INTEROFFICE MEMORANDUM

TO: FILE
FROM: DIVISION OF ECONOMIC AND RISK ANALYSIS
SUBJECT: CORNERSTONE ANALYIS OF THE IMPACT OF STRADDLE STATES ON OPTIONS MARKET QUALITY
DATE: FEBRUARY 8, 2016

The Division of Economic and Risk Analysis contracted with Cornerstone Research ("Cornerstone"), an economic and financial consulting firm, to conduct analyses related to investigating the extent to which the underlying market going into a limit up-limit down ("LULD") event, such as a straddle state or limit state, has had an adverse impact on market quality in the options market. This analysis supplements the analysis of the effect of LULD events on the options market presented in the Supplemental Joint Assessment.[1] In particular, the Cornerstone analysis attempts to disentangle the effect of LULD on options market liquidity from the effect of recent large stock price movements, even in the absence of LULD. The Division believes that the methodology employed by Cornerstone in the analysis is appropriate to address the questions presented and agrees with the conclusions drawn by Cornerstone based on that analysis.

Main Finding:
With respect to straddle states, the Cornerstone analysis observes that when a stock experiences such an event, but is not in a trading pause, liquidity in the options market significantly deteriorates.[2] This deterioration starts in the moments leading up to the LULD event (the straddle state) with further deterioration at the time of the LULD event. Follow-up tests by Cornerstone considered both limit and straddle states and controlled for the possibility that the deterioration results from the price movement and not the LULD event itself. The analysis finds that the deterioration is similar to that seen for other large price movements. This finding implies either that liquidity would have deteriorated in the absence of the LULD event or that liquidity deteriorated in anticipation of the LULD event.

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[1] *See* Supplemental Joint Assessment on the Plan to Address Extraordinary Market Volatility, May 28, 2015, available at http://www.sec.gov/comments/4-631/4631-39.pdf. The Supplemental Joint Assessment contains the results of the requirement in the Plan for the Participants to "evaluate concerns from the options markets regarding the… impact of Limit States on liquidity and market quality in the options markets." *See* Plan to Address Extraordinary Market Volatility, available at https://www.finra.org/sites/default/files/regulation-NMS-plan-to-address-extraordinary-market-volatility.pdf.

[2] The analysis uses the National Best Bid and Offer (NBBO) spread and the quoted depth at the NBBO to measure liquidity.

The analysis also notes that LULD events on optionable stocks are infrequent and have short durations; that little options trading occurs during these events; and that market quality reverts to pre-event levels soon after the event ends. The analysis concludes that only a small amount of trading volume is likely to be adversely affected by the deterioration in liquidity and that it is not clear whether the overall impact on option market quality should be considered economically significant.

Comparison to the Supplemental Joint Assessment:
The analysis by Cornerstone differs from that described in the Supplemental Joint Assessment and thus provides additional information regarding the effect of LULD on the options market. The Supplemental Joint Assessment, which focuses on limit states, provides charts that show how liquidity during a limit state compares to liquidity in the 15 seconds before the limit state and summarizes the results for each month during the LULD pilot. The Supplemental Joint Assessment concludes that liquidity generally decreases during limit states, which the Assessment describes as a "good response that helps to stabilize the market." In particular, the Supplemental Joint Assessment explains that "[w]ider spreads in the options market during limit states deter investors from getting around the limit state by trading in options rather than cash equities."

While Cornerstone also finds that limit events are associated with a decrease in options market liquidity, the analysis runs additional statistical tests and expands on the Supplemental Joint Assessment by attempting to disentangle the effect of LULD from the effect of the large price moves that result in the LULD event (either a straddle state or limit state). This allows better assessment of the potential harm of the LULD event on the options markets.

Analysis:
The Cornerstone analysis shows the evolution of options market liquidity during a 10-minute window surrounding the first LULD straddle state of the day in the underlying security on days when multiple straddle or limit states occur.[3] This analysis finds that options market liquidity, on average, begins to decrease in the minutes leading up to the straddle state and then decreases dramatically at the trigger of the straddle state. Options market liquidity increases in the five minutes following the trigger but does not return to levels observed five minutes prior to the straddle state.[4]

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[3] The Cornerstone analysis excludes instances in which the straddle state ended in an LULD trading pause. Is also excludes instances in which the straddle state occurred within 0.25 seconds of 9:45 a.m. Note that the Supplemental Joint Assessment finds that when straddle states end in a limit state, the limit state follows "immediately." Further, the DERA White Paper on Limit Up-Limit Down finds that 37% of straddle states end in a limit state, based on SRO data. That statistic does not account for multiple repeated straddle states in the same stock.

[4] Subsequent straddle states followed many of these straddle states during the five-minute period following the first trigger.

The analysis also shows separate results for when there was only one straddle state in the day.[5] Like the analysis of days with multiple straddle states, the analysis on days with one straddle event shows that options market liquidity decreases leading up to the straddle event and then options market liquidity decreases dramatically at the trigger of the straddle event. Unlike the results for multiple events, the single event results show that options market liquidity fully reverts to pre-straddle state levels within a few minutes.

Cornerstone also ran several tests that attempt to separate the effect of LULD from the effect of the price changes resulting in LULD straddle or limit states. As stated in the Supplemental Joint Assessment, large price movements in underlying securities reasonably lead to decreased options market liquidity. Specifically, according to the Supplemental Joint Assessment, large price moves are a sign of high volatility that would lead to wider spreads and lower depth and confound analysis of the impact of LULD. The Supplemental Joint Assessment further noted that the trading restrictions imposed under LULD may impair the ability of options market participants to hedge exposures, which could also result in reduced liquidity. The Supplemental Joint Assessment results do not, however, disentangle the effects of the price volatility from the trading restrictions of LULD.

The Cornerstone analysis attempts to separate the effects of LULD from the effects of price changes using two different methods. First, it examines market quality around LULD events such as straddle states and limit states at 9:45 a.m., when the LULD price bands narrow. The narrowing of the price bands can trigger a straddle state without an accompanying price change if the quoted spread of the underlying equity is sufficiently wide. However, absent a wide quoted spread, the underlying equity would not enter a LULD event without some recent price movement that would result in trading significantly above or below the reference price. The graphical results suggest that entering straddle or limit states causes a temporary deterioration in market quality, separate from changes in market quality due to price movements. This analysis does not, however, examine whether the temporary changes are statistically significant.

The second method employed by Cornerstone to separate the effects of LULD from the effects of price changes involves estimating a regression model that captures the effect of being close to a trigger separately from the effect of hitting a trigger. To be close to hitting a trigger, the underlying stock must have experienced a large price change, making this test a comparison of the effects of a large price change coupled with hitting the trigger to the effects of a large price change alone. Unlike the 9:45 a.m. analysis, this analysis does examine the statistical and economic magnitude of the effects. The regression results suggest that the effects on market quality of hitting the trigger are statistically and economically similar to the effects of nearly hitting the trigger.

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[5] It also excludes instances in which the straddle state occurred within 0.25 seconds of 9:45 a.m.

MEMORANDUM

To: Division of Economic and Risk Analysis

From: Stewart Mayhew, Cornerstone Research

Date: December 23, 2015

RE: Analysis of Options Market Quality during LULD States

Executive Summary

This memo summarizes research requested by the staff of the Commission's Division of Economic and Risk Analysis ("DERA") under the terms of contract SECHQ1-12-C-0162 with Cornerstone Research,[1] related to the effects of the "Limit Up-Limit Down" ("LULD") pilot program.[2] DERA staff requested that we provide economic analysis on issues related to how the LULD program impacts option markets. The current memo summarizes our research investigating the extent to which the underlying market going into a LULD state has an adverse impact on market quality in the options market.

