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Volatility spillover around price limits in an emerging market

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\textbf{ABSTRACT}

The intraday volatility effects of price-limit hits for stocks in the BIST-50 index during a volatile period are examined. Our evidence supports the volatility no-effect, dampening and spillover hypotheses depending on whether the lower or upper price limit is hit and on when the hit begins and ends. Post-hit volatilities tend to be lower for limit hits near the beginning of the first trading session, unchanged for those that transcend a trading session and for upper price-limit hits near the end of either trading session, and higher for lower price-limit hits near the end of either trading session. These results are robust using samples differentiated by cross-listed status, same-day news, equi-distant and trade-by-trade returns and volatility measures accounting for return-series autocorrelations. Our findings have implications for emerging markets planning to impose price-limit bands or to increase their efficacy.

1. Introduction

Many stock markets, including those in North America, use different mechanisms with different configurations to address stock price volatility. Little agreement exists on the merits of one such mechanism, price limits, for dealing with price volatility. Advocates (e.g., Anderson, 1984; Chou et al., 2000) argue that price limits moderate stock price volatility, and help to correct short-term overreaction by providing a cooling off period for investors to digest new information, and that price reversals, lower price volatilities and thinner trading volumes are more likely after price limit hits (henceforth PLHs). Critics (e.g., Kim and Rhee, 1997; Lee and Kim, 1995) argue that price limits only delay price discovery by inefficiently stopping order flow and causing volatility spillover. The mixed empirical evidence includes some studies finding no stock volatility effects (e.g., Phylaktis et al., 1999; Diacogiannis et al., 2005).

We investigate the effects of the price-limit configuration on stock market volatility for the Borsa Istanbul (BIST) Stock Exchange. This provides an ideal laboratory for such a test since the BIST is a fully computerized order-driven market using price and time priority for order matching. This market which is open to foreign investment is situated in a major developing economy with a Western-style economy with great importance to regional peace, stability and security among Balkan countries due to its unique geographic location, and its role in oil distribution from the Middle East to Europe and in NATO (second largest standing military force). The price limit

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rules in place during our sample period allowed stock prices to fluctuate to a maximum of 10% plus any rounding up to the nearest tick in each session from the “base price” calculated based on the previous trading session. A “limit lock” occurred when trading was either interrupted or continued at the limit prices given an excessive number of buy (sell) orders at a limit price with no offsetting orders (Bildik and Gulay, 2006). The interruption continued until a seller (buyer) was willing to trade at a price within the set limits for that session. For limit locks remaining at session close, trading resumed in the following session after a resetting of the price limits.

To ensure a sufficient number of observations to compute measures of volatility, our sample is confined to limit hits surrounded by 30-minute windows with no transacted price at the limit hit. We find evidence to support the volatility no-effect, dampening and spillover hypotheses since the impact on volatility depends on whether the lower or upper limit is hit, on when during the day the PLH begins and ends, and whether the stock is cross-listed. Our base-line findings are robust using ARIMA models with either trade-by-trade or equi-distant returns.

Our paper contributes to the literature on price-limit effects by examining the performance of a specific price-limit configuration during a period of extreme global volatility that is likely to repeat given the recent COVID-19 pandemic. It also contributes to the extensive and growing literature on the effects of a global shock, the 2008-9 financial crises, on such diverse topics as: cost of corporate debt financing (e.g. Pianeselli and Zaghini, 2014), financial constraints or frictions on various firm decisions (e.g. Campello, Graham and Harvey, 2010; Benmelech, Frydman and Papanikolaou, 2019), social capital’s association with firm performance (Lins, Servaes and Tamayo, 2017), stock market contagion (Bekaert et al., 2014) and media tone and readability for IPO firms (Bhardwaj and Imam, 2019).

2. Sample description

Our sample consists of BIST-50 index members, an index which represents 70% of the BIST’s total stock trading volume during the studied period. We used all cleaned transactions and incoming orders, and our reconstructed full limit-order book for all stocks in our sample. Following Bildik and Gulay (2006), we use \( H_s \approx \text{VWAP}_s - 1(1 + 0.10) \) and \( L_s \approx \text{VWAP}_s - 1(1 - 0.10) \) for upper and lower price limits, respectively, where \( \text{VWAP}_s - 1 \) is the volume-weighted average price from the previous session \( s-1 \) and 0.10 is the permitted price divergence from \( \text{VWAP}_s - 1 \).

