

# “Limit Up-Limit Down” Pilot Plan and Associated Events

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## ABSTRACT

This paper assesses the frequency of certain events, including Limit States, Straddle States, Trading Pauses<sup>2</sup> and clearly erroneous trades, that occurred before and after the implementation of the Limit Up-Limit Down (“LULD”) National Market System (“NMS”) Plan (the “LULD Plan” or “Plan”).<sup>3</sup>

The Plan was filed to create a market-wide limit up-limit down mechanism to address extraordinary volatility in individual NMS securities, which can undermine the integrity of the securities market. The Plan was intended as a replacement for the single-stock circuit breaker (“SSCB”) pilot program, which was an earlier attempt to address extraordinary volatility and was implemented through a series of rule filings by the exchanges and the Financial Industry Regulatory Authority, Inc. (“FINRA”). The LULD Plan provides for market-wide, single-stock price bands designed to prevent trades in individual NMS stocks from occurring outside of specified price bands while allowing trading to continue if a price move is only temporary. The LULD Plan was implemented in two phases. During the first phase, the Plan operated only in larger, more liquid securities (“Tier 1 securities”), except during short periods following the open and preceding the close. During the second phase, the Plan extended to all other NMS securities (“Tier 2 securities”) and operated throughout the trading day.

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<sup>1</sup> The U.S. Securities and Exchange Commission (“Commission” or “SEC”), as a matter of policy, disclaims responsibility for any private publication or statement of any of its employees. The views expressed in this White Paper are those of the authors and do not necessarily reflect the views of the Commission or of the authors’ colleagues on the staff of the Commission. We prepared this white paper as a part of the Division of Economic and Risk Analysis (DERA) White Paper series. Mark Flannery, Narahari Phatak, and Amy Edwards reviewed the paper, and PK Jain, Lauren Moore, Mike Watson, and Aidan Flattery assisted in its preparation. We also thank the staff in DERA, especially Iliia Rainer and Laura Tuttle, and the staff in the Division of Trading and Markets (“TM”) for providing helpful comments.

<sup>2</sup> Capitalized terms used herein but not otherwise defined shall have the meaning ascribed to such terms in the Plan. See infra Section A.1, “How the LULD Plan Works,” for descriptions of LULD events.

<sup>3</sup> See Order Approving, on a Pilot Basis, the National Market System Plan to Address Extraordinary Market Volatility by BATS Exchange, Inc., BATS Y-Exchange, Inc., Chicago Board Options Exchange, Incorporated, Chicago Stock Exchange, Inc., EDGA Exchange, Inc., EDGX Exchange, Inc., Financial Industry Regulatory Authority, Inc., NASDAQ OMX BX, Inc., NASDAQ OMX PHLX LLC, The Nasdaq Stock Market LLC, National Stock Exchange, Inc., New York Stock Exchange LLC, NYSE MKT LLC, and NYSE Arca, Inc. (“Approval Order”), Release No. 34-67091 (May 31, 2012), 77 FR 33498 (June 6, 2012) (File No. 4-631). The original text of the Plan is attached to the Approval Order as Exhibit A (“The Plan”). Subsequent amendments are available at <https://www.sec.gov/rules/sro/nms.htm>.

We document a large number of Limit States, Straddle States, and Trading Pauses in Tier 2 securities, though both tiers experience a large percentage of these events at the beginning of the trading day. Further, the data suggest that there was no reduction in clearly erroneous trades (as captured by canceled trades) during the LULD period compared to the SSCB period. Also compared to the SSCB period, we find an increase in the frequency of Trading Pauses for Tier 2 securities, but a reduction in the frequency of Trading Pauses for Tier 1 securities.

