit hits, it will resume the process as the market reopens, thus continuing its earlier trend.

Moreover, there is an asymmetry between upper and lower limit hits in that lower limit hits are less likely followed by price continuation than upper limit

5 Prices do not need to reach actual limit prices to effectively trigger price limits because of the tick rule. One tick is the minimum price movement and it is dependent on the stock price level.

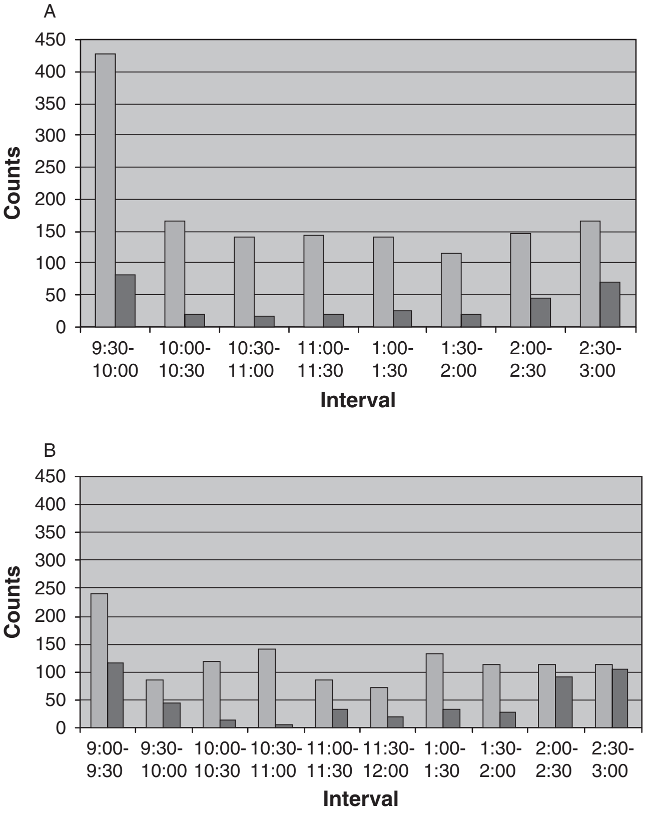

Figure 1 Intraday Distribution of Price Limit Hits.
Plots the distribution of price limit hits in half an hour interval during the trading day in the pre- and post-regimes. Price limit hits are identified as instances when prices reach the floor or ceiling prices governed by daily price limits for the first time within a trading day. The pre-regime is from September 1 to December 6, 1998 when price limit is 12% and the post-regime is from December 7, 1998 to March 31, 1999 when the price limit is 15%. The sample of limits hits are groups in four categories: the pre-up, the pre-down, the post-up, and the post-down limit hits, with the prefix representing the regime and the suffix representing the direction of limit hits. The morning trading session in the pre-regime is 9:30 a.m.–11:30 a.m. and it is 9:00 a.m.–12:00 noon in the post-regime. The afternoon trading session is 1:00 p.m.–3:00 p.m. in both regimes. The bars on the left in blue represent upper limit hits and the bars on the right in purple represent lower limit hits. (A) Pre-Regime. (B) Post-Regime.

hits. This may be explained by investors' over-optimistic sentiment and the tendency of overreacting to positive news. De Bondt and Thaler (1990) and Butler and Lang (1991) report that financial analysts systematically produce over-optimistic forecasts on stock prices and earnings. Following these suggestions, investors are prone to chase upward trends more persistently than downward trends.

Table 1 Descriptive statistics

	Pre-up	Pre-down	Post-up	Post-down
Panel A: Limit hits summary statistics				
Total limit hits	1449	300	1219	492
Daily limit hits	18.1	3.8	16.5	6.6
Morning limit hits	870 (60%)	140 (47%)	744 (61%)	234 (48%)
Afternoon limit hits	579 (40%)	160 (53%)	475 (39%)	258 (52%)
Limit hits at market open	244 (17%)	42 (14%)	148 (12%)	91 (18%)
Locked limit hits	975 (67%)	139 (46%)	794 (65%)	267 (54%)
Price continuation	776 (80%)	73 (53%)	610 (77%)	177 (66%)
Price reversal	118 (12%)	46 (33%)	115 (14%)	73 (27%)
Panel B: Intraday statistics				
Multiple limit hits per day				
Mean	5.4	5.1	8.4	5.2
Median	(4)	(2)	(5)	(3)
Maximum	[94]	[90]	[288]	[75]
Duration of limit hits (minutes)				
Mean	82	50	62	93
Median	(57)	(11)	(30	(32)
Maximum	[242]	[240]	[300]	[302]
Limit hits by individual stocks				
Mean	5.2	2.4	4.1	2.3
Median	(4)	(2)	(3)	(2)
Maximum	[21]	[7]	[14]	[11]

The daily and intraday summary statistics of limit hits. Price limit hits are identified as instances when prices reach the floor or ceiling prices governed by daily price limits in KRX. Our sample of limit hits are groups into four categories: the pre-up, the pre-down, the post-up, and the post-down limit hits, with the prefix representing the regime and the suffix representing the direction of the limit hit. The pre-regime is from September 1 to December 6, 1998 when price limits are 12% and the reminder of the period is the post-regime when price limits are 15%.
Panel A presents summary statistics of limit hits for our sub-groups. It lists the total number of limit hits and the average daily limit hits. It also shows the number of limits hits that occurred in the morning, in the afternoon trading sessions, and at the market open, Values in parentheses are ratios these limit hits relative to the total number of limit hits. We further define locked limit hits as cases when prices stay at limit prices until the market closes. If a limit hit locks at the upper (lower) limit price and the subsequent first non-limit-hit day opens at a higher (lower) price, it is defined as price continuation. Price reversal is identified if the market reopens at a lower (higher) price subsequent to a locked upper (lower) limit hit. The percentage of price continuation and reversals, shown in parentheses are relative to the number of locked limit hits.
Panel B presents intraday statistics of limit hits. It presents the mean, the median (in parentheses) and the maximum (in brackets) of three variables: (1) number of limit hits per day; (2) duration of limit hits, defined as the time period from the first moment of a limit hit to the last moment that prices stay at limit prices; (3) number of limit hits by an individual stock that has at least one limit hit in the study period.

Panel B of Table 1 shows that most stocks trigger price limits repeatedly within a limit hit day. The average number of intraday limit hits ranges from 5.1 of pre-down limit hits to 8.4 of post-up limit hits. The limit hit duration is the time period from the first time limit hit to the first time that the execution price deviates from the limit price after the hit, which varies on average from 50 min for pre-down limit hits to 93 min for post-down limit hits.[6] The maximum number of limit-hit-days by an individual stock ranges from 7 for pre-down limit hits to 21 for pre-up limit hits.

III. RESEARCH METHODOLOGY

A. Time-distanced quadratic modeling

The primary objective of this paper is to confirm the existence of the magnet effect. We use a time-distanced quadratic function to model the trading activities before limit hits.

$$\text{Market Microstructure Variable}_{k,t,i} = \alpha + \beta \cdot INT_{k,t,i} + \gamma \cdot SQINT_{k,t,i} + \varepsilon_{k,t,i},$$

where INT takes the value of 1–10 from the furthest to the closest 3-min interval before price limit hits, and SQINT is the squared INT. *k*, *t*, *i* is the index for stock *k*, day *t* and interval *i*, respectively. Dummy variables are introduced to the baseline model to facilitate the comparison of estimated coefficients between pre- and post-regimes and between upper and lower limit hits. The choice of a time-distanced quadratic function is justified for the convenience of gauging the pattern of acceleration across five sets of dependent variables. Rather than fitting different non-linear functions to a set of variables, we rely on this quadratic function which is simple but robust across all five variables. The choice is also motivated by our purpose of demonstrating the existence of the magnet effect, knowing that the price limit already occurs, rather than predicting when and whether the limit hit is going to happen.