As in Kim and Yang (2008), limit hits are classified as single, consecutive and closing. Consecutive limit hits are as a series of limit hits without a 30-minute window available between two consecutive limit hits, and closing limit hits are hits remaining at trading session end. For reasonable sample sizes, we focus on subsamples of upper/lower PLHs triggered during the first session’s first 30 minutes; during the first and second session’s last 30 minutes; and in place at session end.

The 328 lower PLHs examined include 133 in the first session’s first 30 minutes, 30 in the second session’s last 30 minutes, and 79 in place at session close. The 267 upper PLHs examined include 77 in the first session’s first 30 minutes, 39 in the second session’s last 30 minutes, and 127 in place at session close. Illiquidity is not a concern since at least 91% and 94% of the pre- and post-PLH windows, respectively, have at least 30 seconds with trades.

3. Volatility spillover and dampening hypotheses tests

3.1. Hypothesis and methodology

The volatility spillover hypothesis argues that price volatility increases after a limit hit or lock (e.g., Kim and Rhee, 1997) if price limits or locks cause greater uncertainty due to informational asymmetry (Spiegel and Subrahmanyam, 2000) and delay price discovery by adversely affecting trading (Fama, 1989; Lehmann, 1989). However, if this type of market intervention provides traders with time to obtain information to reduce informational asymmetry, reassess the market price, and avoid or correct overreaction, then it follows from the volatility dampening hypothesis that price volatility is expected to be lower after a limit hit or lock (Kim and Yang, 2008). Another possible outcome is that these two opposing effects neutralize each other so that price volatility remains unchanged.

The resulting testable null hypothesis is: No pre-to-post PLH change in volatility (\( H^s_0; \) volatility no-effect hypothesis). Alternative hypotheses are lower volatility post-hit (\( H^s_{a1}; \) volatility dampening hypothesis) and higher volatility post-hit (\( H^s_{a2}; \) volatility spillover hypothesis).

Among the three types of benchmarks used in the literature to test the volatility spillover hypothesis, we choose the one that compares volatilities in the 30 minutes before and after a limit hit or lock (see Section A3.1, Online Supplementary Appendix (OSA) for greater details). While most studies choose a discrete sampling scheme to control for microstructure noise, the severity of any bias introduced with this choice is unclear. Since the value of the metric being examined seldom coincides with the end of each equi-distant interval due to trade randomness, the calculation of evenly spaced high-frequency returns necessarily relies on some form of interpolation among prices recorded around the endpoints of the given sampling intervals. This results in a nonsynchronous trading or quotation effect that may induce negative autocorrelation and heteroscedasticity in the interpolated return series. These biases may be exacerbated in a multivariate context since varying degrees of interpolation are employed in the calculation of the returns for different securities. Since the impact on the examined metric (e.g., price) of intra-interval events with informational content is imperfectly
captured by the choice of equi-distant intervals, the equi-distant intervals may discard valuable information. Thus, the choice of measurement interval involves a tradeoff between statistical measurement error that decreases and untreated microstructure-induced bias (e.g., significant autocorrelation from bid-ask bounce (Roll, 1984)) that may increase as the sampling frequency increases.

Our base-case results use ten three-minute (equi-distant) intervals\(^1\) based on an examination of estimated ARIMA (1,0,0) models using trade-by-trade returns. Dickey-Fuller tests find evidence of a unit root in both the paired pre- and post-windows for only seven lower PLHs and only two upper PLHs. We also find that price reversals or bid-ask bounce is likely to be a problem using trade-by-trade returns for all samples. Thus, Section 4 provides results using unequally spaced intervals to assess the impact (if any) of this high level of negative autocorrelation in our trade-by-trade returns on our base-case inferences.