The research summarized herein represents a high-level investigation of the extent to which trading restrictions in the stock market arising from the LULD program may have an adverse impact on market quality in option markets, in particular as measured by quoted spreads

[1] The analysis summarized in this memo was undertaken by a team of researchers under the direction of Dr. Stewart Mayhew at Cornerstone Research. The team also included Dr. Amber Anand of Syracuse University, Dr. D. Timothy McCormick, and the staff of Cornerstone Research. The findings presented herein are results of analysis performed by the research team in response to specific requests and questions from DERA staff. This memo does not seek to offer any policy recommendations, and should not be construed as an endorsement by the authors or by Cornerstone Research of any particular policy alternative. Any views and interpretations expressed in this report are solely those of Dr. Mayhew, Dr. Anand, and Dr. McCormick, who are responsible for the content, and do not necessarily represent the views of Cornerstone Research.

[2] The LULD rules, described in detail in section I-A, below, restrict trading outside of certain upper and lower price limits. Essentially, when the quoted spread is partially outside of the price limits, the market is said to be in a "straddle" state and quotes beyond the price limit are not executable. When the entire quoted spread is outside of the price limits, the market is in a "limit" state and trades cannot be executed. A limit state persisting for 15 seconds triggers a five-minute trading halt

and quoted depth. The analysis below is based on data on LULD "events" provided by the primary listing exchanges to the SEC staff, covering all reported LULD events from April 15, 2013 to April 30, 2014. Some of the analyses below (those reported in Section V) are based on "Phase II" data beginning on August 5, 2013.

Note that if a LULD event triggers a trading halt, trading in the option market is also halted, so in this sense, LULD events have a mechanical impact on option market liquidity.[3] If the stock is in a LULD state but a trading halt has not been triggered, quoting continues in the option market.

As described below, our findings indicate that when the stock experiences a LULD event but is not in a trading halt, a significant deterioration in liquidity in the option market is observed. Specifically, our results indicate an increase in the National Best Bid and Offer ("NBBO") spread in the option market, and a corresponding decrease in the number of contracts quoted at the NBBO. This deterioration in liquidity is observed in the moments or minutes leading up to a LULD event in the underlying stock, suggesting that the turbulent conditions leading to the LULD may already be adversely affecting option market liquidity prior to the moment the LULD is triggered, or alternatively suggesting that option market liquidity deteriorates in anticipation of a likely LULD event. A further increase in NBBO spreads and decrease in depth at NBBO is observed at the time of the LULD event, indicating that the LULD

[3] From an overall market quality and policy standpoint, the impact is not clear because option market liquidity may also have been adversely affected by the large price movements the LULD rules were intended to control. There is a potential trade-off between halting trading to protect traders from lower liquidity episodes and allowing trading to take place during these episodes of potentially higher trading costs.

event itself has a negative impact on option market liquidity. These results are presented graphically in section III and IV below.

Formal modeling based on a multivariate regression analysis confirms that NBBO option spreads are (statistically) significantly higher when the stock is in a LULD state, but after controlling for the possibility that spreads may be wider as a result of the recent stock price movement, the impact is similar to that seen for large price movements. These results are summarized in section V below.

The graphs in sections III and IV show a clear impact on market quality at the time of LULD events. Moreover, the regression results reported in section V indicate a statistically significant effect of LULD events on option spreads. However, these regression results also indicate that a similar impact on spreads is observed at times when the market is not in a LULD state but the quote movement is nearly large enough to trigger a LULD event (within 1% of the trigger). This suggests that either (1) option market liquidity may be adversely affected even when the market is not in a LULD state if the market anticipates a likely LULD state in the near future, or (2) option spreads may become wider as a result of large sudden stock price movements even in the absence of a LULD rule.

In our assessment, the results suggest that LULD events on stocks with listed options have an impact on market liquidity large enough that it may have an appreciable economic effect on option market participants trading at that time (although “economic significance” is inherently subjective). Given that the ability to trade the underlying stock for purposes of hedging is a central component of risk management for option specialists and market makers, it is not surprising in our view that restrictions on trading the underlying stock should have a contemporaneous negative impact on liquidity in the option market.

It should be noted, however, that LULD events on optionable stocks are infrequent, tend to have short durations, experience little trading during the event, and the graphs below suggest that market quality tends to revert toward its pre-event state after LULD events cease. Consequently, it appears that only a small amount of trading volume in the option market is likely to be adversely affected by LULD events. Even if LULD events do have an economically significant adverse impact on market quality in the affected classes, it is not clear whether the overall impact on option market quality should be considered economically significant.

I. Background: Limit Up-Limit Down

The Plan to Address Extraordinary Market Volatility ("Plan") is a National Market System Plan, developed by the exchanges and FINRA, designed to prevent a recurrence of severe disruptions in the equity market, such as the "Flash Crash" that occurred on May 6, 2010. The Plan created a new mechanism, known as Limit Up-Limit Down ("LULD"), for restricting and temporarily suspending trading in individual stocks in circumstances where the market experiences a large price movement over a short period of time. The Plan was designed to replace the "single-stock circuit breaker" pilot program, an earlier program implemented through exchange and FINRA rules implemented in the immediate aftermath of the Flash Crash.

The Plan was initially approved on a pilot basis on May 31, 2012[4] and was implemented in phases, with the first phase effective on April 8, 2013. In Phase I, LULD applied only to "Tier 1" securities, defined as stocks in the S&P 500 and Russell 1000 indices and certain exchange-

[4] SEC Release No. 34-67091; File No. 4-631.

traded products. Moreover, in Phase I, LULD only applied from 9:45 AM to 3:30 PM. Beginning August 5, 2013, Phase II, Stage 1 was implemented. In this phase, all Tier 1 and Tier 2 securities, except for rights and warrants, were covered, and price bands were in effect from 9:30 AM through 3:45 PM.[5] Phase II, Stage 2, which extended price bands to 4:00 PM, began on February 24, 2014 for all exchange-listed securities except NASDAQ and on May 12, 2014 for NASDAQ-listed securities. The LULD pilot was initially approved for one year but was later extended through October 23, 2015.[6]

The LULD mechanism involves a stock-specific "Reference Price" as well as an "Upper Band" and a "Lower Band," which together limit trades to prices within a set proximity of the average price over the preceding five minutes. Specifically, the Reference Price is defined as the average trading price of a stock's eligible reported transactions over the preceding five minutes, and the Upper Band and Lower Band are set five, ten, or twenty percent above and below the Reference Price.[7] The Plan requires exchanges and other trading centers to implement policies and procedures designed to prevent trades at prices outside of the upper and lower price bands.

If the National Best Offer ("NBO") exceeds the Upper Band and/or the National Best Bid ("NBB") drops below the Lower Band, the stock is said to enter a "Straddle State." When the stock is in a Straddle State, some but not all of the prices within the NBBO spread fall outside of

[5] On NYSE Arca, 530 symbols were removed from the pilot on August 28, 2013, and reintroduced on December 2, 2013.
[6] SEC Release No. 34-74323; File No. 4-631, February 19, 2015.
[7] The width of the price bands depends on the time of day, the price level of the stock, and the type of the security. When the reference price is greater than $3.00, the price bands are set at 5% for Tier 1 stocks and 10% for Tier 2 stocks. Price bands are doublewide for all stocks from 9:30 to 9:45 and from 3:35 to 4:00. When the reference price is less than or equal to $3.00 but greater than or equal to $0.75, the price bands are set at 40% from 9:30 to 9:45 and from 3:35 to 4:00, and 20% otherwise. When the reference price is less than $0.75, the price bands are set at the lesser of $0.30 or 150% (for the upper band only) from 9:30 to 9:45 and from 3:35 to 4:00, and the lesser of $0.15 and 20% otherwise.

the price bands. When the market enters a Straddle State, the primary listing exchange is required to indicate that quotes outside of the price bands are no longer executable.