## SUMMARY

This paper studies events associated with the LULD Plan (“LULD events”) including Limit States, Straddle States, Trading Pauses, and clearly erroneous trades.<sup>4</sup> The Plan was filed to address extraordinary volatility in the securities market, i.e., significant fluctuations in individual securities’ prices over short periods of time, such as those recorded during the Flash Crash of May 6, 2010.<sup>5</sup> Replacing the earlier SSCB rules, which were first implemented on June 10, 2010, LULD provides single-stock price bands intended to abate rapid price fluctuations in NMS stocks.<sup>6</sup> The LULD Plan is a more finely calibrated mechanism than the SSCB rules and is designed to guard against potentially harmful market volatility while also reducing the number of clearly erroneous trades and the frequency of Trading Pauses.<sup>7</sup> The self-regulatory organizations (“SROs”) implemented the LULD Plan in two phases. In the first phase (“Phase I”), which began on April 8, 2013, the Plan operated only from 9:45am to 3:30pm and affected only Tier 1 securities. In the second phase (“Phase II”), which began on August 5, 2013, the Plan operated throughout the trading day and included Tier 1 and Tier 2 securities.

Our goal is to report statistics on LULD-associated events. For the two types of events that also occurred before the implementation of the Plan — Trading Pauses and clearly erroneous trades — we estimate changes in their occurrence around the LULD Plan implementation. We use Phase I and Phase II of the Plan as the treatment periods and we use two prior periods as controls: (1) the period in which the SSCB, another curb on volatility, was in effect (used for both analyses); and (2) the period before the implementation of SSCB, when the Flash Crash event occurred (used only for the clearly erroneous trades analysis).<sup>8</sup> (Panel A in Appendix A provides detailed dates for the LULD Plan implementation, while Panel B provides the dates for the periods that we use in our analyses.) We report statistics on Limit States and Straddle States, which are unique to the Plan, for the first and second phases of the LULD Plan implementation only.

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<sup>4</sup> We use canceled trades as a proxy for clearly erroneous trades in our analyses. The term “canceled trades” used here means all trades identified as canceled records by the Trade and Quote database (“TAQ”), our data source. A clearly erroneous trade is one type of canceled trade. As explained below, TAQ identifies canceled trades but does not indicate which of those canceled trades were clearly erroneous trades as defined under SRO rules.

<sup>5</sup> See Approval Order, *supra* note 3, at 4-6.

<sup>6</sup> See *id.*

<sup>7</sup> See *id.* at 39-42.

<sup>8</sup> While each Phase of the Plan was gradually implemented across the securities market, we consider as Phase I and Phase II the time periods when the Plan was completely implemented across all relevant securities for that phase (see Appendix A for details).

We summarize below our overall findings on the events associated with the LULD Plan, which include Limit States, Straddle States, Trading Pauses, and clearly erroneous trades.

- LULD events such as Limit States, Straddle States, and Trading Pauses occur much more often in Tier 2 securities, suggesting that the LULD Plan price bands do not result in a uniform potential for LULD events across the two tiers of securities. These events occur in Tier 2 stocks on every day examined. In fact, we observed over two million Straddle States in Tier 2 stocks in less than four months. As for Tier 1 securities, we observed Limit States only on 28% of days, Trading Pauses on 18% of days, and Straddle States on 42% of days, over the same sample period (i.e., during Phase II).
- LULD events do not occur uniformly across the trading day in either tier. The findings show that a disproportionate percentage of LULD events occur during the first 15 minutes of the trading day and during the five minutes that follow a narrowing of the price bands (i.e., from 9:45am to 9:50am). A high percentage of Limit and Straddle States in Tier 1 securities occur during the last 25 minutes of regular trading hours, but we observe no Trading Pauses in these securities during this period.
- According to the data provided by the SROs, most of the Trading Pauses in both tiers result from “SRO-defined liquidity gaps” (as each SRO defines that term). Also, most of the Limit State events result from temporary “SRO-defined liquidity gaps” and are reversed within 15 seconds for both tiers. We caution against drawing strong conclusions based on these data, however, as the terminology used by the various exchanges in defining the “reasons” for a Limit State or Trading Pause is not uniform. For example, the SROs identify a “liquidity gap” as a reason for Limit State and Trading Pause events under different circumstances.
- Further analysis reveals that following a Trading Pause, prices revert back to within the price bands in place prior to the Trading Pause, suggesting that LULD Trading Pauses occur not only to accommodate fundamental price moves but are also triggered by “liquidity gaps,” or instances where a temporary depletion of liquidity results in a large price change that reverts quickly with the restoration of liquidity. Unless denoted by “SRO-defined liquidity gaps,” any reference to “liquidity gaps” in this paper uses this definition.
- We find that the vast majority of Straddle States reverse within five minutes. Yet, in a period of less than four months, more than 4,000 Tier 2 Straddle States lasted longer than five minutes (and less than 30 minutes), and more than 4,000 Tier 2 Straddle States lasted longer than 30 minutes.
- We document a significant decline in the number of Trading Pauses per day in Tier 1 securities during the LULD Plan implementation, compared to SSCB. In contrast, we find significantly more Trading Pauses for Tier 2 securities during the second phase of the

Plan compared to SSCB.