We use the following model-free but definition dependent metrics to measure volatility or variation in each 30-minute window:

\[
\text{Vol}_{ij} = \sqrt{(n-1)^{-1} \sum_{t=1}^{n} (R_{ij} - \bar{R}_{ij})^2},
\]

\[
\text{Vol}_{2j} = \frac{\sum_{t=1}^{n} R_{ij}^2}{n};
\]

\[
\text{Vol}_{3j} = \sum_{t=1}^{n} R_{ij}^2 + 2 \sum_{t=1}^{n-1} R_{ij} R_{ij,t-1}^3;
\]

\[
\text{Vol}_{4j} = \frac{1}{\sqrt{2/\pi}} \sum_{t=1}^{n-1} \left| R_{ij}^e \right| \left| R_{ij,t-1}^e \right|.
\]

where \(R_{ij}\) and \(R_{ij}^e\) are the \(n = 10\) not demeaned and demeaned 3-minute returns, respectively, for limit hit \(i\) in window \(j\) (pre- or post-limit hit) for a window of length \(l\) (= 30 minutes herein). The measure given by (4) is the \((l, l)\)-order realized bipower variation for the special case where \(r = s = 1\) (Barndorff-Nielsen and Shephard, 2004). The second term under the square root sign in (3) includes an autocorrelation \((\rho)\) adjustment used by French, Schwert and Stambaugh (1987), Wei and Zhang (2005), amongst others. Goyal and Santa-Clara (2003, fn. 6, p. 769) find that about 5% of their volatility estimates are negative because the second term dominates the first when \(\rho < -0.5\).\(^2\)

3.2. Results

We report summary statistics for each of the four volatility estimates for lower and upper PLHs for the full sample and three differentiated subsamples in Tables 1 and 2, respectively. We observe that all means are significantly lower after the lower PLHs for the full sample (panel A in both tables)\(^3\) and for the lower PLHs triggered during the first session’s first 30 minutes (panel B in both tables). In contrast, all means are higher and significant (with one exception) after the lower PLHs (panel C of Table 1) and insignificant after the upper PLHs that are triggered during the last 30 minutes of the first or second session (panel C of Table 2), and only one of the means is significantly different for lower and upper PLHs remaining at trading session end; namely, the significantly lower mean difference for Vol4 for the upper PLHs (panel D of Table 2). Thus, the average effect of both a lower and upper PLH depends upon when during the day the PLH is first triggered and also on whether it remains at trading session close.

For robustness, we examine PLH samples of cross-listed firms with(out) U.S. ADRs and for firms with/without no same-day firm-specific news. The OSA results (Section A.3.3) provide support for all three specifications of our first hypotheses since the post-window impact of a PLH depends on its beginning and ending time-of-day. While PLH volatilities tend to be lower post-limit-hit near first trading session beginnings, higher (unchanged) post-hit for lower-price (upper-price) limit hits near trading session ends, and unchanged post-hit for those still in place at session end. The changes post PLHs tend to differ depending upon cross-listed status but not on same-day news.

4. Further tests of robustness

Our previous variance results based on 3-minute returns are now shown to be robust using ARIMA models with trade-by-trade returns in this section and three-minute interval returns in OSA section A4. This buttresses our previous inference that our test results support our second null and our two second alternative hypotheses since the post-window impact on return variances of a PLH

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\(^1\) Satisfies the minimum number of observations (five) for an ARIMA (p, d, q) based on Jarrett and Kyper (2011) and six for the SAS proc ARIMA procedure.

\(^2\) We get no negative Vol estimates using the demeaned three-minute returns but do using the non-demeaned three-minute returns.

\(^3\) Not unexpectedly, the mean differences either become insignificant or change sign for the full sample for both lower and upper PLHs and become insignificant for the sample of upper PLHs triggered during the first session’s first 30 minutes when trade-by-trade returns are used in the calculation of the two volatility measures that capture the effect of bid-ask bounce; namely, \(\text{Vol}_3\) and \(\text{Vol}_4\).
Table 1
Volatility changes around lower price limit hits (PLHs)
This table reports various summary statistics for estimates of four volatility measures in the pre- and post-thirty minute windows centered on lower PLHs. Paired differences and tests thereof for the post-minus pre-windows for each limit hit are reported in the third column for each volatility measure. T- and Wilcoxon tests of the means and medians, respectively, and their associated p-values are presented in the table.