If the NBB reaches the Upper Band, or the NBO reaches the Lower Band, the stock is said to enter a "Limit State." When the stock is in a Limit State, both the NBB and NBO fall either above the upper price band or below the lower price band, and trades cannot be executed at any price within the quoted NBBO spread. If a stock remains in a continuous Limit State for 15 seconds, trading is halted for five minutes, after which the price bands are recalculated and the market reopens.

II. Data

DERA staff provided data on LULD events on all stocks for the period April 2013 through April 2014. These data were originally provided to the Commission staff by the primary-listing exchanges.[8] The data include the start and end time of each event, the relevant stock ticker and symbol, and a flag for whether the event ended in a trading halt. The data from NASDAQ also include a flag that indicated whether the event was a limit up event or limit down event. For example, for a straddle event the flag would indicate whether the cause of the LULD state was the bid hitting the lower band, the ask hitting the upper band, or a large spread where both the bid and ask were outside of the lower and upper price bands, respectively.

[8] LULD events were only included when reported by the primary listing exchange. In some instances, limit events were recorded as straddle events as well, and the duplicate straddle events have been excluded. Events that started or ended beyond the boundaries of the applicable phase and stage were also excluded. Finally, limit states with durations greater than 15 seconds were present in the data, and we assume that the end time of these events fell during a trading halt. Given that there were no potential trades at issue during these trading halts, these overstated limit state durations do not affect our conclusions.

DERA staff also provided intraday data on upper and lower price bands, which were also provided to the Commission staff by the exchanges. We understand that the primary-listing exchanges calculate these price bands every 30 seconds and disseminate them when they change.

The research reported below is based on LULD events on optionable stocks for which OPRA quote and trade data were available. Based on the timestamps reported by the exchanges, there were 608,029 LULD events that lasted at least one millisecond over this period, but only 6,738 events (approximately 1%) lasting at least one millisecond occurred on securities with exchange-listed options. These events occurred on 668 unique day-tickers. The regression results in section V below are based on the data from Phase II, and thus cover the period August 5, 2013 through April 30, 2014. This includes a total of 5,586 events.

Intraday option market quotes, as reported by the exchanges to the Option Price Reporting Authority ("OPRA"), were obtained from TickData. The data employed in this research include all option quotes on days when the underlying stock experienced at least one LULD event.

The contemporaneous NBBO of the underlying stock was appended by TickData to each option quote update. The research described below relies on these contemporaneous snapshots of the NBBO, and does not employ the full intraday record of quotes from the underlying stock market, such as would be available through the NYSE's Trades and Quotes ("TAQ") database.

III. Changes in Option Market Quality Surrounding LULD Events

In this section we provide graphical results summarizing the impact of LULD events on market quality. In particular, the graphs in this section show how option market quality evolves in the minutes leading up to the first straddle event of the day, averaged across all option series

corresponding to stock/days that experienced a LULD event during the period. A sudden degradation in option market quality after a stock experiences its first straddle event of the day is indicative that the LULD may have an adverse effect on option market quality.

It should be noted that LULD events tend to cluster in time, with one event frequently followed by other events on the same stock in the following seconds or minutes. Potentially, the fact that a LULD event occurred recently might affect market quality even if the market is currently not in a straddle or limit state. This makes it more complicated to isolate the effect of a single event on market quality. In an effort to shed further light on this issue, we bifurcate the sample of LULD events into instances where multiple events occurred on the same day, and instances where only a single LULD occurred.

Figure 1 shows how NBBO option spreads evolved during a 10-minute time window surrounding the first LULD event of the day, for a sample of all option series on 113 stock/days for which there were multiple LULD events, and the first event of the day was a straddle event.[9] The X-axis in Figure 1 represents the number of seconds before or after the first straddle event, with the vertical line at zero representing the event. The graph includes instances where the market later re-entered a limit or straddle state, but excludes instances where the LULD event or subsequent LULD events terminated in a trading halt. For reasons discussed below, this graph omits events occurring within 0.25 seconds of 9:45:00 AM.

[9] This graph excludes events prior to 9:35 (or during Phase I prior to 9:50) and is thus restricted to events where data are available over the entire five-minute period prior to the event. The graph focuses on the first event of the day in order to ensure that five-minute period prior to the event represents a period free of LULD events. In the large majority of instances, when the first LULD event of the day occurred after 9:35, the first event was a straddle event, not a limit event. Review of the eight instances after 9:35 where the first LULD event of the day was a limit event shows a pattern substantively similar to that in Figure 1.

As Figure 1 indicates, the NBBO option spread (on average) begins to rise in the minutes leading up to the first LULD event of the day, then increases dramatically when the LULD event occurs. In the five minutes following the first LULD event of the day, option spreads, on average, begin to decrease toward their pre-event levels but do not fully revert within five minutes. Due to the clustering of LULD events, for many of the events underlying Figure 1, more LULD events will have occurred during the post-event period shown on the graph.

In contrast, Figure 2 shows the same graph for a sample of all option series on 81 stock/days where there was only one LULD event on the day (and where the event was a straddle event). This graph also excludes events occurring within 0.25 seconds of 9:45:00 AM. For this sample, again, NBBO option spreads tend to rise leading up to the event, and spike upwards dramatically when the event occurs. For all the events underlying Figure 2, there were no further LULD events, so the right hand side of this graph shows how NBBO spreads tend to return to normal following an isolated straddle event. As the graph indicates, if no further LULD events occur, the NBBO spread (on average) gradually returns to its prior level over the next three or four minutes.

Figures 3 and 4 show the aggregate quoted depth at the NBB and NBO in the ten-minute window surrounding the first LULD event of the day, for the multiple-event and single-event samples corresponding to Figures 1 and 2. As indicated in Figure 3, for 113 stock/days where there were multiple LULD events beginning with a straddle event, the aggregate depth quoted at both the NBB and the NBO declines significantly in the minutes leading up to the first event of the day. As indicated in Figure 4, for stock days where there was only one LULD (straddle) event, quoted depth drops precipitously at the time of the event, but recovers in the subsequent few minutes.

IV. Changes in Market Quality Surrounding LULD Events at 9:45

A subset of LULD events occurred at exactly 9:45:00 AM. During Phase II of the LULD implementation, the LULD rule was in effect starting at 9:30 AM. However, prior to 9:45 AM, price bands were double wide.[10] For Tier 1 stocks over $3, the price bands are defined as 10% above and below the reference price from 9:30 AM to 9:45 AM and from 3:35 PM to 4:00 PM, but only 5% above and below the reference price starting at 9:45. For Tier 2 stocks, the bands are similarly defined but with bands of 10% and 20%. In other words, at 9:45 AM the threshold for triggering a LULD event drops by half. At nearly any other time of day, a stock entering a LULD state would do so as a result of a movement in its stock price within the prior 5 minutes. At 9:45, a stock may enter a LULD state because the price was already beyond the 5% threshold, but had not surpassed the 10% threshold, when the narrower bands go into effect. Examining the change in market quality surrounding LULD events at 9:45 allows us, at least to some degree, to isolate the effect of a LULD state from the effects of a sudden price movement.

Figure 5 shows the average NBBO spread in a ten-minute window from 9:40 to 9:50, for the 41 stock/days that experienced a LULD event at 9:45:00. As was the case in Figures 1 and 2, the quoted spreads widen at 9:45, but the magnitude of the change is smaller than in the other samples, and the reversion back to a normal spread is faster. Compared to LULD events occurring at other times, a LULD event at 9:45:00 is more likely to be anticipated, and less associated with the uncertainty of rapidly moving stock prices.

[10] See https://www.nasdaqtrader.com/content/MarketRegulation/LULD_FAQ.pdf and https://www.nyse.com/publicdocs/nyse/markets/nyse/luld_overview_faq.pdf.