- We observe a significant reduction in the occurrence of clearly erroneous trades (as captured by canceled trades) expressed as a daily average number during the first phase of the LULD Plan when compared to the prior periods for both tiers (i.e., regardless of a security having the LULD mechanism in place or not). However, we document a larger occurrence of clearly erroneous trades during the second phase of the LULD Plan (when the LULD mechanism applied to all securities) compared to the SSCB period. Overall, the data suggest that there was no reduction in clearly erroneous trades (as captured by canceled trades) during the LULD period compared to the SSCB period.

The LULD Plan required Plan participants (SROs) to provide the SEC with an assessment relating to specific questions raised in the comment process and the calibration of particular elements of the Plan, such as the length of the Limit State and the percentage parameters for the price bands. The Plan participants submitted their Supplemental Joint Assessment on May 28, 2015.<sup>9</sup> The Assessment analyzes Limit States and Trading Pauses, while filtering for the “bad opening reference prices” (i.e., instances where using the midpoint of the opening quotations on the Primary Listing Exchange when there is no opening transaction leads to an opening Reference Price that may not be indicative of a realistic Reference Price). It also reports results on the incidence of Limit States, Straddle States, and Trading Pauses aggregated over all securities and over the period from the inception of the LULD Plan until December 31, 2014 (one exception is the report on the duration of Limit States, which is performed by tier group, although this analysis still covers the whole period). In addition, the Assessment groups multiple daily canceled trades in one security in one trade per day, called a Multiple Cancellation Event, and it reports results for such events.

Rather than focusing on the calibration issues addressed in the Supplemental Joint Assessment, this White Paper examines the events associated with the Plan. Our approach focuses on the frequency of events and separately analyzing Tier 1 securities and Tier 2 securities to assess whether the tiers experience events at similar frequency. Further, because the Plan designs the price bands’ parameters by tier group, we are interested in relating stocks’ characteristics, such as the stock illiquidity, to the associated events when studying the incidence of Limit States, Straddle States, Trading Pauses, and clearly erroneous trades. And, because the Plan was implemented in two phases, we perform our analyses while also partitioning our sample by time period. The latter allows us to also detect any significant changes in Trading Pauses before and after the implementation of the Plan. Finally, and differently from the Supplemental Joint Assessment, we provide results using all of the clearly erroneous trades (as captured by canceled trades) recorded during the study period.

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<sup>9</sup> See Limit Up – Limit Down: National Market System Plan Assessment To Address Extraordinary Market Volatility (the “Supplemental Joint Assessment” or “Assessment”), available at <https://www.sec.gov/comments/4-631/4631-39.pdf>.

## ANALYSIS

This paper examines the incidence of events associated with the LULD Plan, including Limit States, Straddle States, Trading Pauses, and clearly erroneous trades (as captured by canceled trades). These events represent the outcome of the procedural mechanisms by which the Plan attempts to address extraordinary volatility. We present our findings below. First, we provide background information on the LULD Plan and the various controls that were in place prior to the LULD Plan. We then summarize the existing academic research on the effects of introducing circuit breakers, price limits and trading pauses on market quality. Finally, we present the incidence of LULD events, while highlighting the number of canceled trades and Trading Pauses that occur before and during the LULD Plan.