|               | \(V_{\text{ij}}\) | \(V_{\text{ij}}\) | \(V_{\text{ij}}\) | \(V_{\text{ij}}\) | \(V_{\text{ij}}\) | \(V_{\text{ij}}\) |
|---------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|               | Pre-              | Post-             | Dif.              | Pre-              | Post-             | Dif.              |
| Mean          | 1.2189            | 1.0333            | -0.1855           | 0.9391            | 0.8180            | -0.1211           |
| Median        | 0.9277            | 0.8389            | -0.0240           | 0.7707            | 0.6751            | -0.0400           |
| Std. Dev.     | 0.8666            | 0.6566            | 0.9202            | 0.6252            | 0.5313            | 0.6770            |
| t-test        | 25.47             | 28.12             | -3.65             | 27.20             | 28.88             | -3.24             |
| p-value       | <.0001            | <.0001            | 0.0003            | <.0001            | <.0001            | <.0001            |
| Wilcoxon      | 26814             | 26163             | -3750             | 26814             | 26163             | -3749             |
| p-value       | <.0001            | <.0001            | 0.0289            | <.0001            | <.0001            | <.0001            |
| Panel A: All PLHs triggered by hitting the lower price limit (\(N = 328\))  
| Mean          | 1.5319            | 0.9881            | -0.5438           | 1.1362            | 0.7876            | -0.3486           |
| Median        | 1.2872            | 0.8149            | -0.1600           | 1.1029            | 0.6435            | -0.1860           |
| Std. Dev.     | 1.0068            | 0.5544            | 1.1113            | 0.6948            | 0.4399            | 0.7842            |
| t-test        | 17.55             | 20.55             | -5.64             | 18.86             | 20.65             | -5.13             |
| p-value       | <.0001            | <.0001            | <.0001            | <.0001            | <.0001            | <.0001            |
| Wilcoxon      | 4389              | 4389              | -1975             | 4389              | 4389              | -1913             |
| p-value       | <.0001            | <.0001            | <.0001            | <.0001            | <.0001            | <.0001            |
| Panel B: PLHs triggered by hitting the lower price limit during the first 30 minutes of the first session (\(N = 133\))  
| Mean          | 0.8745            | 1.1086            | 0.2340            | 0.7008            | 0.8533            | 0.1525            |
| Median        | 0.7037            | 0.9650            | 0.2821            | 0.7971            | 0.7883            | 0.1675            |
| Std. Dev.     | 0.5304            | 0.6550            | 0.6598            | 0.4834            | 0.5161            | 0.7842            |
| t-test        | 12.66             | 13.00             | 2.72              | 13.18             | 13.56             | 2.27              |
| p-value       | <.0001            | <.0001            | <.0001            | <.0001            | <.0001            | <.0001            |
| Wilcoxon      | 885               | 434               | -491             | 885               | 434               | -384              |
| p-value       | <.0001            | <.0001            | 0.0007            | <.0001            | <.0001            | 0.0030            |
| Panel C: PLHs triggered by hitting the lower price limit during the last 30 minutes of the first and second session (\(N = 59\))  
| Mean          | 0.9923            | 0.9931            | 0.0007            | 0.8012            | 0.7837            | -0.0175           |
| Median        | 0.8166            | 0.8558            | 0.0412            | 0.6857            | 0.6699            | -0.0110           |
| Std. Dev.     | 0.6519            | 0.4945            | 0.6794            | 0.5159            | 0.3970            | 0.5593            |
| t-test        | 13.53             | 17.85             | 0.01              | 13.88             | 17.55             | -0.28             |
| p-value       | <.0001            | <.0001            | <.0001            | <.0001            | <.0001            | <.0001            |
| Wilcoxon      | 1541              | 1541              | 100              | 1541              | 1541              | -19               |
| p-value       | <.0001            | <.0001            | 0.6281            | <.0001            | 0.9267            | <.0001            |
| Panel D: PLHs triggered by hitting the lower price limit during the trading day that were in place at market close (\(N = 79\))  
| Mean          | 0.9923            | 0.9931            | 0.0007            | 0.8012            | 0.7837            | -0.0175           |
| Median        | 0.8166            | 0.8558            | 0.0412            | 0.6857            | 0.6699            | -0.0110           |
| Std. Dev.     | 0.6519            | 0.4945            | 0.6794            | 0.5159            | 0.3970            | 0.5593            |
| t-test        | 13.53             | 17.85             | 0.01              | 13.88             | 17.55             | -0.28             |
Table 2
Volatility changes around upper price limit hits (PLHs)
This table reports various summary statistics for estimates of four volatility measures in the pre- and post-thirty minute windows centered on upper PLHs. Paired differences and tests thereof for the post-minus pre-windows for each PLH are reported in the third column for each volatility measure. T- and Wilcoxon tests of the means and medians, respectively, and their associated p-values are presented in the table.