Figure 6 shows quoted depth at the NBBO surrounding LULD at 9:45. Again, there is a reduction in quoted depth at the time of the event, but the magnitude and duration of the effect appears to be lower than for the other samples.

These graphical results suggest that entering a LULD states causes a temporary deterioration in market quality, separate from changes in market quality due to price movements.

V. Regression Analysis

This section presents a multivariate regression framework designed to measure the marginal effect of a LULD event on NBBO spreads in the option market.

For each stock/day, and for each option series in the corresponding option classes, we use the NBBO spreads observed at the end of five-second intervals throughout the trading day. Each observation of the NBBO spread was then normalized by dividing by the average NBBO spread for that option series that day across these five-second observations. Thus, for example, an NBBO spread observation of 1.10 means that the observed NBBO spread was 10% wider than the average of the NBBO spread for that option series on that day.[11]

Spreads are normalized in this way so that the design of the regression methodology can focus on explaining intraday variations in option spreads, and in particular whether the spread is impacted by LULD events, without having to explicitly model and correct for the various factors

[11] The calculation of the average spread excludes instances where the market was crossed or the spread was greater than $5. Observations during trading halts due to LULD events, instances where there was a null update in the price band data, and extreme observations in the underlying stock data that appear to be stub quotes were excluded from the sample. Only stock/days where the price bands implied that the closing price on the previous day was above $3 were included. In rare instances, the width of the price bands reported in the data conflicted with the price bands indicated by the LULD rules. These observations were excluded from our analysis.

that explain the cross sectional variation in the level of spreads across option series. For example, prior research has documented that option spreads may be related to various factors such as the option price, trading volume, and volatility, and may be related to these variables in complex, non-linear ways.[12] Normalizing the spread by its daily weighted average allows us to abstract away from all these factors and focus on modeling what factors explain intraday variation of option spreads.

For some observations, normalized spreads can take on extreme values. For example, if a particular option series has an average spread of $0.05 but for one moment liquidity vanishes and the spread increases to $5.00, the normalized spread would take on a value of 100. To reduce the extent to which the regression results are driven by such extreme outliers, the sample was winsorized, with normalized spread observations greater than 10 replaced with a value of 10.

As described above, the market enters a LULD state when the quoted price on at least one side of the market exceeds the price bands, defined relative to a "reference price" representing the average price over the previous five minutes. Because limit events are triggered by a relatively rapid, large price movement in the stock price (or by a wide quoted spread in the stock market), option market liquidity may be affected through two separate channels. Option liquidity may be impacted as a directly result of the LULD restrictions themselves, or they may be affected by the underlying market changes that triggered the LULD event. Ideally, an empirical examination into the effects of the LULD rule should seek to disentangle these two effects.

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[12] Mayhew, S. "Competition, Market Structure, and Bid-Ask Spreads in Stock Option Markets," *Journal of Finance* (April 2002), pp. 931-958.

The regression analysis reported below is based exclusively on data from August 5, 2013 through April 30, 2014, when Phase II of the LULD regime was in effect. An empirical comparison of the effects of large price movements on market quality before and after the effective date of the LULD rules would be a useful analysis, but is beyond the scope of our current research. Instead, the current research employs a methodology that seeks to determine if there is a LULD effect and to distinguish the effects of LULD events from the effects of large price movements by identifying times when the stock market was close to triggering a LULD event, but not actually in a LULD state.

The methodology employs a panel regression model, where the normalized NBBO spread is regressed on an indicator variable for a LULD event (instances where the quote is at least 10% from the reference price before 9:45 and after 3:35 or at least 5% from the reference price during the rest of the day for Tier 1 stocks, and instances where the quote is at least 20% from the reference price before 9:45 and after 3:35 or at least 10% from the reference price otherwise for Tier 2 stocks). The model is estimated separately for Tier 1 and Tier 2 stocks and is designed to estimate the difference between the mean normalized spread during a LULD state and the mean normalized spread during a non-LULD state. Additional indicator variables for the first two 15-minute intervals of the day (9:30 to 9:45 and 9:45 to 10:00) are included to control for the wider normalized spread in the early morning. For robustness, this specification is also estimated over the 9:45 to 3:35 period, during which price bands are constant at 5% for Tier 1 stocks or 10% for Tier 2 stocks. To correct for serial correlation of errors, standard errors are estimated by clustering on option series-date. The model is estimated on a panel sample consisting of all option series on stock/days that experienced at least one LULD event, but includes multiple observations from throughout the entire day, not just around the time of the LULD event(s).

The results of this specification are presented in the first four columns of Table 1. The coefficient of 1.506 on the "LULD Indicator" for the Tier 1 sample means that during LULD events, quoted NBBO spreads in option markets are on average 150.6% wider than average for Tier 1 stocks. The coefficient of 0.551 on the "LULD Indicator" for the Tier 2 sample means that during LULD events, quoted NBBO spreads in option markets are on average 55.1% wider than average for Tier 2 stocks. The coefficients on the morning indicator variables confirm the well-known result that quoted spreads are significantly wider in the morning. All coefficients reported in Table 1 are statistically different from zero at the 1% confidence level.

Columns 5 through 8 report alternative specifications including a "Near Trigger" indicator variable reflecting times when the market is not in a LULD state, but the quote is close to the price limit. In particular, this specification involves identifying instances where the NBB was above but within 1% of the lower price band or the NBO was below but within 1% of the upper price band.[13] Under these circumstances, a relatively small move of the quote further from the reference price would be sufficient to push the market into a straddle state, and in that sense the market is "close" to triggering a LULD event. In many instances, the Near Trigger indicator will be operative at times when the market recently experienced a LULD event but is not currently in an event.

The Near Trigger indicator variable provides a benchmark with which to compare the LULD event indicator variable. The difference between the two coefficients measures the extent

[13] For Tier 1 stocks, this involves identifying instances where the NBB (NBO) was at least 4% but less than 5% below (above) the reference price when the bands were set at 5%, and instances where the NBB (NBO) was greater than 9% but less than 10% below (above) the reference price when the bands were set at 10%. The same method is used for Tier 2 stocks, but the Tier 2 price bands of 10% and 20% are used.

to which spreads are wider when the market is actually in a LULD event, over and above the effect of "nearly" being in a LULD event. Thus, the regression model provides a reasonable way to investigate the direct effect of being in a LULD state on market quality.

As with the previous specification, the model is estimated separately for Tier 1 and Tier 2 stocks and is estimated over both the full day and the 9:45 to 3:35 period. The results, reported in columns 5 through 8 of Table 1, show that the coefficients on the Near Trigger indicator are positive and statistically significant, and are of an economic magnitude similar to the coefficients on the LULD indicators. It is unclear whether the difference between the coefficients on the Near Trigger indicator and the LULD indicator are economically significant.[14] .

There are multiple possible economic interpretations of the difference between the LULD indicator and the Near Trigger indicator that may be difficult to disentangle. For example, the Near Trigger indicator may be capturing the extent to which large stock price movements lead to wider option spreads even in the absence of a LULD regime. Alternatively, it may be capturing elevated spreads resulting from the market anticipating an impending trade restriction due to a likely LULD event in the near future, or it may be capturing a period of reduced liquidity as the market is recovering from a recent LULD event.

[14] The statistical significance of the difference between the LULD indicator and the Near Trigger indicator was tested using standard errors that were estimated by clustering on option series and date. The difference between the coefficients is only statistically significant for the 9:45 to 3:35 samples (columns 7 and 8). For Tier 1 stocks the coefficient on LULD indicator is higher than the coefficient on the Near Trigger indicator, and for Tier 2 stocks the coefficient of the LULD indicator is lower than the coefficient on the Near Trigger indicator. The statistical significance of the difference between the two coefficient estimates is noted in the footnotes of Table 1.