Five market microstructure variables are introduced as dependent variables: price return, trading volume; volatility; order flow; and the order types, which are of most interest to investors and academicians. Each of the variables is standardized by subtracting its mean and divided by its standard deviation measured on non-limit-hit-days in respective regimes. The standardization is to control the U-shape intraday trading pattern documented in earlier research. We focus on a 30-min period immediately preceding limit hits because this period is considered long enough to capture the dynamics of the magnet effect and short enough not to be confounded by other events. Chordia et al. (2005) suggest that price adjustments associated with weak form market efficiency are not instantaneous but well under way within 30 min.

The baseline model allows us to examine the behavior of each variable in three dimensions: (i) magnitude; (ii) acceleration rates; and (iii) duration of acceleration. First, the magnitude of standardized market microstructure variables measures the degree of abnormal market activities as limit prices are approached. Second, the acceleration rate of each variable is measured by the estimated coefficient of SQINT (γ) in the above time-distance-based regression

6 When prices remain at the limit prices until the end of the trading day, the duration is defined as the time period from the limit hit to the market close.

during the 30-min pre-hit period. We believe that acceleration rates represent the key attribute of the magnet effect. As described by Subrahmanyam (1994), investors start to panic when continuous trading cannot be assured, resulting in the perverse effect of increasing price volatility. For example, when the market is trending up, buyers are prone to submit buy orders quickly to ensure execution at a lower price and sellers may be more patient and hold on to their sell orders for a higher price. The imbalances between the buy and sell orders drive stock prices to reach the upper limit. Lastly, we define the duration of magnet effect as the time period during which we observe accelerated market activities, from the time of the expected minimum level of variable to the time of the limit hit. β and γ jointly determine the minimum point of a quadratic function. If γ is positive, the minimum point of the convex curve is obtained for INT$=-\beta/2\gamma$. Therefore, the duration of acceleration is $3\times(10+\beta/2\gamma)$ min.

B. Magnet effect versus intraday momentum effect

The second objective of this paper is to identify the magnet effect after controlling for the intraday momentum effect. This is not an easy task because both forces might lead to accelerating trading activities. An intraday momentum effect on the basis of high-frequency transaction data has not been well-defined in the literature while price momentum over intermediate-term investment horizons (ranging from 3 months to 1 year) has been extensively researched.[7] In this paper, we take the following three approaches to make this distinction.

First, we hypothesize that the momentum effect is dominated by the magnet effect if the pre-regime period with its narrower price limit band features higher acceleration rates than the post-regime period. A narrower price limit band will be associated with more intense acceleration driven by the magnet effect since the likelihood of triggering price limits is higher. In contrast, a narrower price limit band should be associated with lower acceleration rates as far as the momentum effect is concerned because a wider range of price movement should trigger stronger speculation and more trend-chasing.

Second, we construct quasi-limit hit cases in the post-regime and compare them with actual limit hits in both pre- and post-regimes. Quasi-limit hits under the post-regime are incidences where prices reach 12% above or below the previous day's closing prices before hitting the price limit of 15% later on the same day. If the actual limit hits in the pre-regime exhibit higher acceleration rates than quasi-limit hits in the post-regime, it suggests that the magnet effect dominates since in both instances the price movement relative to the prior day's close is the same 12%. In addition, the comparison between quasi-limit hits and actual limit hits in the post-regime will allow us to

7 Refer to Jegadeesh and Titman (1993, 2001), Griffin et al. (2003), Chan et al. (1996), Hong and Stein (1999), Conrad and Kaul (1993), Moskowitz and Grinblatt (1999), Grundy and Martin (2001), among others.

differentiate the momentum effect from the magnet effect. Actual limit hits are driven by both magnet and momentum effects whereas the quasi-limit hits are driven by the momentum since they represent large price changes but not large enough yet to hit the limit. Therefore, the difference between, for example, acceleration rates estimated for actual limit hits in the post-regime period and those of quasi-limit hits will help measure the impact of the magnet effect.

Third, we impose hypothetical 12% and 15% price limits on Nasdaq securities. These hypothetical limit hits are referred to as pseudo-limit hits. Since there is no price limits on the Nasdaq market, no differences in acceleration rates are expected between the two hypothetical price limit regimes on the Nasdaq. On the KRX market, the 12% limit band in the pre-regime is expected to exhibit more intense acceleration than the 15% limit band in the post-regime. The absence of a difference on the Nasdaq market would be strong evidence of a magnet effect caused by price limits.

To summarize, our methodology goes beyond those in past studies in that we define the magnet effect in a time-distanced functional model and review the behavior of five market microstructure variables in three dimensions: the magnitude, acceleration rates, and the duration of the period of acceleration. Moreover, we identify the magnet effect while controlling for intraday momentum effects and confirm that the magnet effect is driven by price limits per se. The empirical results are reported in Sections IV, V, and VI.

IV. EMPIRICAL RESULTS

A. Magnitude of market microstructure variables

This section provides the definitions and the stylized facts of five market microstructure variables: the rates of return, trading volume, volatility, order flow, and order type. Since the variable constructions are similar, we use the rates of return as an example to demonstrate the computation. First obtain the raw return in each 3-min interval, being the percentage change between the last transaction prices from two consecutive intervals. It is standardized by subtracting the mean and divided by the return standard deviation for this stock at the same time interval across non-limit-hit days.[8]

$$\text{Upper Limit Hits} : RET_{k,t,i} = (P_{k,t,i} - P_{k,t,i-1})/P_{k,t,i-1}$$
$$\text{Lower Limit Hits} : RET_{k,t,i} = (P_{k,t,i-1} - P_{k,t,i})/P_{k,t,i-1}$$

$$STRET_{k,t,i} = (RET_{k,t,i} - MRET_{k,i})/SDRET_{k,i} \quad MSTRET_i = \sum STRET_{k,t,i}/N_i$$

8 We include limit hits that occurred during the first half hour of trading in the morning and afternoon sessions even though they do not have all ten 3-minute intervals. However, we do not extend the half hour pre-hit period into another trading session. Our empirical results are not sensitive to the sample selection.

$P_{k,t,i}$ is the last transaction price of stock k on day t at interval i. $RET_{k,t,i}$ is the 3-min rate of return from interval $i-1$ to interval i on day t for stock k. $RET_{k,t,i}$ is standardized by subtracting the mean ($MRET_{k,i}$) and divided by the standard deviation ($SDRET_{k,i}$) of stock k at interval i within respective regimes. Lastly, we compute the cross-sectional average of rates of return ($MSTRET_i$) for each interval i, where N_i is the number of limit hits in interval i.

Trading volume is measured by the share volume of transactions during each interval. We also measure the dollar amount of transactions and the frequency of transactions and their results are qualitatively similar to those based on share volume. We use three widely accepted intraday volatility measures: (i) the absolute value of returns; (ii) high-low price differences; and (iii) the number of quote revisions within each 3-min interval. To conserve space, we report the results based on absolute returns, ABSRETURN, and the other two variables provide similar results.

In addition, we examine the order flow from the side of the market that ultimately leads to limit hits, which is the buy-side for upper limit hits and the sell-side for lower limit hits. Order flow is the share volume of all orders that submitted during the interval, which indicates investors' eagerness to trade. We also measure order imbalances using the ratio of buy (sell) orders out of the total amount of submitted orders for upper (lower) limit hits.[9] Lastly, we investigate the choice between market and limit orders, which together consists of over 99% of total orders. The immediacy of market orders versus more patient limit orders could also reveal investors' eagerness to trades.

Figure 2 plots the cross sectional averages of each variable during the 10 3-min intervals before limit hits. Three empirical regularities emerge from Figure 2. First, all market microstructure variables are significantly positive during the 30-min pre-hit period and their magnitude rises as prices approach price limits. Increasing positive values imply that investors intensify their trading activities when price limits are being approached, consistent with the predictions of the magnet effect. We characterize the rising pattern of respective variables formally in the next section.