|            | Vol$_{1ij}$ |            | Vol$_{2ij}$ |            | Vol$_{3ij}$ |            | Vol$_{4ij}$ |            |
|------------|-------------|------------|-------------|------------|-------------|------------|-------------|------------|
|            | Pre-        | Post-      | Dif.        | Pre-        | Post-      | Dif.        | Pre-        | Post-      |
| Panel A: All PLHs triggered by hitting the upper price limit (N = 267) |
| Mean       | 1.1232      | 0.9166     | -0.2065     | 0.8700      | 0.7360     | -0.1340     | 3.3696      | 2.7500     |
| Std. Dev.  | 0.8032      | 0.7542     | -0.0880     | 0.7167      | 0.6212     | -0.0970     | 2.6512      | 2.2627     |
| t-test     | 22.85       | 26.07      | -4.03       | 25.56      | 25.84      | -3.62       | 22.85      | 26.07      |
| p-value    | <.0001      | <.0001     | <.0001      | <.0001     | <.0001     | <.0001      | <.0001     | <.0001     |
| Wilcoxon   | 17490       | 17490      | -3929       | 17490       | 17490      | -3928       | 17490       | 17490      |
| Panel B: PLHs triggered by hitting the upper price limit during the first 30 minutes of the first session (N = 77) |
| Mean       | 1.6734      | 1.1015     | -0.5718     | 1.2451      | 0.8870     | -0.3580     | 5.0202      | 3.3046     |
| Std. Dev.  | 1.0291      | 0.8008     | 1.2429      | 0.6502      | 0.6575     | 0.8415      | 3.0875      | 2.4025     |
| t-test     | 14.27       | 12.07      | -4.04       | 16.80      | 11.84      | -3.73       | 14.27      | 12.07      |
| p-value    | <.0001      | <.0001     | <.0001      | <.0001     | <.0001     | <.0001      | <.0001     | <.0001     |
| Wilcoxon   | 1502        | 1502       | -707        | 1502        | 1502       | -742        | 1502        | 1502       |
| Panel C: PLHs triggered by hitting the upper price limit during the last 30 minutes of the first and second session (N = 69) |
| Mean       | 0.8333      | 0.8120     | -0.0213     | 0.6686      | 0.6536     | -0.0149     | 2.5001      | 2.4362     |
| Std. Dev.  | 0.4812      | 0.3753     | 0.4274      | 0.3687      | 0.2873     | 0.3640      | 1.4437      | 1.2159     |
| t-test     | 14.38       | 17.97      | -0.41       | 15.06      | 18.90      | -0.34       | 14.38      | 17.97      |
| p-value    | <.0001      | <.0001     | <.0001      | <.0001     | <.0001     | <.0001      | <.0001     | <.0001     |
| Wilcoxon   | 1208        | 1173       | -15         | 1208        | 1173       | 17          | 1208        | 1208      |
| Panel D: PLHs triggered by hitting the upper price limit during the trading session that were in place at the session’s close (N = 127) |
| Mean       | 0.9878      | 0.9412     | -0.0465     | 0.7784      | 0.7690     | -0.0093     | 2.9635      | 2.8238     |
| Std. Dev.  | 0.7463      | 0.4775     | 0.7562      | 0.5395      | 0.3904     | 0.5237      | 2.3337      | 2.6146     |
| t-test     | 14.92       | 22.21      | -0.69       | 16.26      | 22.20      | -0.20       | 14.92      | 22.21      |
| p-value    | <.0001      | <.0001     | <.0001      | <.0001     | <.0001     | <.0001      | <.0001     | <.0001     |
| Wilcoxon   | 3875        | 3938       | 296         | 3875        | 3938       | 387         | 3875        | 3938      |
Table 3
Volatility changes around lower PLHs using an MA(1) model with trade-by-trade returns

This table reports mean and median estimates for the variances in the pre- and post-windows for lower price limit hits (PLHs) using a MA(1) model with trade-by-trade returns. The MA (1) or ARIMA(0,0,1) model is given by

\[ r_t = \mu_t + \epsilon_t + \theta \epsilon_{t-1} \]

where \( \theta \) is the first-order \( \rho \) for the MA(1); \( \rho \) is the correlation between successive return observations in the AR(1); and \( \epsilon_t \) are the error terms assumed to be mean zero and IID normal distributed. As widely documented, the theoretical variance is given by

\[ \sigma^2(\epsilon_t) = \sigma^2(\epsilon_1) (1 + \rho^2) \]

and by \( \sigma^2(\epsilon_t) / (1 - \rho^2) \) for the AR(1) model. Pre- and post-windows for each PLH are examined only for the series found to be stationary (i.e., \( \rho < 1 \)) based on the Dickey-Fuller test.