VI. Interpretations and Suggestions for Further Research

The graphs above suggest that LULD events in the stock market have a negative contemporaneous impact on liquidity in the option market, as reflected in quoted spreads and depth. The regression analysis confirms that stock quote movements large enough to trigger a LULD event are statistically associated with wider spreads in the option market, but also finds that an effect of similar economic magnitude is observed when the market is "near" (within 1% of) triggering a LULD. Thus, the evidence that LULD has a detrimental impact on spreads is mixed. It is possible that our regression model that attempts to isolate the LULD effect on market quality is confounded by other important factors. For example, it is difficult to know the extent to which this elevated spread during these "Near Trigger" events are driven by the market anticipating likely LULD events, or the extent to which spreads would have been wider even without a LULD regime.

Further research could attempt to distinguish more precisely the direct effects of a LULD event from effects of large market movements. One possible way to approach this would be to conduct a similar analysis during a time period before the LULD regime went into effect. This approach would have the advantage of being able to employ a control sample of events with price movements large enough to trigger a LULD event, but when the rule was not in effect. This would require screening the universe of intraday stock quotes to identify events that would have triggered a LULD event had the rules been in place at that time. One could then use a difference-in-difference approach to compare the impact of 5% price movements before and after the LULD framework, or to compare the difference between a 4%-5% price movement and a price movement greater than 5% before and after. This approach would also have its limitations, inasmuch as there may be other differences between the time period before and after the LULD

regime. One additional difficulty would be how to account for the single-stock circuit breakers that were in effect prior to LULD. Thus, comparison to a period prior to the implementation of single-stock circuit breakers may be more appropriate.

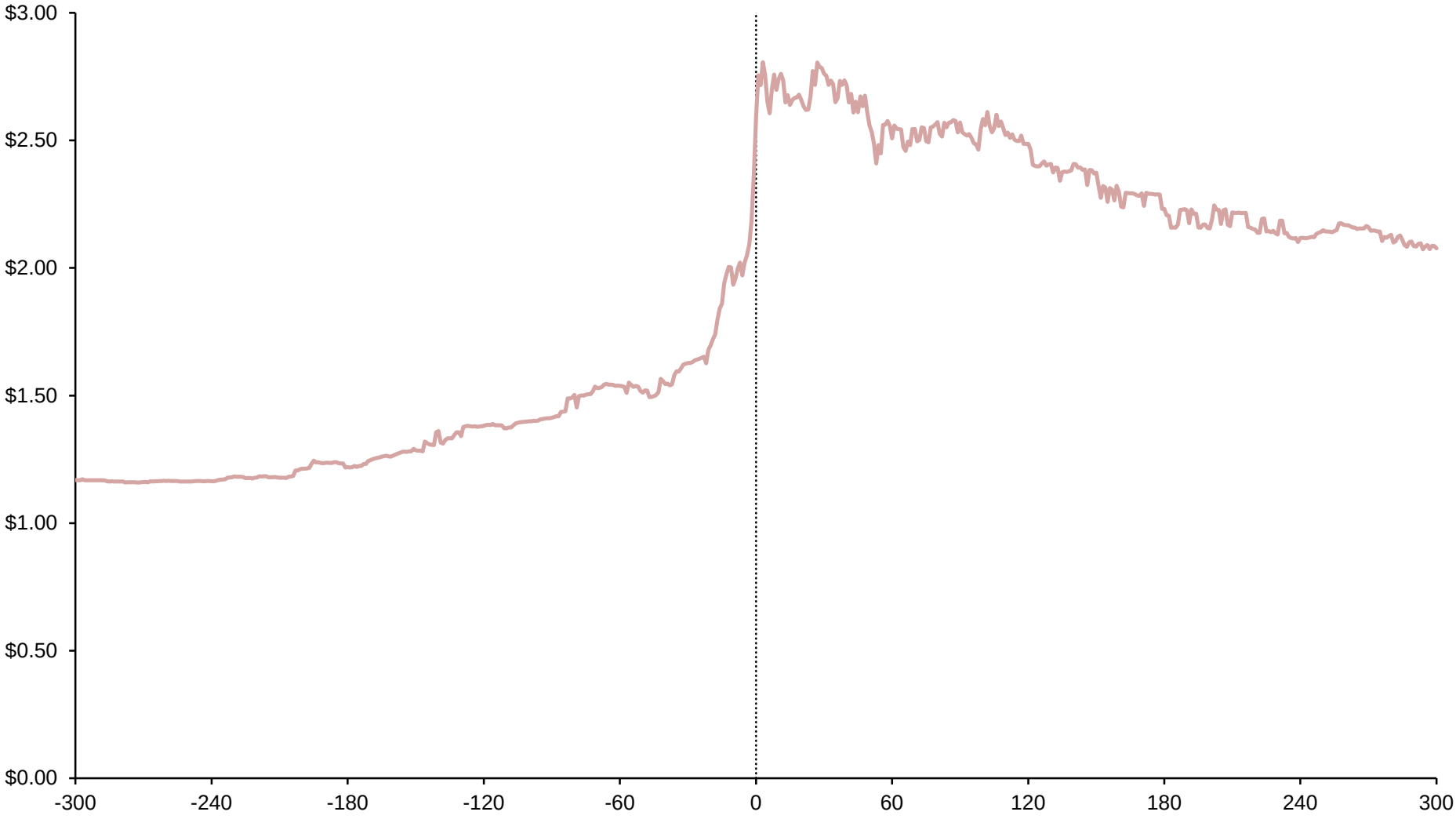
Although the results from the regressions show a statistically significant increase in the spreads during a LULD event, whether the impact of the LULD event on investors is economically significant is a more complicated question. Option exchanges generally reject market orders during LULD states, so quoted spreads are less likely to impact investor trading costs during this period. On the other hand, the fact that exchanges reject market orders itself indicates that the reduction in liquidity is likely to be significantly greater than reflected in the spread. The fact that option exchanges generally reject market orders during LULD states may also explain in part why spreads are wider during these events since the absence of market orders may reduce the incentives for liquidity providers to quote more aggressively. Whether overall market quality in the option markets can be improved with alternative policies is beyond the scope of this analysis.[15]

[15] We also note that alternative LULD policies may hinge on improvements in stock market quality as well as improvements in option market quality.