Second, upper limit hits draw heavier trading volume, greater order flow, and make use of a greater number of market orders than lower limit hits in the same regime, particularly during the intervals closest to limit hits. In contrast, lower limit hits are associated with higher volatility than upper limit hits in the same regime and the average 3-min rates of return do not significantly differ. The lack of short sale infrastructure in the KRX could contribute to heavier volumes of upper limit hits. Investors can capitalize on their positive expectations by placing more buy orders, but the high costs associated with short sales inhibit the capitalization of negative expectations. As a result, investors are restricted

9 The results on order imbalances are qualitatively similar to those of order flow. We report their acceleration rates and duration in later sections.

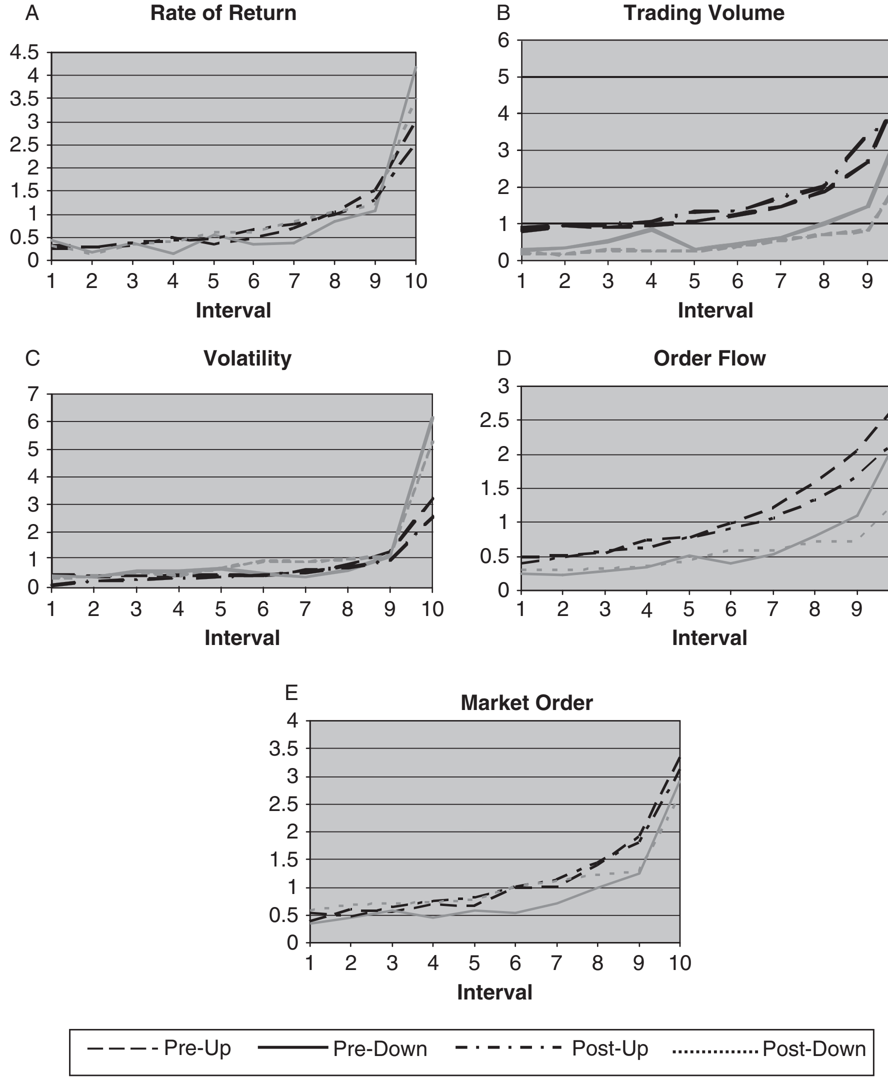

Figure 2 Behavior of Market Microstructure Variables before Limit Hits. (A–E) plots the cross sectional average of five market microstructure variables during the half hour period before limit hits for the four price limit hit groups. Intervals 1–10 represent the 10 3-min intervals before limit hits from the furthest to the closest interval. The variables are rate of return, trading volume, volatility, order submission (buy orders on upper limit hit days and sell orders on lower limit hit days), and volumes of market orders (market buy orders on upper limit hit days and market sell orders on lower limit hit days). All the values are standardized by subtracting the mean and dividing by the standard deviation on non-limit-hit days. The four groups are: the pre-up, the pre-down, the post-up, and the post-down limit hits, with the prefix representing the regime and the suffix representing the direction of limit hits.

from chasing a downward trend and fewer transactions take place before lower limit hits.[10]

Third, pre-regime limit hits do not show significantly heavier trading activities than post-regime limit hits across the 30-min pre-hit period. However, the trading activities for pre-regime limit hits tend to become slightly higher than those of post-regime limit hits during the last 6–9 min before limit hits.

In summary, we conclude that investors intensify their transactions when limit hits become imminent. Price variations, trading volume, volatility, order flow and market orders rise substantially during the 30-min period before limit hits. In addition, the direction of limit hits has a strong impact on the magnitude of trading activities, while the width of price limits does not show substantial impact. There seems to be an accelerating pattern before limit hits by casual observation and we examine this possibility more rigorously in the next section.

B. Acceleration rates

Acceleration is the most direct measure of the magnet effect considering its self-fulfilling nature. We run two sets of regressions for upper and lower limit hits, respectively. Within each regression, dummy variables are introduced to differentiate the pre- and post-regimes. Table 2 only reports γ values estimated from the quadratic function.[11] Panel A through E each uses a 2×2 matrix to contrast pre- with post-regimes and upper with lower limit hits. We observe that market activities accelerate significantly before the limit hits and the acceleration rates are sensitive to the width of daily price limit bands. Acceleration rates are consistently higher in the pre-regime with a 12% limit band than in the post-regime with a 15% limit band. As we discussed earlier in the research methodology section, higher acceleration in the pre-regime indicates that the intraday momentum effect is subsumed by the magnet effect during the 30-min period before limit hits. In Section V, we take two further steps to isolate the momentum and the magnet effect by introducing quasi- and pseudo-limit hits.

i. Rates of return

We observe from Panel A of Table 2 that all four limit hit cases (pre-up, pre-down, post-up, and post-down) have significantly positive coefficients and the goodness of fit is fairly strong. γ-Values are 0.06 for pre-up limit hits, 0.09 for pre-down limit hits, 0.04 for post-up limit hits, and 0.06 for post-down limit

10 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 materially none.

11 The intercept term α and the loadings on the linear term β are not reported here since they do not directly reveal information on the acceleration rates. β's are used later for the calculation of duration combined with γ's.

Table 2 Acceleration rates of market microstructure variables

γ	Upper limit hits	Lower limit hits	*F*-test (upper versus lower)
Panel A: Rates of return			
Pre-regime	0.06 (0.002)	0.09 (0.01)	32.95 [<0.0001]
Post-regime	0.04 (0.002)	0.06 (0.004)	17.44 [<0.0001]
Adjusted R^2	0.34	0.32	
F-test			
Pre- versus post-regime	32.22 [<0.0001]	17.43 [<0.0001]	
Panel B: Trading volume			
Pre-regime	0.10 (0.01)	0.10 (0.01)	0.09 [0.76]
Post-regime	0.08 (0.01)	0.06 (0.01)	1.39 [0.24]
Adjusted R^2	0.13	0.15	
F-test			
Pre- versus post-regime	4.58 [0.03]	9.16 [0.003]	
Panel C: Volatility			
Pre-regime	0.07 (0.002)	0.13 (0.01)	103.46 [<0.0001]
Post-regime	0.04 (0.002)	0.10 (0.01)	200.05 [<0.0001]
Adjusted R^2	0.26	0.28	
F-test			
Pre- versus post-Regime	57.49 [<0.0001]	12.82 [0.0003]	