### A. The LULD Plan

On May 6, 2010, from 2:40pm to 3:00pm, over 20,000 trades across more than 300 separate securities were executed at prices 60% or more away from their 2:40pm prices. After the market close, the securities exchanges and FINRA met and jointly agreed to cancel (or break) all such trades under their respective “clearly erroneous” trade rules.<sup>10</sup> On April 5, 2011, the SROs that oversee the U.S. equity markets filed the LULD Plan with the SEC to help address severe financial market disruptions of the kind that occurred on the afternoon of May 6, 2010.<sup>11</sup> On May 31, 2012, the Commission approved the Plan on a one-year pilot basis.<sup>12</sup>

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<sup>10</sup> See Findings Regarding the Market Events of May 6, 2010: Report of the Staffs of the CFTC and SEC to the Joint Advisory Committee on Emerging Regulatory Issues (September 30, 2010) (“Flash Crash Report”), available at <https://www.sec.gov/news/studies/2010/marketevents-report.pdf>, at 7.

<sup>11</sup> NYSE Euronext, on behalf of the participants, filed the LULD Plan with the SEC pursuant to Section 11A of the Securities Exchange Act of 1934 and SEC regulations (17 CFR § 242.608). At that time, LULD “participants” included the following entities: BATS Exchange, Inc., BATS Y-Exchange, Inc., Chicago Board Options Exchange Incorporated (CBOE), Chicago Stock Exchange, Inc., EDGA Exchange, Inc., EDGX Exchange, Inc., Financial Industry Regulatory Authority, Inc., NASDAQ OMX BX, Inc., NASDAQ OMX PHLX LLC, Nasdaq Stock Market LLC, National Stock Exchange, Inc., New York Stock Exchange LLC (NYSE), NYSE Amex LLC (NYSE Amex), NYSE ARCA, Inc. (NYSE ARCA).

<sup>12</sup> See Approval Order, *supra* note 3.

## 1. *How the LULD Plan Works*

The LULD Plan provides market-wide, single-stock price bands that are designed to prevent trades in individual NMS stocks from occurring outside of specified price bands, while allowing trading to continue when the price move is temporary. The Securities Information Processors (“SIPs” or “Processors”) responsible for consolidating information for each NMS stock pursuant to Rule 603(b) of Regulation NMS under the Securities Exchange Act of 1934 (the Act) calculate the price bands for each stock.<sup>13</sup> The price bands are determined using dynamic “Reference Prices,” based on moving averages of trade prices, and are coupled with “Limit States” to keep momentary gaps in liquidity from causing a rapid and large price change.<sup>14</sup> The Plan also provides for “Trading Pauses,” as defined in Section VII of the Plan, to accommodate more fundamental price movements (as opposed to clearly erroneous trades or momentary gaps in liquidity). The Plan defines price bands for two distinct groups of securities: Tier 1 NMS Stocks (S&P 500, the Russell 1000, and some high volume exchange-traded products (ETPs)) and Tier 2 (the remainder of NMS stocks).

The LULD Plan introduced the novel concept of a Limit State. A stock enters a Limit State when one side of the market for an individual security is outside the applicable price band (i.e., when the National Best Bid (“NBB”) is below the lower limit band or the National Best Offer (“NBO”) is above the upper limit band), and the other side of the market reaches the applicable price band (i.e., when the NBO is equal to the lower limit band or the NBB is equal to the upper limit band). When a stock is in a Limit State, the quote that equals the price band is flagged as a “Limit State Quotation”, while the quote that is outside of the price bands is flagged as a “Non-Executable Quotation”. Trading in a stock would exit a Limit State if, within 15 seconds of entering the Limit State, all Limit State Quotations are executed or canceled. After that time window, if the quoted prices do not revert back to the allowable trading range, the Primary Listing Exchange declares a five-minute Trading Pause, which is applicable to all markets trading the security. Trading reopens with an auction similar to the opening auction at the beginning of that day. The Primary Listing Exchange can also declare a Trading Pause for an NMS stock when the stock is in a “Straddle State” (i.e., when one quote is outside the price bands and the stock is not in a Limit State).<sup>15</sup>

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<sup>13</sup> 17 CFR § 242.603.

<sup>14</sup> Limit States are defined in the Plan. See The Plan, supra note 3, at Section VI.

<sup>15</sup> See Approval Order, supra note 3, at 8.