We only tabulate summary results of interest for the MA(1) model for the lower PLHs (Table 3) and for the upper PLHs (Table 4) since those for the AR(1) are generally similar and are available upon request. We then compare the mean and median Adj. \( \sigma \) reported in both tables with their counterparts reported earlier in Tables 1 and 2 for the variances that account for serial autocorrelation (i.e., \( \text{Vol}_3 \) and \( \text{Vol}_4 \)). We observe the following consistencies for the lower PLHS: significantly lower volatilities post-window for the full sample and during the first session’s first 30 minutes, higher (either significant or nearly so) variances post-window during both session’s last 30 minutes, and not significantly different variances post-window for session ending PLHs. Similarly, we observe the

\[ \text{Adj. } \sigma = \sigma / \sqrt{1 - \rho^2} \]

Table 3

| Statistic | Pre-limit hit | Post-limit hit | Paired Difference |
|-----------|--------------|---------------|------------------|
|          | \( \mu \)     | \( \sigma \)   | \( \delta \)    |
| Panel A: All lower PLHs, ARIMA(0,0,1), \( N = 319 \) | | | |
| mean      | 0.0055       | 0.49          | 0.0074          | 0.0051          | 0.0065      | -0.0009     | 0.02          | -0.0009     |
| median    | 0.0019       | 0.55          | 0.0026          | 0.0017          | 0.0054      | 0.0023      | -0.0001     | 0            | -0.0001     |
| t-test    | 1.075        | 28.91         | 9.89            | 9.41            | 37.12       | 8.48        | -2.5         | 1.08         | -1.46       |
| \( p \)-value | <.0001       | <.0001        | <.0001          | <.0001          | <.0001      | <.0001      | 0.0131       | 0.28         | 0.1461      |
| Wilcoxon  | 25520        | 24757         | 25520           | 25273           | 25520       | -3787       | 1586         | -3659        |
| Panel B: Lower PLHs during first 30 minutes of first session, ARIMA(0,0,1), \( N = 130 \) | | | |
| mean      | 0.0068       | 0.44          | 0.0086          | 0.0037          | 0.0052      | 0.0049      | -0.0031     | 0.08         | -0.0037     |
| median    | 0.003        | 0.47          | 0.0037          | 0.0017          | 0.0055      | 0.0024      | -0.001      | 0.06         | -0.001      |
| t-test    | 7.79         | 15.72         | 7.29            | 5.53            | 24          | 6.07        | -5.01        | 2.4          | -4.46       |
| \( p \)-value | <.0001       | <.0001        | <.0001          | <.0001          | <.0001      | <.0001      | <.0001      | <.0001      | 0.02        |
| Wilcoxon  | 4258         | 4090          | 4258            | 4258            | 4190        | 4258        | -2028       | 1065         | -1945       |
| Panel C: Lower PLHs during last 30 minutes of both sessions, ARIMA(0,0,1), \( N = 58 \) | | | |
| mean      | 0.0033       | 0.57          | 0.0049          | 0.0046          | 0.5         | 0.0066      | 0.0013       | -0.07        | 0.0018      |
| median    | 0.0013       | 0.64          | 0.0019          | 0.0019          | 0.51        | 0.0022      | 0.0002       | -0.15        | 0.0002      |
| t-test    | 4.63         | 13.96         | 4.56            | 4.9             | 16.07       | 4.36        | 2.41         | -1.36        | 2.05        |
| \( p \)-value | <.0001       | <.0001        | <.0001          | <.0001          | <.0001      | <.0001      | <.0001      | <.0001      | <.0001      |
| Wilcoxon  | 856          | 799           | 856             | 856             | 851         | 856         | 308         | -297         | 219         |
| Panel D: Lower PLHs that remained in place at session close, ARIMA(0,0,1), \( N = 77 \) | | | |
| mean      | 0.0034       | 0.51          | 0.0047          | 0.0033          | 0.5         | 0.0045      | -0.0001      | -0.01        | -0.0002     |
| median    | 0.0014       | 0.65          | 0.0021          | 0.0018          | 0.51        | 0.0024      | 0.0001       | 0            | 0.0001      |
| t-test    | 5.35         | 13.36         | 5.39            | 7.93            | 19.39       | 7.38        | -0.19        | -0.22        | -0.3        |
| \( p \)-value | <.0001       | <.0001        | <.0001          | <.0001          | <.0001      | <.0001      | 0.8482       | 0.82         | 0.7673      |
| Wilcoxon  | 1502         | 1405          | 1502            | 1502            | 1497        | 1502        | 165         | -78          | 105         |
| \( p \)-value | <.0001       | <.0001        | <.0001          | <.0001          | <.0001      | <.0001      | 0.4071       | 0.7          | 0.599       |