γ	Upper limit hits		Lower limit hits	
	Buy Volume	Buy ratio	Sell volume	Sell ratio
Panel D: Order flow				
Pre-regime	0.04 (0.002)	0.006 (0.001)	0.04 (0.01)	0.01 (0.002)
Post-regime	0.02 (0.002)	0.002 (0.001)	0.02 (0.004)	0.006 (0.003)
Adjusted R^2	0.38	0.29	0.22	0.24
F-test				
Pre- versus post-regime	15.26 [<0.0001]	32.28 [<0.0001]	21.27 [<0.0001]	16.93 [<0.0001]

γ	Upper limit hits		Lower limit hits	
	Market buy volume	Market buy ratio	Market sell volume	Market sell ratio
Panel E: Market order				
Pre-regime	0.05 (0.003)	0.03 (0.002)	0.05 (0.006)	0.03 (0.004)
Post-regime	0.04 (0.003)	0.02 (0.002)	0.03 (0.005)	0.02 (0.003)
Adjusted R^2	0.29	0.18	0.25	0.16
F-test				
Pre- versus post-regime	3.81 [0.05]	3.91 [0.05]	6.63 [0.01]	8.16 [0.004]

Panels A through E of Table 2 report the estimated acceleration rates of five market microstructure variables using the quadratic function in the main text. OLS regression is run for upper and lower limit hits respectively and dummy variables are used to differentiate the pre- and the post-regimes. The dependent variables are the rate of return in panel A, trading volume in panel B, market volatility in panel C, order flow (the share volume and the ratio of buy (sell) orders on upper (lower) limit hit days] in panel D, and market orders (the share volume and the ratio of market buy (sell) orders on upper (lower) limit hit days] in panel E. The independent variables are INT and SQINT. INT takes the value of 1 to 10, from the furthest to the closest 3-minute interval prior to limit hits. SQINT is the squared INT. The acceleration rate is defined as the coefficient of SQINT in the quadratic function.
In each panel, it reports the estimated coefficients of SQINT (γ), the standard errors in parentheses, and the adjusted R^2. We select limit hits that occur before 2:50PM to avoid the last 10 minute call auction period. All dependent variables are standardized by their mean and standard deviation of non-limit-hit days. *F*-tests report the coefficient comparison between the pre- and the post-regimes for all variables and between upper and lower limit hits for rates of return, trading volume and volatility. *P*-values of *F*-tests are reported in brackets. All coefficient estimations are significant at 1% level.

hits. A positive coefficient of SQINT delineates a convex function of rates of return and confirms the existence of the magnet effect.

In addition, we compare the acceleration rates between two regimes and between upper and lower limit hits. The bottom row and the last column reports *F* tests between pre- and post-regimes and between upper and lower limit hits, respectively.[12] Pre-regime limit hits have significantly higher acceleration rates than post-regime limit hits for both upper and lower limit hits. Higher acceleration rates in the pre-regime confirm our hypothesis that the magnet effect prevails over the intraday momentum effect. The narrower price limits in the pre-regime gives investors less opportunity for uninterrupted trading and implies a higher likelihood of the crossing of a price limit. Consequently, the cost of non-execution imposed by limit hits becomes more prominent and investors respond more in their trading behaviors than under a wider price limit regime. We also observe that lower limit hits are associated with stronger acceleration than upper limit hits within the same regime. This may be explained by investors' overoptimistic sentiment as discussed in the examination of the duration of acceleration in the next section.

ii. Trading volume

Another important market microstructure variable is liquidity as measured by share trading volume. Theoretical studies on the magnet effect have predicted heavier trading before 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. Empirically, Lee et al. (1994) and Kim and Rhee (1997) document higher trading activities on days subsequent to trading halts and limit hits but their analyses rely on daily observations.

We expect to observe accelerated trading volume during the pre-hit period. Panel B of Table 2 reports that all four limit-hit cases demonstrate significantly positive acceleration patterns. This indicates that increasingly more transactions are drawn to the market as prices approach the limit. The acceleration rates are 0.10, 0.08, 0.10, and 0.06 for pre-up, post-up, pre-down, and post-down limit hits. Once again pre-regime limit hits feature significantly higher acceleration rates than post-regime limit hits, which indicates that the magnet effect dominates the intraday momentum effect. The comparison of acceleration rates between upper and lower limit hits in the same regime shows no significant differences in acceleration even though upper limit hits attract heavier trading volume than lower limit hits.

12 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.

iii. Volatility

Proponents of price limits cite the cooling-off effect as a primary benefit of price limits. Since previous studies use daily data, their focus is primarily on the post limit hit period. Ma et al. (1989) document attenuated volatility during the post-hit period. Berkman and Lee (2002) report that the widening of price limits increased long-term volatility and reduced overall trading volume in the KRX market. However, Gerety and Mulherin (1992) and Subrahmanyam (1994) suggest the opposite. Lee et al. (1994) and Corwin and Lipson (2000) state that volatility increases significantly on days subsequent to price limit hits.

More recently, the use of transaction data allows the researchers to examine intraday volatility. For example, Kim and Yang (2008) report that the cooling-off effect is observed only when limit hits are consecutive and the duration of the consecutive hits and the magnitude of the cooling-off effect are positively related. Cho et al. (2003) conclude that the conditional volatility increases before upper limit hits, but not before lower limit hits. However, without controlling for the momentum effect, it is difficult to attribute higher conditional volatility solely to the magnet effect. In addition, the comparison between two price-limit regimes allows us to differentiate the magnet effect from the momentum effect.

All four limit-hit cases exhibit significantly positive acceleration rates in volatility as reported in panel C of Table 2. The acceleration rates are 0.07, 0.04, 0.13, and 0.10 for pre-up, post-up, pre-down, and post-down cases, respectively. Rising volatility, measured as the absolute return, before both upper and lower limit hits refute any notion of cooling-off before limit hits. What is more notable is that the pre-regime exhibits significantly higher acceleration rates than the post-regime for both upper and lower limit hits, consistent with our predictions of the magnet effect. A narrower price limit imposes more pronounced non-execution costs to investors, and therefore leads to higher price volatility. This finding appears inconsistent with the conclusion drawn by Berkman and Lee (2002) that price volatility is associated with a widening of price limits.[13] We also observe that lower limit hits have significantly higher acceleration rates than upper limit hits, in line with our earlier findings on the rate of return.

iv. Order flow

The predictions on trading volume can be naturally extended to order flow. If investors become nervous and sub-optimally submit orders to avoid non-execution, we expect to observe increasingly high order submissions and high order imbalances during the pre-hit period. In Figure 2, we have observed unusually high order flows during the 30-min pre-hit period. Panel D of Table 2 reports the regression results on the acceleration rates when the dependent

13 This inconsistency may be explained by different measures of volatility: weekly volatility in Berkman and Lee (2002) versus 3-min volatility in our study. The approach by Berkman and Lee (2002) is motivated by their interest in the changes in stock characteristics in terms of volatility and volume over a relatively long period.

variables are buy (sell) orders buy (sell) order ratio out of total number of submitted orders for upper (lower) limit hits.[14]

All the estimated coefficients of SQINT are significantly positive. It implies that investors place increasingly more orders on one side of the market, which causes larger order imbalances and ultimately leads to limit hits. The bottom row of panel D reports the *F*-test between two regimes. The pre-regime has significantly higher acceleration rates than the post-regime for both order flow and order imbalances. For example, the acceleration rate of buy order volume for pre-up limit hits is 0.04, relative to 0.02 for post-up limit hits. Likewise, the acceleration rate of the buy order ratio for pre-up limit hits is 0.006, relative to 0.002 for post-up limit hits. The same relation between the pre- and the post-regimes holds true for lower limit hits as well. Higher acceleration rates in the pre-regime once again support the hypothesis that the magnet effect dominates the momentum effect. In addition, we compare acceleration rates between upper and lower limit hits within the same regime and do not find significant differences.

v. Order types

We have observed in part A of section IV that investors choose more market buy (sell) orders before upper (lower) limit hits. The choice between limit and market orders is contingent on their costs and benefits. Greenwald and Stein (1991) point out that limit orders have two limitations. First, limit orders carry a risk of non-execution. Second, 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. Bae et al. (2003) provide additional evidence of the impact of non-execution on order types. 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. Based on Australian stock market experience, Verhoeven et al. (2004) report that the probability of traders submitting a limit order increases with (i) an increase in the spread; (ii) a decrease in the depth at the best price on the same side; and (iii) an increase in the depth at the best price at the opposing position.