## 2. *Phase-in of the LULD and Covered Securities*

The LULD Plan was implemented in two phases from April 8, 2013, to May 12, 2014.<sup>16</sup> On April 8, 2013, the Participants started the implementation of Phase I of the LULD Plan, which applied to the S&P 500, the Russell 1000, and some high volume ETPs (Tier 1 NMS Stocks) from 9:45am to 3:35pm. The Participants completed implementation of Phase I on May 31, 2013.<sup>17</sup> During Phase I, the first price bands were calculated and disseminated 15 minutes after the start of regular trading hours; no price bands were calculated and disseminated less than 30 minutes before the end of regular trading hours; and trading could not enter a Limit State less than 25 minutes before the end of regular trading hours.

The Participants started implementing Phase II of the LULD Plan on both Tier 1 securities and the remainder of NMS stocks (Tier 2 securities) on August 5, 2013. During Phase II, price bands were in place during the opening, with wider bands from 9:30am to 9:45am. Implementation of Phase II of LULD was completed for stocks listed on the NYSE, NYSE MKT, ARCA, and BATS for the entire trading day across all NMS stocks on February 24, 2014, while Nasdaq completed implementation for its listed stocks on May 12, 2014. Panel A of Appendix A gives detailed dates for the LULD Plan implementation.

## 3. *LULD Plan Structure: Price Bands, Limit States, Straddle States, and Trading Pauses*<sup>18</sup>

The LULD Plan imposes price bands to restrict trades and thereby to address extraordinary market volatility in NMS Stocks.<sup>19</sup> These price bands are an established percentage from a

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<sup>16</sup> For details, see NASDAQ Limit Up-Limit Down Frequently Asked Questions (“LULD FAQs”), available at [https://www.nasdaqtrader.com/content/MarketRegulation/LULD\\_FAQ.pdf](https://www.nasdaqtrader.com/content/MarketRegulation/LULD_FAQ.pdf).

<sup>17</sup> See id.

<sup>18</sup> See generally The Plan, supra note 3, at Sections V-VIII.

<sup>19</sup> See Approval Order, supra note 3, at 10. Since the sample period used in this study, Amendments 10 and 12 changed parts of the structure of the LULD Plan. See Order Approving the Tenth Amendment to the National Market System Plan to Address Extraordinary Market Volatility by Bats BZX Exchange, Inc., Bats BYX Exchange, Inc., Chicago Stock Exchange, Inc., Bats EDGA Exchange, Inc., Bats EDGX Exchange, Inc., Financial Industry Regulatory Authority, Inc., NASDAQ BX, Inc., NASDAQ PHLX LLC, The Nasdaq Stock Market LLC, National Stock Exchange, Inc., New York Stock Exchange LLC, NYSE MKT LLC, and NYSE Arca, Inc. (“Amendment 10”), Release No. 34-77679 (April 21, 2016), 81 FR 24908 (April 27, 2016) (File No. 4-631) at 2, and Notice of Filing of the Twelfth Amendment to the National Market System Plan to Address Extraordinary Market Volatility by Bats BZX Exchange, Inc., Bats BYX Exchange, Inc., Bats EDGA Exchange, Inc., Bats EDGX Exchange, Inc., Chicago Stock Exchange, Inc., Financial Industry Regulatory Authority, Inc., Investors Exchange LLC, NASDAQ BX, Inc., NASDAQ PHLX LLC, The Nasdaq Stock Market LLC, National Stock Exchange, Inc., New York Stock Exchange LLC, NYSE MKT LLC, and NYSE Arca, Inc. (“Amendment 12”), Release No. 34-79845 (November 28, 2016), 81 FR 87114 (December 2, 2016) (File No. 4-631).

“Reference Price” which equals the arithmetic mean price of Eligible Reported Transactions for an NMS stock over the immediately preceding five-minute period, except for periods following openings and reopenings.<sup>20</sup> The first Reference Price of the day is the Opening Price. The next Reference Price following a Trading Pause is the Reopening Price. The upper and lower price bands provide limits on permitted execution prices. The Plan is intended to permit unrestricted trading when bid and offer quotes are between the lower and upper price bands and to prevent trading at a bid or offer quote that is outside of the specified bands.<sup>21</sup>

The Processor also calculates a “Pro-Forma Reference Price,” which is continuously updated throughout the day as a five-minute arithmetic average of the previous trade prices.<sup>22</sup> The Pro-Forma Reference Price and the Reference Price start at the opening or reopening price.<sup>23</sup> The Reference Price stays constant until the Pro-Forma Reference Price deviates from the Reference Price by at least 1%, at which point the Reference Price updates to the Pro-Forma Reference Price.<sup>24</sup> Thus, while the Pro-Forma Reference Price displays a continuous moving average type of path (with intermittent jumps or discontinuities only when there is a Trading Pause), the Reference Price is a step function with many jumps throughout the trading day.