\[ \text{Adj. } \sigma = \sigma / \sqrt{1 - \rho^2} \]

\[ \text{Adj. } \sigma = \sigma / \sqrt{1 - \rho^2} \]

depends on time-of-day when the PLH begins (e.g. beginning or end of a trade session) and when it ends (e.g., same or subsequent session).

We use ARIMA models with trade-by-trade returns since several studies suggest ARIMA(0,0,1) or ARIMA(1,0,0) models (known as MA(1) and AR(1) models, respectively) help to mitigate any autocorrelation biases when using trade-by-trade returns. The MA(1) and AR(1) models estimated herein are:

\[ \text{MA}(1) : r_t = \mu_t + \epsilon_t + \theta \epsilon_{t-1} \]

\[ \text{AR}(1) : r_t = \tau + \rho r_{t-1} + \epsilon_t \]

where \( \theta \) is the first-order \( \rho \) for the MA(1); \( \rho \) is the correlation between successive return observations in the AR(1); and \( \epsilon_t \) and \( \epsilon_{t-1} \) are the error terms assumed to be mean zero and IID normal distributed. As widely documented, the theoretical variance is given by

\[ \sigma^2(\epsilon_t) = \sigma^2(\epsilon_1) (1 + \rho^2) \]

and by \( \sigma^2(\epsilon_t) / (1 - \rho^2) \) for the AR(1) model. Pre- and post-windows for each PLH are examined only for the series found to be stationary (i.e., \( \rho < 1 \)) based on the Dickey-Fuller test.
Volatility changes around upper PLHs using an MA(1) model with trade-by-trade returns

This table reports mean and median estimates for the variances in the pre- and post-windows for upper price limit hits (PLHs) using a MA(1) model with trade-by-trade returns. The MA(1) or ARIMA(0,0,1) model is given by \( r_t = \mu + \rho r_{t-1} + \epsilon_t \), where \( \epsilon_t \) is the first-order innovation \( \rho \) for the MA(1); and \( \epsilon_t \) and \( \epsilon_{t-1} \) are error terms assumed to be mean zero and IID normal. The adjusted variance (Adj. \( \sigma \)) is computed as \( \sigma^2(\epsilon_t)(1+\theta^2) \) for the MA(1) model. First-order \( \rho \) for the MA(1) are given by \( \theta_1/(1+\theta^2) \), but are not reported in this table.