The trigger of price limits virtually closes continuous trading and the non-execution cost becomes increasingly prominent as prices approach price limits. Therefore, we expect that investors will use more and more market orders to put their orders in the front of the order queue in order to avoid the non-execution costs. Panel E of Table 2 lists the acceleration rates (γ) for market buy (sell) orders and the ratio of market buy (sell) orders out of the total amount of buy (sell) orders for upper (lower) limit hits. We observe that the acceleration rates are

14 We also investigate revised orders during the pre-hit period. 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. In unreported results, we find that investors revise their buy orders more often before upper limit hits, and revise their sell orders more often before lower limit hits. Their results are qualitatively similar to those of regular order flows.

positive and significant for four limit hit cases, demonstrating that investors use increasingly more market orders in both absolute and relative terms.

The pre-regime features significantly higher acceleration rates than the post-regime for both upper and lower limit hits, reinforcing our prediction of the magnet effect. For instance, the acceleration rate for market sell orders is 0.05 for pre-down limit hits, significantly higher than 0.03 for post-down limit hits. The acceleration rate of market sell ratio is 0.03 for pre-down limit hits, relative to 0.02 for post-down limit hits. The same relation between two regimes holds true for upper limit hits, with the only difference being that the level of statistical significance is 5% rather than 1%. There are, however, no significant differences in acceleration rates between upper and lower limit hits within the same regime.

C. Duration of acceleration

This section presents the third dimension of the magnet effect: the duration of the acceleration process. In this paper, the duration is defined as the time period from the minimum point of the convex function, derived from the quadratic function to the moment of limit hit. Mathematically, it is $=3\times(10+\beta/2\gamma)$ in units of minutes. Table 3 reports the duration for various market variables and the comparisons between two regimes and between upper and lower limit hits.

The duration ranges from 17 to 24 min for various market microstructure variables, indicating that it usually takes this much time for the order

Table 3 Duration of acceleration

Variables	Pre-up limit hits		Post-up limit hits	Pre-down limit hits		Post-down limit hits	Upper versus lower: Pre-regime	Upper versus lower: Post-regime
Rate of return	19.75	<	21.00	17.67	<	20.00	>	=
Trading volume	18.75	<	20.81	18.45	=	19.00	=	>
Market volatility	18.00	=	19.13	17.19	<	19.35	=	=
Order flow share	22.88	=	22.50	19.88	<	24.00	>	=
Order flow ratio	22.50	=	22.50	19.50	=	20.00	>	>
Market order share	20.10	=	20.63	18.90	=	19.50	>	>
Market order ratio	21.00	=	21.00	18.00	<	23.25	>	<

Table 3 reports the duration measure for various market microstructure variables. Duration is measured as the time period from the minimum point of the convex function onward to the moment of limit hit, stated in number of minutes. Numerically, it is calculated as $3(10 + \beta/(2\gamma))$, where β is the coefficient of INT and γ is the coefficient of SQINT from the quadratic function. In addition, we compare duration measures between the pre- and the post-regimes and between upper and lower limit hits within the same regime. The delta method is used to compute the approximate standard errors for the comparisons. > and < show the direction of the comparisons that are significant at 5% level. =Indicates that the comparisons of two paired groups are insignificant at 5% level.
Refer to Oehlert, G. W. (1992), A Note on the Delta Method, *The American Statistician*, Vol. 46, No. 1, pp. 27–29.

imbalances to accumulate and trigger price limits. When we compare the duration between the pre- and the post-regime limit hits of the same direction and between upper and lower limit hits within the same regime, two empirical regularities emerge. First, the post-regime has a significantly longer duration than the pre-regime in many cases, and there is not a single case in which the pre-regime has a longer duration than the post-regime. Second, upper limit hits have statistically longer duration than lower limit hits in many cases. The only exception is that post-down limit hits have a longer duration than post-up limit hits when the dependent variable is the market order ratio.

Using the rates of return as an example, the duration of 21 min observed for post-up limit hits, is statistically longer than 19.75 min duration associated with pre-up limit hits. The duration for post-down limit hits is 20 min, relative to 17.67 min of pre-down limit hits. At the same time, upper limit hits have longer duration than lower limit hits within the pre- and the post-regime, respectively. Duration measures for other variables are similar in scale. For example, the duration of trading volume is 18.75, 18.45, 21.81, and 19 min for pre-up, pre-down, post-up, and post-down limit hits, respectively.

Longer duration in the post-regime can be interpreted from two perspectives. Mechanically, the pre-regime has positive and higher γ, negative and smaller β, and therefore higher $\beta/2\gamma$ in the post-regime. More intuitively, a narrower price limit is associated with more imminent non-execution risk, and investors tend to react more aggressively when the non-execution risk is higher. A wider price limit also implies more profit taking potential for speculators and they might start building their positions earlier and more gradually than in a narrow regime. Both explanations could lead to a shorter acceleration duration in the pre-regime.

The difference between upper and lower limit hits could be explained by investors' over-optimistic sentiment and the lack of short sale. If investors believe that an upward trend tends to persist, liquidity buyers will start to build their positions earlier in anticipation of a limit hit and speculators will bid up prices upfront with the expectation of realizing their profits at higher prices. In addition, an up-trending market draws additional investors into the market. However, when prices are going down, investors tend to believe it is transitory. Liquidity sellers are likely to wait for the price reversal until the last chance of execution and speculators will defer locking in their losses as long as possible. Because of the short sale restriction, investors with no initial positions cannot actively reveal their negative expectations. As a result, investors jump onto an upward trend at an earlier stage with relatively mild acceleration and investors respond to a downward trend at a later stage but in a more concentrated fashion, resulting to shorter duration and higher acceleration.

In summary, we conclude that the magnet effect, featured by not only more trading activities, but also accelerated trading activities, lasts for about 20 min before ultimately triggering price limits. There is some evidence that the pre-regime has a shorter duration than the post-regime and upper limit hits exhibit longer duration than lower limit hits, both with some exceptions.

V. THE INTRADAY MOMENTUM EFFECT VERSUS THE MAGNET EFFECT

As discussed in section IV, higher acceleration rates are observed in the pre-regime than in the post-regime. This finding confirms that the magnet effect prevails over the momentum effect given the existence of the price limit. The underlying rationale is that the magnet effect implies stronger accelerations in trading activities under narrower price limits and the momentum effect implies the opposite because the momentum effect should become more significant under wider price limits when prices are allowed to move by a larger degree. In this section, we isolate the momentum effect from the magnet effect by introducing quasi-limit hits under the post regime. In addition, we confirm that the magnet effect does not exist in the US Nasdaq market where no price limit system is in place.

A. Quasi-limit hits in KRX

The rationale of quasi-limit hits has been discussed in Part B of Section III. Briefly, quasi-limit hits are the cases that prices move 12% relative to the previous closing price before hitting the 15% price limit under the post-regime. The reason we constrain the quasi limit hits to be on the same day as post-regime limit hits is to make sure that quasi limit hits have the same information set as the actual limit hits, which is a more rigorous design than relaxing this constraint.[15] In total, we identify 247 quasi upper limit hits and 114 quasi lower limit hits in the post-regime, and all the observations have at least half an hour trading before quasi limit hits. Table 4 reports summary statistics and regression results on two representative market microstructure variables, the rates of return and trading volume.[16]

Panel A reports the average standardized 3-min rates of return and trading volume during the half an hour before limit hits for quasi limit hits under post regime and actual limit hits under pre- and post-regimes. The last two rows report the *t*-test of the mean difference between quasi-limit hits and actual limit hits. It is evident that quasi-limit hits have significantly lower trading activities than the actual limit hits. For example, the average 3-min rate of return for quasi upper limit hits is 0.32, which compares with 0.85 of actual upper limit hits in the pre-regime, and 0.82 for the upper limit hits in the post-regime. The average 3-min trading volume for quasi upper limit hits is 1.36, significantly lower than 1.91 and 1.96 of actual upper limit hits in the pre- and post-regimes.