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<sup>20</sup> See The Plan, supra note 3, at Section V.

<sup>21</sup> See The Plan, supra note 3, at Sections VI and VII.

<sup>22</sup> The first Reference Price for a trading day is the Opening Price on the Primary Listing Exchange if such price occurs less than five minutes after the start of regular trading hours. If the Opening Price on the Primary Listing Exchange does not occur within five minutes after the start of trading hours, the first Reference Price is the arithmetic mean of eligible reported transactions over the preceding five minutes. The Pro-Forma Reference Price is the arithmetic average of prices from the time of open, if five minutes have not elapsed. See The Plan, supra note 3, at Sections V(B)(1)-(2). At the time of the study, in a reopening following a Trading Pause that is not a Regulatory Halt, the next Reference Price is the Reopening Price on the Primary Listing Exchange if such price occurs within ten minutes after the beginning of the Trading Pause. If such price does not occur within ten minutes after the beginning of the Trading Pause, the first Reference Price following the Trading Pause is equal to the last effective Reference Price before the Trading Pause. Following a Regulatory Halt, the next Reference Price is the Opening or Reopening Price on the Primary Listing Exchange if such price occurs within five minutes after the end of the Regulatory Halt. See The Plan, supra note 3, at Section V(C)(1).

<sup>23</sup> At the time of the study, in the absence of an opening transaction, the first Reference Price was the opening quote midpoint. This provision was amended in Amendment 10 to the Plan, which was approved after our sample period, and modified the definition of the Opening Price in these circumstances to be the closing price of the security on the Primary Listing Exchange on the previous trading day, or if no such closing price exists, the last sale on the Primary Listing Exchange reported by the Securities Information Processor (“SIP”). See Amendment 10, supra note 19, at 2.

<sup>24</sup> In addition to deviating from the Reference Price by at least 1%, the Pro-Forma Reference Price can replace the Reference Price only if the Reference Price has been in effect for at least 30 seconds. See The Plan, supra note 3, at Sections VI(A)(2), (B)(1), and (C)(2).

The percentage deviations from the Reference Price that are used to define the price bands vary across the two tiers of securities and are doubled at the beginning and end of the trading day. For Tier 1 securities with prices greater than \$3 — generally larger market capitalization, more liquid, and less volatile than Tier 2 securities — the price bands are 5% above and below the Reference Price, except at the open and close of trading, when the percentages used to calculate the price bands are doubled. Tier 2 securities with prices greater than \$3 have price bands that are 10% above and below the Reference Price, except at the open and close of trading, when the percentages used to calculate the price bands are doubled. Lower priced securities in both Tier 1 and Tier 2 have wider price bands. Panels C and D of Appendix A report these percentages.<sup>25</sup>

“Limit States” were introduced under the LULD Plan to allow the market to quickly correct and resume normal trading, without resorting to a Trading Pause.<sup>26</sup> When a NBO is equal to the Lower Price Band or a NBB is equal to the Upper Price Band for an NMS Stock, the stock enters a Limit State.<sup>27</sup> During a Limit State, trades can be executed only at a quote that matches the price band. The Reference Price freezes when a security enters a Limit State. Market participants can supply additional liquidity during a Limit State to reverse the Limit State and bring a quote within its price band. The Limit State ends if the quote returns to a price within the price band. If this does not occur within 15 seconds, trading in the security pauses for five minutes. Trading reopens after a pause with an auction.<sup>28</sup>

A “Straddle State” occurs when at least one quote is outside the price bands, the stock is not in a Limit state, and trading in the stock deviates from normal trading characteristics. For instance, a Straddle State would occur when the NBO is above the upper price band, but the NBB is not; or the NBB is below the lower price band, but the NBO is not. A Straddle State can end in any of four ways: (1) when both quotes are inside price bands, (2) when the stock enters a Limit State, (3) when trading closes, or (4) when the Primary Listing Exchange declares a

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<sup>25</sup> During Phase I of the LULD Plan, there were no upper or lower price bands from 9:30am to 9:45am and from 3:35pm to 4:00pm. The upper and lower price bands are a function of: 1) the price of the stock or ETP; and 2) whether a stock or ETP is a member of the S&P 500, the Russell 1000, or an ETP derived from one of these indices or constituent stocks.