Figure 1

NBBO Spread

5 Minutes Preceding and Following First of Multiple LULD Events



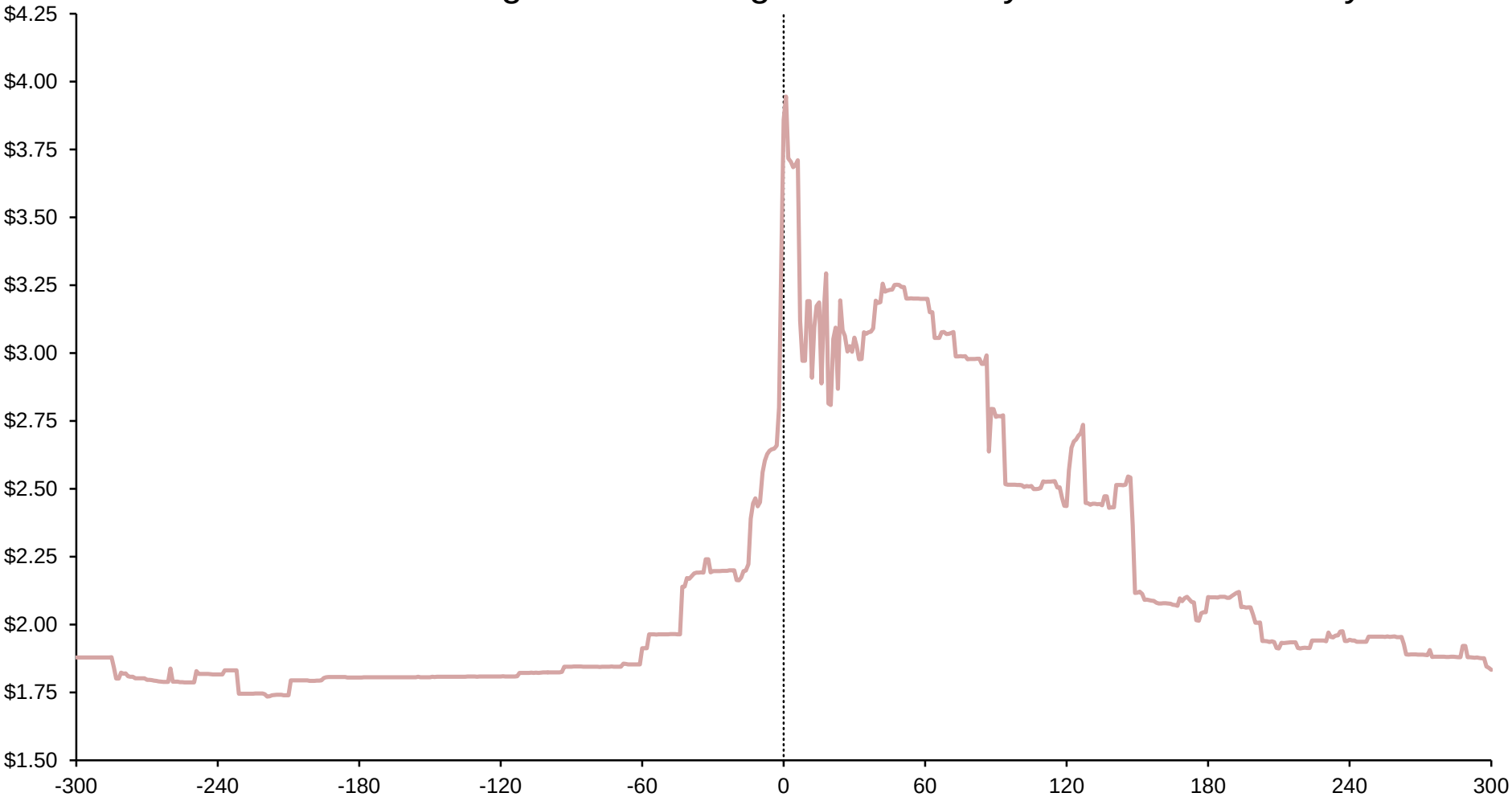
Source: OPRA; Exchange LULD Datasets

Note:
The NBBO spread was averaged each second across all series related to the 113 LULD events that were the first, but not only, event in a given symbol-date. Only straddle events were considered. Series for which the symbol entered a halt within 5 minutes following the event were excluded as were series in which the data were insufficient for this analysis (i.e. missing reference price, missing best bid, missing best offer, etc.).

Figure 2

NBBO Spread

5 Minutes Preceding and Following First and Only LULD Event of Day



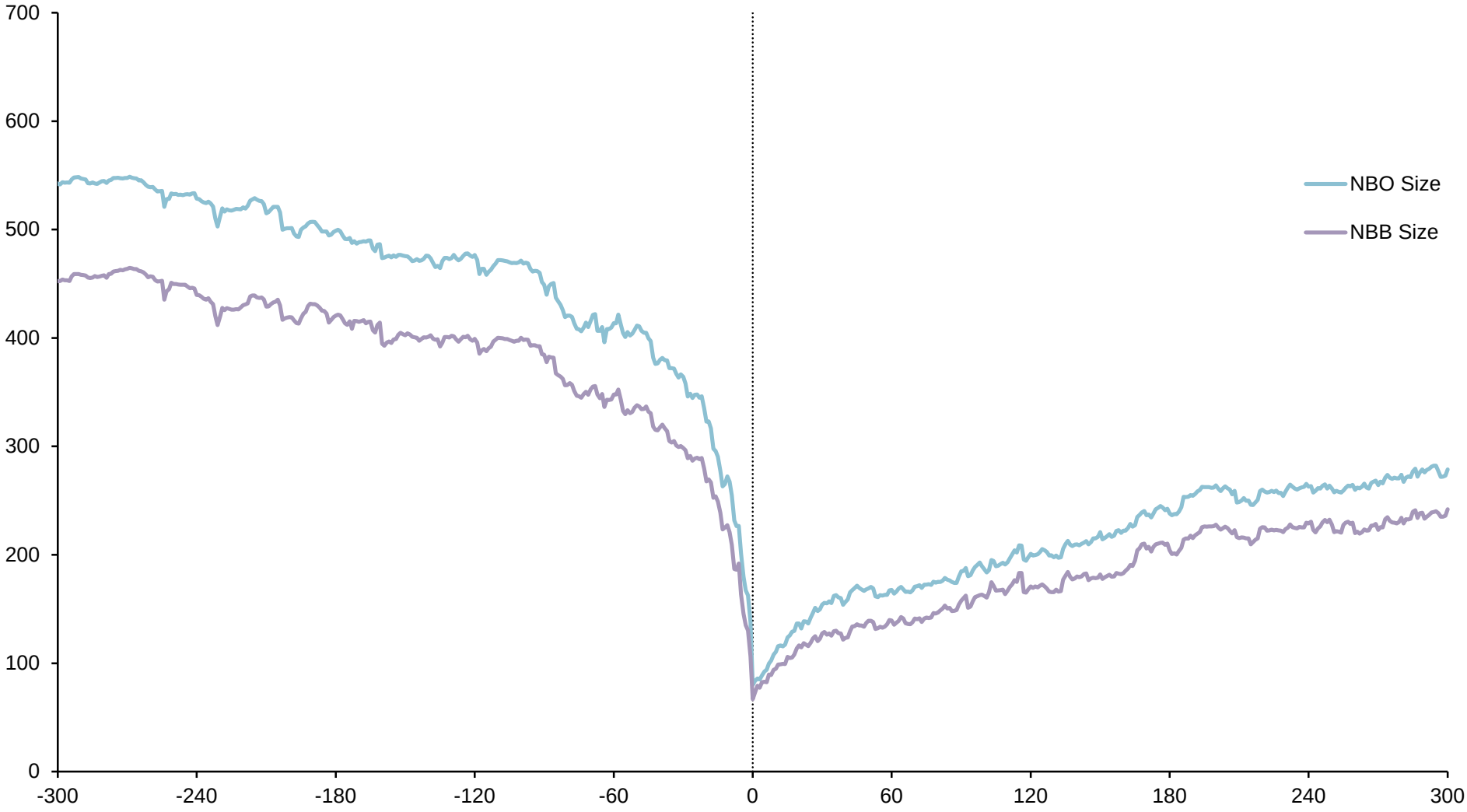
Source: OPRA; Exchange LULD Datasets

Note:
The NBBO spread was averaged each second across all series related to the 81 LULD events that were the first, and only, event in a given symbol-date. Only straddle events were considered. Series for which the symbol entered a halt within 5 minutes following the event were excluded as were series in which the data were insufficient for this analysis (i.e. missing reference price, missing best bid, missing best offer, etc.).