15 We also tried to relax the constraint, and identify quasi limit hits as days when prices move 12% for the first time in a trading day from the previous day's closing price regardless whether it hits the price limit in the post-regime. The results are quantitatively similar.

16 All empirical results are similar with the sample including quasi limit hits that occur within the first half hour of morning and afternoon trading session. The quasi limit prices are not exactly 12% above or below the previous day's closing prices due to tick size rule. The results on all other microstructure variables are similar.

Table 4 Quasi-limit hits in Korea stock exchange

	Rates of return			Trading volume		
	Upper	Lower	*T*-test	Upper	Lower	*T*-test
Panel A: Summary statistics						
Quasi-limit hits	0.32	0.78	[<0.0001]	1.36	0.43	[<0.0001]
Pre-regime actual limit hits	0.85	0.85	[0.82]	1.91	1.23	[<0.0001]
Post-regime actual limit hits	0.82	0.91	[0.25]	1.96	0.77	[<0.0001]
T-test						
Quasi versus pre-regime actual hits	[<0.0001]	[<0.0001]		[<0.0001]	[<0.0001]	
Quasi versus post-regime actual hits	[<0.0001]	[<0.0001]		[<0.0001]	[<0.0001]	

γ	Rates of return		Trading volume	
	Upper	Lower	Upper	Lower
Panel B: Regression results				
Quasi-limit hits	0.02 (0.002)	0.04 (0.01)	0.04 (0.004)	0.01 (0.01)
Adjusted R^2	0.05	0.11	0.11	0.04
F-test				
Pre-regime actual hits	0.06 (0.002) [<0.0001]	0.09 (0.01) [<0.0001]	0.10 (0.01) [<0.0001]	0.10 (0.01) [<0.0001]
Post-regime actual hits	0.04 (0.002) [<0.0001]	0.06 (0.004) [0.03]	0.08 (0.01) [<0.0001]	0.06 (0.01) [<0.0001]

Table 4 reports the summary statistics and the regression results of quasi-limit hits and its comparison with actual price limit hits in KRX. Quasi-limit hits are defined as cases that prices move 12% before hitting 15% price limits under the post regime. Two hundred and fifty-seven quasi-upper limit hits and 114 quasi lower limit hits are identified. All values are standardized by their mean and standard deviation of non-limit-hit days. Panel A reports the cross-sectional average of 3-minute rate of return and trading volume during half hour periods before quasi-limit and actual limit hits. It also reports the *t*-tests on mean differences between upper and lower limits and between quasi and actual limit hits. Values in brackets are the *P*-values of *T*-tests between paired groups. Panel B reports the estimated coefficients of SQINT for quasi-limit hits. The bottom two rows in panel B repeat the acceleration rates of respective groups of actual limit hits and present the *F*-tests between quasi- and actual limit hits. Standard errors are reported in parentheses. Values in brackets are the *P*-values of the *F*-tests. The mean values in panel A and estimations in panel B are all significant at 1% level.

Panel B of Table 4 reports the regression results from the time-distanced quadratic model for quasi-limit hits. Both upper and lower quasi-limit hits exhibit significant acceleration in rates of return and trading volume. At the bottom of Panel B, it repeats the acceleration rates for actual limit hits and reports the *F*-test between quasi limit hits and the actual limit hits. Quasi-limit hits have significantly lower acceleration rates than actual limit hits. For example, the acceleration rate for upper quasi-limit hits is 0.02, significantly lower than 0.04 for post-up limit hits and 0.06 for pre-up limit hits. Trading volume accelerates at 0.04 for quasi upper limit hits, relative to 0.08 for post-up limit hits and 0.10 for pre-up limit hits.

The observed differences in acceleration rates and the intensity of market activities between quasi-limit and actual limit hits are attributed to the binding price limit in the latter cases. In particular, if there is no magnet effect associated with price limits, we expect to observe indistinguishable trading patterns between quasi- and pre-regime limit hits. Moreover, if we attribute the differences between quasi limit hits and pre-regime limit hits solely to the magnet effect, on average, over half of the trading activities before price limit hits come from the magnet effect.

B. Pseudo-limit hits in Nasdaq

In this section, we conduct an experiment on Nasdaq where there is no price limit rule and design an experimental setting similar to the two regimes in KRX. We impose hypothetical price limits of 12% and 15% on Nasdaq-listed securities, and identify pseudo-limit hits following the same logic for identifying actual limit hits in KRX. We focus on the acceleration aspect of the magnet effect. In the absence of price limits, we expect to observe insignificant differences between 12% and 15% pseudo-limit hits cases in NASDAQ, in contrast to significant differences between the pre- and the post-regime limit hits and between the quasi and actual limit hits in the KRX market. This pseudo-limit hit based approach allows us to avoid making cross-country comparisons which are virtually impossible unless fundamental differences between the KRX and the Nasdaq are adequately controlled.

Our sample consists of 587 Nasdaq common stocks with the daily average number of transactions above 100 and the average price >US$5 to avoid any distortion caused by penny stocks. The study period is from September 1 to December 31, 1998. The tick data are obtained from the Trade and Quote (TAQ) database and the filters in Bessembinder (2003) are used to eliminate the errors in the dataset. Overall, we identify 540 upper limit hits and 367 lower limit hits under the 12% price limit regime and 276 upper limit hits and 143 lower limit hits under the 15% price limit regime.[17] Table 5 reports the results based on rates of return and trading volume during the 30-min period before pseudo-limit hits.

Panel A, Table 5 reports the average standardized 3-minute rate of return and trading volume before pseudo-limit hits. We observe that both the rate of return and trading volume increase before pseudo-limit hits, consistent with the notion that large price movements are associated with heavier trading volume.

17 We use more flexible cutoff points, (11.5%, 12.5%) and (14.5%, 15.5%) for pseudo upper limit hits, and (−12.5%, −11.5%), (−15.5%, −14.5%) for pseudo lower limit hits in two regimes, respectively. We do not use the exact cutoff at 12% and 15% because the number of pseudo-limit hits based on exact cutoffs is fairly small. The results based on exact cutoffs are qualitatively similar to our reported results.

Table 5 Pseudo-limit hits in NASDAQ

	Rates of return			Trading volume		
	Upper	Lower	*T*-test	Upper	Lower	*T*-test
Panel A: Summary statistics						
12% pseudo limit hits	2.41	2.75	[0.06]	4.55	3.36	[0.03]
15% pseudo limit hits	2.8	3.66	[0.02]	5.17	3.62	[0.001]
T-test						
12% versus 15% pseudo limit hits	[0.05]	[0.01]		[0.31]	[0.53]	

γ	Rates of return		Trading volume	
	Upper	Lower	Upper	Lower
Panel B: Regression results				
12% pseudo limit hits	0.22 (0.02)	0.29 (0.02)	0.16 (0.06)	0.11 (0.03)
15% Pseudo limit hits	0.24 (0.02)	0.35 (0.03)	0.11 (0.09)$^{+}$	0.15 (0.05)
Adjusted R^2	0.18	0.19	0.02	0.08
F-test				
12% versus 15% pseudo limit hits	0.62 [0.43]	2.10 [0.15]	0.25 [0.62]	0.70 [0.40]

Table 5 reports the statistics of rates of return and trading volume for pseudo-limit hits in NASDAQ. We introduce hypothetical 12% and 15% price limits to the NASDAQ common stocks and days that stocks trigger these price limits are termed pseudo-limit hits. There are 540 upper limit hits and 367 lower limit hits under the hypothetical 12% price limit and 276 upper limit hits and 143 lower limit hits under the hypothetical 15% price limit. All values are standardized by their mean and standard deviation of non-limit-hit days.
Panel A reports the cross-sectional average of standardized 3-minute rate of return and trading volume during the half hour pre-hit period. It also reports *T*-tests of the mean comparison between pseudo-limit hits in two hypothetical regimes and between upper and lower pseudo-limit hits within the same regime. Values in brackets are *P*-values of the *t*-tests. Panel B reports the estimated coefficients of SQINT from the quadratic regression, where the dependent variables are the rate of return and trading volume respectively. The last row reports the F-statistics and *P*-values (in brackets) on the coefficient comparison between two regimes. Standard errors are in parentheses. All the mean values in panel A and coefficient estimates in panel B are significant at 1% level unless marked by $^{+}$.