| Statistic | Pre-limit hit | Post-limit hit | Paired Difference |
|-----------|---------------|----------------|------------------|
|           | \( \sigma \)  | \( \sigma \)  | \( \sigma \)  | \( \sigma \)  | \( \sigma \)  | \( \sigma \)  | \( \sigma \)  |
| Panel A: |             |               |                 |               |               |               |
| All upper PLHs, ARIMA(0,0,1), N=265 | 0.0043 | 0.53 | 0.0059 | 0.003 | 0.58 | 0.0047 | -0.0012 | 0.05 | -0.0012 |
| mean      |             |               |                 |               |               |               |
| median    | 0.0013      | 0.55          | 0.0016          | 0.0012        | 0.59          | 0.0016        | 0.0012        | 0.05 | 0.0012        | 0.05 |
| t-test    | 8.2         | 38.18        | 8.4            | 9.61          | 44.39         | 8.5            | -2.89          | 3.2  | -2.31          |
| p-value   | <.0001      | <.0001        | <.0001          | <.0001        | <.0001        | <.0001          | <.0001        | 0.0042 | 0.0219         |
| Wilcoxon  | 17623       | 17601         | 17623          | 17623         | 17608         | 17623          | -3832          | 4119 | -2357          |
| Panel B: |             |               |                 |               |               |               |
| Upper PLHs during first 30 minutes of first session, ARIMA(0,0,1), N=76 | 0.0083 | 0.47 | 0.0106 | 0.0038 | 0.63 | 0.0061 | -0.0045 | 0.16 | -0.0045         |
| mean      |             |               |                 |               |               |               |
| median    | 0.0032      | 0.5           | 0.0039          | 0.0015        | 0.65          | 0.002          | -0.001         | 0.12  | -0.001        |
| t-test    | 5.52        | 15.71         | 5.79            | 5.47          | 26.28         | 5.07           | -3.46          | 5.15  | -3.18          |
| p-value   | <.0001      | <.0001        | <.0001          | <.0001        | <.0001        | <.0001          | <.0001        | 0.0009 | <.0001         | 0.0021 |
| Wilcoxon  | 1463        | 1452          | 1463            | 1463          | 1462          | 1463           | -1044          | 879   | -838           |
| Panel C: |             |               |                 |               |               |               |
| Upper PLHs during last 30 minutes of both sessions, ARIMA(0,0,1), N=69 | 0.0018 | 0.52 | 0.0026 | 0.0017 | 0.55 | 0.0023 | -0.0001 | 0.03  | -0.0004         |
| mean      |             |               |                 |               |               |               |
| median    | 0.001       | 0.53          | 0.0013          | 0.001         | 0.57          | 0.0013         | 0            | 0.05  | 0              |
| t-test    | 4.25        | 25.25         | 3.47            | 4.83          | 24.23         | 5              | -0.53          | 1.22  | -1.03          |
| p-value   | <.0001      | <.0001        | <.0001          | <.0001        | <.0001        | <.0001          | <.0001        | 0.616  | 0.23           | 0.3044 |
| Wilcoxon  | 1208        | 1208          | 1208            | 1208          | 1205          | 1208           | 4              | 308   | 15             |
| Panel D: |             |               |                 |               |               |               |
| Upper PLHs that remained in place at session close, ARIMA(0,0,1), N=126 | 0.0027 | 0.56 | 0.0038 | 0.0028 | 0.6 | 0.0041 | 0.0001 | 0.03  | 0.0002         |
| mean      |             |               |                 |               |               |               |
| median    | 0.0012      | 0.57          | 0.0016          | 0.0013        | 0.61          | 0.0017         | 0.0001         | 0.04  | 0.0002         |
| t-test    | 6.46        | 29.96         | 6.29            | 6.87          | 40.18         | 6.43           | 0.42           | 1.71  | 0.95           |
| p-value   | <.0001      | <.0001        | <.0001          | <.0001        | <.0001        | <.0001          | 0.6752         | 0.09  | 0.3646         |
| Wilcoxon  | 4001        | 4001          | 4001            | 4001          | 4001          | 4001           | 536            | 659   | 776            |
| p-value   | <.0001      | <.0001        | <.0001          | <.0001        | <.0001        | <.0001          | 0.1934         | 0.11  | 0.0587         |

following consistencies for the upper PLHs: significantly lower variances post-window for the full sample and during the first session’s first 30 minutes, and not significantly different variances post-window for PLHs during the last 30 minutes of both sessions. The only inconsistencies are sign and significance changes in the variances post-window for session-ending PLHs.

5. Conclusion

This study analyzes the effect of price limits on stock return volatilities using intraday data from an emerging market, Borsa Istanbul, over the period from March 2008 through March 2009. This period provides a good laboratory for examining the volatility effects of price limits since it covers a significant period of the global financial crisis of 2007-2009.

We find supportive evidence for the volatility no-effect, volatility dampening and volatility spillover hypotheses for members of the BIST-50 index depending on when during the day the PLH begins and/or ends, and whether it is a lower or upper PLH. Our findings are robust using trade-by-trade returns as well as ARIMA models. These results have implications for studies examining PLH effects across markets with different PLH configurations, and for emerging markets planning to impose price-limit bands or to adjust to more efficient price limits rules. Strict price limit applications without considering time-of-day effects when configuring price limits may not lower stock price volatility without damaging the price discovery process.

Credit author statement

All authors made an equal contribution.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.frl.2020.101610.
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