Figure 3

NBBO Quoted Depth

5 Minutes Preceding and Following First of Multiple LULD Event



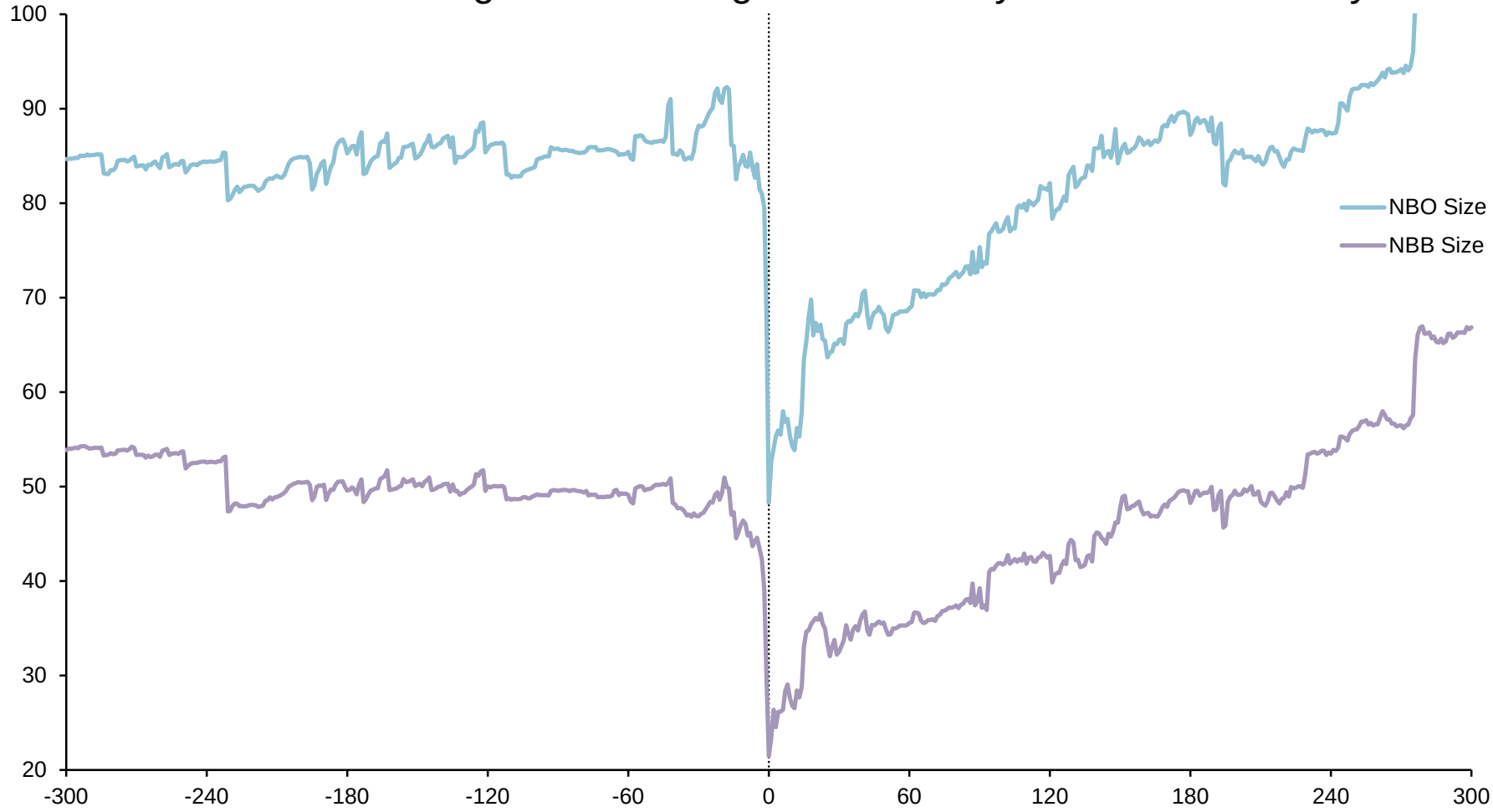
Source: OPRA; Exchange LULD Datasets

Note:
The NBB and NBO depths were averaged each second across all series related to the 113 LULD events that were the first, but not only, event in a given symbol-date. Only straddle events were considered. Series for which the symbol entered a halt within 5 minutes following the event were excluded as were series in which the data were insufficient for this analysis (i.e. missing reference price, missing best bid, missing best offer, etc.).

Figure 4

NBBO Quoted Depth

5 Minutes Preceding and Following First and Only LULD Event of Day



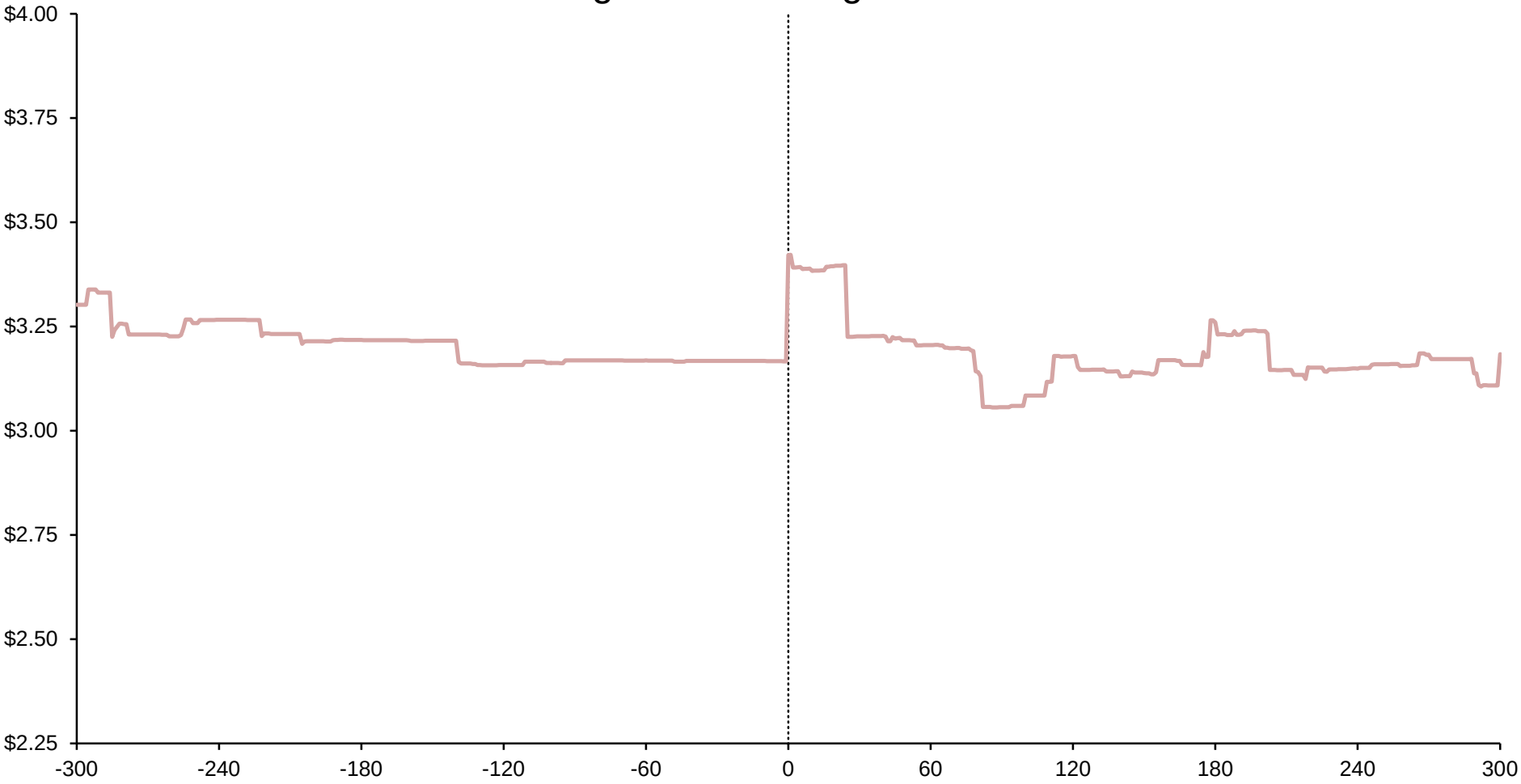
Source: OPRA; Exchange LULD Datasets

Note:
The NBB and NBO depths were averaged each second across all series related to the 81 LULD events that were the first, and only, event in a given symbol-date. Only straddle events were considered. Series for which the symbol entered a halt within 5 minutes following the event were excluded as were series in which the data were insufficient for this analysis (i.e. missing reference price, missing best bid, missing best offer, etc.).