It is also shown that 15% pseudo-limit hits have greater rate of return than 12% pseudo limit hits but trading volume between the two cases does not show significant differences.

Panel B, Table 5 reports the estimated coefficients of SQINT for respective pseudo-limit hits groups. All the coefficients are significantly positive except for trading volume of 15% pseudo upper limit hits, consistent with both momentum and the magnet effect. The differences between two pseudo limit regimes are crucial in differentiating the two intraday effects. The last row shows the *F*-test between the 12% and 15% pseudo limit hits, and we observe that 12% and 15% pseudo limit hits show no significant differences on the rate of return or trading volume for either upper or lower limit hits. This is a striking difference from KRX where the pre-regime features significantly higher acceleration rates in all market variables than the post-regime.

Therefore, we conclude that the lack of price limits in the Nasdaq market explains the insignificant differences between the two pseudo-limit hit cases. It supports our argument that the magnet effect is led by price limits per se, not by large price movements. And the magnet effect is unique to markets with price limits.

VI. FIRM SIZE EFFECT

This section examines the impact of firm size on the observed magnet effect. Firm size is of particular interest to us because earlier studies show that the price limit system is more effective for small-sized firms known for greater volatility. Chen et al. (2005) report that illiquid stocks with wide bid-ask spreads hit price limits more often than liquid stocks. Berkman and Lee (2002) report that small-cap stocks are more susceptible to volatility increase when price limit band widens. Kim and Limpaphayom (2000) report that volatile stocks and small-cap stocks hit price limits more often than other stocks. We group our sample stocks into three sub-groups: small-, medium-, and large-cap. Table 6 reports the summary statistics and the regression results on the standardized rates of return and trading volume.[18]

Panel A indicates that small-cap stocks have the highest average limit hits per stock among three capitalization groups. The average number of upper limit hits in the pre-regime is 4.4 for the small cap, 2.2 for the medium cap and 2.9 for the large cap stocks. The average post-up limit hits are 3.8, 2.2 and 2.3 for the small, medium, and large cap stocks. Higher probability of limit hits for small-cap stocks is consistent with earlier studies. The standardized rates of return and trading volume are significantly positive for all three groups sorted by market cap. The mean test shows that small-cap stocks have significantly lower trading volume than large-cap stocks for both upper and down limit hits. However, there is no consistent ranking in rates of return among size-sorted groups.

Panel B of Table 6 reports estimated coefficients of SQINT where dummy variables identify three groups. All the coefficients are significantly positive indicating that the existence of an acceleration pattern is not sensitive to firm size. The last row reports the *F*-test on the acceleration rates between the small and large cap stocks. The large and small cap stocks do not show significant differences in the acceleration rates of trading volume for all four limit hit cases, pre-up, pre-down, post-up and post-down. However, the relationship on the rates of return is less consistent. Small-cap stocks show a lower acceleration rate on rates of return than large-cap stocks for pre-up limit hits, but a higher acceleration rate for post-down limit hits; and it is not significantly different from large-cap stocks for post-up and pre-down limit hits. We, therefore, conclude that the magnet effect stands out significantly across all three

18 The results on other microstructure variables are qualitatively similar to those on the rate of return and trading volume and they are not reported here.

Table 6 Firm size effect

	No. of limit hits		Rates of return		Trading volume	
	Upper	Lower	Upper	Lower	Upper	Lower
Panel A: Summary statistics						
Pre-regime						
Small-cap	973 (4.4)	208 (0.9)	0.80	0.89	1.49	0.75
Medium-cap	172 (2.2)	37 (0.5)	0.93	0.76	2.06	1.16
Large-cap	253 (2.9)	34 (0.4)	0.99	1.00	2.24	1.71
T-tests (small versus large cap)			[0.0001]	[0.58]	[0.0001]	[0.04]
Post-regime						
Small-cap	839 (3.8)	340 (1.5)	0.72	0.90	1.45	0.44
Medium-cap	169 (2.2)	80 (1.0)	0.82	1.03	2.16	0.59
Large-cap	201 (2.3)	50 (0.6)	0.80	1.20	1.88	0.84
T-tests (small versus large cap)			[0.08]	[0.01]	[0.001]	[0.001]

γ	Rates of return				Trading volume			
	Upper		Lower		Upper		Lower	
	Pre-regime	Post-regime	Pre-regime	Post-regime	Pre-regime	Post-regime	Pre-regime	Post-regime
Panel B: Regression results								
Small-cap	0.05 (0.003)	0.03 (0.003)	0.10 (0.01)	0.07 (0.005)	0.10 (0.005)	0.08 (0.01)	0.10 (0.01)	0.07 (0.01)
Medium-cap	0.07 (0.01)	0.03 (0.01)	0.05 (0.02)	0.07 (0.01)	0.13 (0.01)	0.09 (0.03)	0.09 (0.03)	0.05 (0.01)
Large-cap	0.07 (0.005)	0.04 (0.005)	0.11 (0.02)	0.02 (0.01)	0.11 (0.01)	0.09 (0.03)	0.16 (0.03)	0.07 (0.02)
Adjusted R^2	0.38	0.30	0.34	0.32	0.33	0.06	0.15	0.12
F-test								
Small- versus large-cap	[0.006]	[0.11]	[0.18]	[0.003]	[0.33]	[0.55]	[0.09]	[0.95]

Table 6 reports the impact of firm size on trading activities prior to limit hits. The sample stocks are divided into the small-, the medium-, and the large-cap stocks based on the standards in the KRX fact book. Small-cap stocks have market capitalization less than 35 billion won on September 1, 1998. Medium-cap stocks' capitalization is between 35 billion won and 75 billion won. Large-cap stocks have market capitalization above 75 billion won. There are 220 small-sized stocks, 77 medium-sized stocks and 88 large-sized stocks.Panel A reports the number of limit hits, the cross-sectional average of standardized 3-min rate of return and trading volume during the half hour period prior to limit hits. The average number of limit hits per stock is reported in parentheses. *T*-tests report the mean comparison between the small- and the large-cap stocks. Panel B reports the estimated acceleration rates for respective groups. Dummy variables are used to differentiate three capitalization groups. Standard errors are reported in parentheses. The last row of panel B reports the *F*-tests of the acceleration rates between the small- and the large-cap limit hits. *P*-values are reported in brackets. All the mean values in panel A and coefficient estimations in panel B are significant at 1% level.

capitalization groups and there is no evidence that the firm size has a meaningful impact on the degree of the magnet effect.

VII. CONCLUSION

This paper uses KRX tick-by-tick data and limit order book to confirm the presence of the magnet effect. We define the magnet effect using a time-distance quadratic function over the 30-min period before limit hits and provide strong evidence of the intraday accelerating nature of the magnet effect in three dimensions: magnitude; acceleration rates; and duration of acceleration for multiple microstructure variables.

Empirical evidence shows that investors alter their trading behavior as security prices approach either upper ceiling or lower floor price limit. It takes approximately 20 min to reach the price limit once investors start to aggressively react to the price movements in an attempt to assure order executions. Specifically, investors place an increasing number of buy (sell) orders when prices approach the upper (lower) limit. Investors also choose disproportionately more market orders on one side of the market. As a result, the rates of return, trading volume and volatility accelerate before limit hits.

This paper distinguishes the magnet effect from the intraday momentum effect by undertaking two sets of comparisons. First, it shows that investors exhibit more strongly accelerating trading behavior in the 12% price limit regime than in the 15% regime. This is consistent with the magnet effect, but opposite to what an intraday momentum effect would predict. Second, it introduces quasi-limit hits on actual limit hit days in the post-regime. Lower acceleration rates and weaker market activity levels for quasi-limit hits than for actual limit hits in the pre-regime confirm that the magnet effect is led by the existence of price limits, not solely by large price movements.

This paper further tests the magnet effect with the existence of the price limit. It shows that there is no significant difference between trading activities from 12% to 15% pseudo-limit hits in Nasdaq. The lack of a difference between the two pseudo regimes in the Nasdaq reinforces our belief that the magnet effect is driven by price limits per se and is therefore unique to markets with price limits. The acceleration rates observed on the Nasdaq market are simply an indication of the intraday momentum effect. Both the upper and lower limit hits demonstrate significant magnet effect. And this paper documents a significant magnet effect for all firms, irrespective of whether their market capitalization is small, medium, or large.

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REFERENCES

Ackert, L., B. Church, and J. Narayanan (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.

Arak, M., and R. Cook (1997), 'Do Daily Price Limits Act as Magnets? The Case of Treasury Bond Futures', *Journal of Financial Services Research*, 121, 5–20.

Bae, K., H. Jang, and K. Park (2003), 'Traders' Choice between Limit and Market Orders: Evidence from NYSE Stocks', *Journal of Financial Markets*, 6, 517–38.

Berkman, H., and J. Lee (2002), 'The Effectiveness of Price Limits in an Emerging Market: Evidence from the Korean Stock Exchange', *Pacific-Basin Finance Journal*, 10, 517–30.

Berkman, H., and O. Steenbeek (1998), 'The Influence of Daily Price Limits on Trading in Nikkei Futures', *Journal of Futures Markets*, 18, 265–79.

Bessembinder, H. (2003), 'Quote-based Competition and Trade Execution Costs in NYSE-listed Stocks', *Journal of Financial Economics*, 70, 385–422.

Butler, P., and L. Lang (1991), 'The Forecast Accuracy of Individual Analysts: Evidence of Systematic Optimism and Pessimism', *Journal of Accounting Research*, 29, 150–6.

Chan, L., N. Jegadeesh, and J. Lakonishok (1996), 'Momentum Strategies', *Journal of Finance*, 51, 1681–713.

Chan, S., K. Kim, and S. G. Rhee (2005), 'Price Limit Performance: Evidence from Transactions Data and the Limit Order Book', *Journal of Empirical Finance*, 12, 269–90.

Chen, G., K. Kim, and O. Rui (2005), 'A Note on Price Limit Performance: The Case of Illiquid Stocks', *Pacific-Basin Finance Journal*, 13, 81–92.

Cho, D., J. Russell, G. Tiao, and R. Tsay (2003), 'The Magnet Effects of Price Limits: Evidence from High-frequency Data on Taiwan Stock Exchange', *Journal of Empirical Finance*, 10, 133–68.

Chordia, T., R. Roll, and A. Subrahmanyam (2005), 'Evidence on the Speed of Convergence to Market Efficiency', *Journal of Financial Economics*, 76, 271–92.

Connolly, R. (1995), 'An Examination of the Robustness of the Weekend Effect', *Journal of Financial and Quantitative Analysis*, 24, 133–69.

Conrad, J., and G. Kaul (1993), 'Long-term Overreaction or Biases in Computed Returns?', *Journal of Finance*, 48, 39–63.

Corwin, S., and M. Lipson (2000), 'Order Flow and Liquidity around NYSE Trading Halts', *Journal of Finance*, 4, 1771–801.

De Bondt, W., and R. Thaler (1990), 'Do Security Analysts Overreact?', *American Economic Review*, 80, 52–7.

Factbook (2005), *Facts & Figures*, Korea Stock Exchange.

Gerety, M., and H. Mulherin (1992), 'Trading Halts and Market Activity: An Analysis of Volume at the Open and the Close', *Journal of Finance*, 5, 1765–84.

Greenwald, B., and J. Stein (1991), 'Transactional Risk, Market Crashes, and the Role of Circuit Breakers', *Journal of Business*, 64, 443–62.

Griffin, J., X. Ji, and J. Martin (2003), 'Momentum Investing and Business Cycle Risk: Evidence from Pole to Pole', *Journal of Finance*, 58, 2515–47.

Grundy, B., and S. Martin (2001), 'Understanding the Nature of the Risks and the Source of the Rewards to Momentum Investing', *Review of Financial Studies*, 14, 29–78.

Hall, A., and P. Korfman (2001), 'Limits to Linear Price Behavior: Futures Prices Regulated by Limits', *Journal of Futures Markets*, 21, 463–88.

Hong, H., and J. Stein (1999), 'A Unified Theory of Underreaction, Momentum Trading and Overreaction in Asset Markets', *Journal of Finance*, 54, 2143–84.

Jegadeesh, N., and S. Titman (1993), 'Returns to Buying Winners and Selling Losers: Implications for Stock Market Efficiency', *Journal of Finance*, 48, 65–91.

Jegadeesh, N., and S. Titman (2001), 'Profitability of Momentum Strategies: An Evaluation of Alternative Explanations', *Journal of Finance*, 56, 699–720.
Kim, K., and P. Limpaphayom (2000), 'Characteristics of Stocks that Frequently Hit Price Limits: Empirical Evidence from Taiwan and Thailand', *Journal of Financial Markets*, 3, 315–32.
Kim, K., and S. G. Rhee (1997), 'Price Limit Performance: Evidence from the Tokyo Stock Exchange', *Journal of Finance*, 32, 885–901.
Kim, Y., and J. Yang (2008), 'The Effect of Price Limits on Intraday Volatility and Information Asymmetry', *Pacific Basin Finance Journal*, 16, 522–38.
Kuserk, G., E. Moriarty, B. Kuhn, and D. 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, E. (1978), *Specification Searches: Ad-hoc Inference with Non-experimental Data*. New York: John Wiley & Sons.
Lee, C., M. Ready, and P. Seguin (1994), 'Volume, Volatility, and New York Stock Exchange Trading Halts', *Journal of Finance*, 49, 183–214.
Lindley, D. (1957), 'A Statistical Paradox', *Biometrika*, 44, 187–92.
Ma, C., R. Rao, and S. Sears (1989), 'Volatility, Price Resolution, and the Effectiveness of Price Limits', *Journal of Financial Services Research*, 3, 165–99.
Miller, M. (1991), 'Volatility, Episodic Volatility and Coordinated Circuit-Breakers', in S. G. Rhee and R. P. Chang (eds), *Pacific-Basin Capital Markets Research*, Volume II, pp. 23–47. Amsterdam: North Holland.
Moskowitz, T., and M. Grinblatt (1999), 'Do Industries Explain Momentum', *Journal of Finance*, 54, 1249–90.
Slezak, S. (1994), 'A Theory of the Dynamics of Security Returns around Market Closures', *Journal of Finance*, 49, 1163–211.
Subrahmanyam, A. (1994), 'Circuit Breakers and Market Volatility: A Theoretical Perspective', *Journal of Finance*, 49, 237–54.
Subrahmanyam, A. (1995), 'On Rules versus Discretion in Procedures to Halt Trade', *Journal of Economics and Business*, 47, 1–16.
Verhoeven, P., S. Ching, and H. Ng (2004), 'Determinants of the Decision to Submit Market or Limit Orders on the ASX', *Pacific-Basin Finance Journal*, 12, 1–18.