Figure 5

NBBO Spread

5 Minutes Preceding and Following LULD Event at 9:45 AM



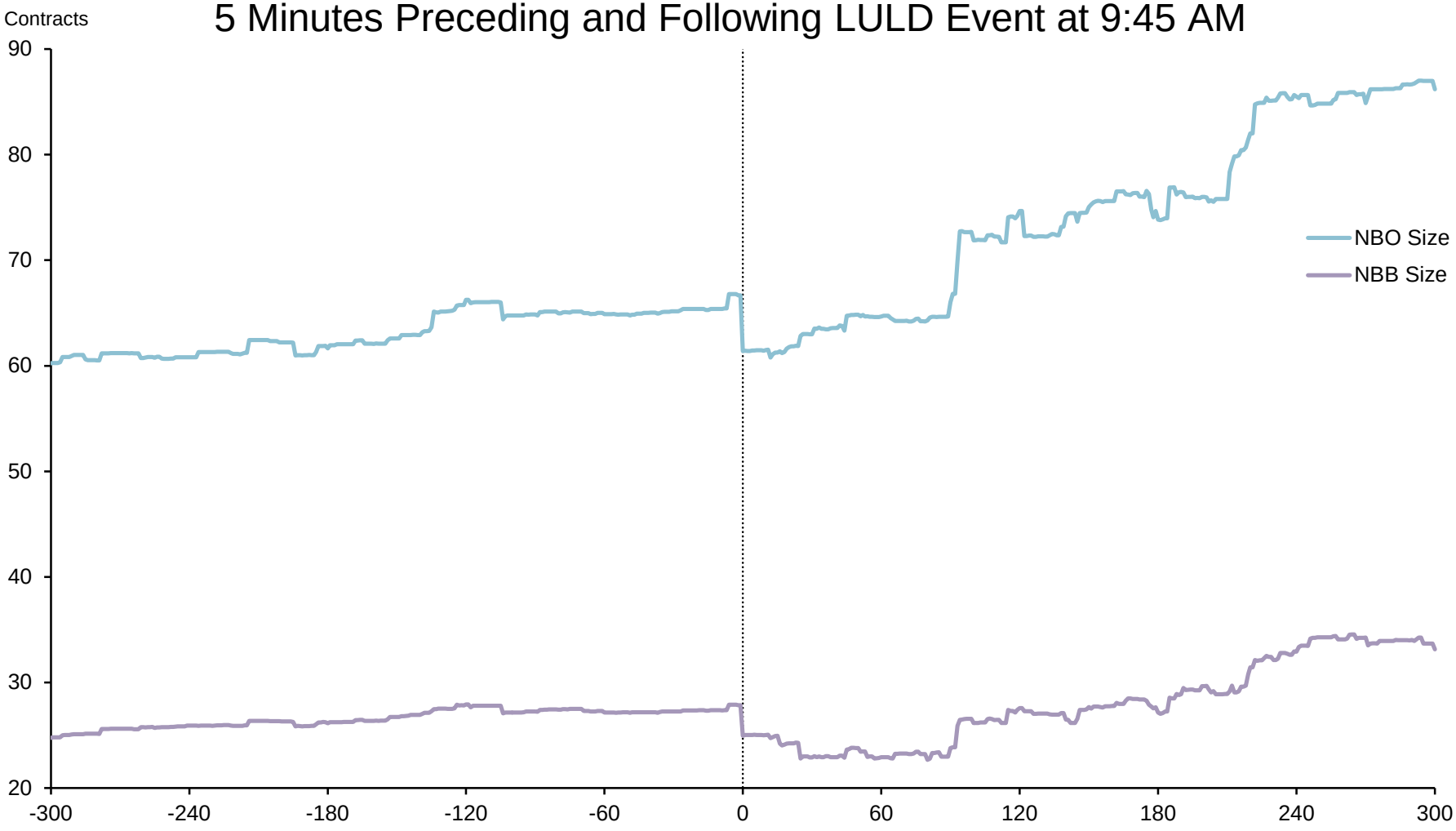
Source: OPRA; Exchange LULD Datasets

Note:
The NBBO spread was averaged each second across all series related to the 41 LULD events that occurred within 0.25 seconds of 9:45 AM, the time at which all price bands narrow. Only straddle events were considered. Series for which the symbol entered a halt within 5 minutes following the event were excluded as were series in which the data were insufficient for this analysis (i.e. missing reference price, missing best bid, missing best offer, etc.). Events that occurred in phase 1 of LULD, when price bands came into effect beginning only at 9:45 AM, were excluded.

Figure 6

NBBO Quoted Depth

5 Minutes Preceding and Following LULD Event at 9:45 AM



Source: OPRA; Exchange LULD Datasets

Note:
The NBB and NBO depths were averaged each second across all series related to the 41 LULD events that occurred within 0.25 seconds of 9:45 AM, the time at which all price bands narrow. Only straddle events were considered. Series for which the symbol entered a halt within 5 minutes following the event were excluded as were series in which the data were insufficient for this analysis (i.e. missing reference price, missing best bid, missing best offer, etc.). Events that occurred in phase 1 of LULD, when price bands came into effect beginning only at 9:45 AM, were excluded.

Table 1: LULD Market Quality Regression Results[1]

Effect on Normalized Options Spread

	Is there an LULD effect?				LULD and Near-LULD Events			
	9:30 - 4:00		9:45 - 3:35		9:30 - 4:00		9:45 - 3:35	
Parameter	**Tier 1**	**Tier 2**	**Tier 1**	**Tier 2**	**Tier 1**	**Tier 2**	**Tier 1**	**Tier 2**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)[2]	(8)[2]
Intercept	0.982	0.960	0.981	0.960	0.981	0.958	0.980	0.959
LULD Indicator	1.506	0.551	1.566	0.489	1.508	0.553	1.568	0.492
Near Trigger Indicator	–	–	–	–	1.450	0.607	1.439	0.584
9:30-9:45	0.234	0.668	–	–	0.236	0.668	–	–
9:45-10:00	0.100	0.273	0.101	0.275	0.098	0.268	0.099	0.270
Number of Stock/Days	100	484	100	483	100	484	100	483
R-Squared	0.010	0.067	0.007	0.025	0.016	0.070	0.013	0.029

Sources: OPRA; Exchange LULD Datasets; Exchange Rollout Schedules; Exchange Price Bands Datasets

[1] This table reports results from a panel regression estimating the effects of LULD events on quoted spreads in the option market. The model is estimated on a sample of stock/days when the underlying stock experienced a LULD event, but is limited to days on which the price bands implied that the closing price on the previous day was greater than $3.00. The model is estimated over the time period from August 5, 2013 to April 30, 2014. The dependent variable is the NBBO option spread for an individual option series, observed at five-second intervals throughout the day, normalized by dividing by the average spread across the day's observations. The normalized spread is winsorized on the upper tail at a normalized spread of 10. The LULD Indicator has a value of one when the stock was in a LULD event and zero otherwise. The Near Trigger Indicator has a value of one when the stock quote was within 1% of triggering an LULD event and zero otherwise. The variables labeled "9:30-9:45" and "9:45-10:00" are indicator variables equal to one during the specified time range and zero otherwise. Standard errors were estimated by clustering on option series and date. All coefficient estimates reported in the table are statistically different from zero at the 1% significance level.

[2] The difference between the LULD Indicator and the Near Trigger Indicator is statistically significant for these specifications.