<sup>26</sup> See Approval Order, *supra* note 3, at 40-41.

<sup>27</sup> See The Plan, *supra* note 3, at Section VI(A)(2).

<sup>28</sup> At the time of the study, if the Primary Listing Exchange was unable to reopen the stock after five minutes, the Trading Pause could be extended for another five minutes. Thereafter, other trading venues could resume trading ten minutes after the start of the initial Trading Pause. See The Plan, *supra* note 3, at Section VII(B)(3). Amendment 12, which was approved after our sample period, modified the reopening process. In addition, in Amendment 12, if the Primary Listing Exchange reopens trading with a zero bid or offer, or if it notifies the Processor that it is unable to reopen trading due to a systems or technology issue, then the next Reference Price is the last effective Price Band that triggered the Limit State that preceded the Trading Pause. See Amendment 12, *supra* note 19.

Trading Pause.<sup>29</sup> During a Straddle State, the processors disseminate the NBB or the NBO with a non-executable flag.

A Straddle State restricts trading on the side of the quote that is outside the price bands. “Straddle States” can, in theory, last for an indefinite period of time, unlike Limit States, which have a maximum duration of 15 seconds.

To visualize how the LULD Plan works, Figure B.1 of Appendix B shows a simulation of the price pattern of a Tier 1 stock that starts trading at 9:30am for \$100. In the simulation, the Pro-Forma Reference Price and the Reference Price start at \$100 at the opening. From then on, the Reference Price updates to the Pro-Forma Reference Price when it differs from the Pro-Forma Reference Price by at least 1%. In the simulation, the first instance this happens is when the Pro-Forma Reference Price hits \$101.10, which happens at 9:35am.

The upper and lower price bands change when the Reference Price changes or when the percentage limits change at the beginning and end of the day. In the simulation, the percentage price bands start at 10% from the Reference Price of \$100, making the upper and lower price bands \$110 and \$90, respectively. At 9:45am, the band narrows to 5% from the Reference Price. Just before 9:45am, the price bands are approximately \$116.60 and \$95.4, around a Reference Price of about \$106. When the percentage limits drop to 5%, the price bands change to approximately \$111.30 and \$100.70.

In the simulation, the stock enters a Straddle State at 10:13:30, when the NBO is above the Upper Price Band and the NBB is in between the price bands. The Straddle State ends when the stock enters a Limit State at 10:14am, when the NBO is above the Upper Price Band and the NBB equals the Upper Price Band. Figure B.2 of Appendix B looks more closely at the time around this Limit State, where the yellow shaded areas represent the Limit State. In the 15 seconds following entry into this Limit State, both bid and offer are outside the price bands. Therefore, the simulated stock remains in the Limit State for the full 15 seconds, triggering a five-minute Trading Pause (shaded in pink).<sup>30</sup> Trading resumes in this simulation at 10:19:15am.

#### 4. *Summary of Differences between the LULD Plan and SSCBs*

The LULD Plan is designed to address extraordinary volatility in the securities market. There are several differences between the LULD Plan and the SSCBs. First, since LULD triggers off activity

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<sup>29</sup> See The Plan, *supra* note 3, at Section VII(A)(2).

<sup>30</sup> See The Plan, *supra* note 3, at Section VI(B)(3). The security would have exited the Limit State and a Trading Pause would not have occurred if, within 15 seconds of entering it, the entire size of all Limit State quotations were executed or canceled.

in the *quoted* prices, its mechanism prevents all trades in individual securities outside of a specified price band. Quotes outside of the price bands are marked as non-executable. In comparison, circuit breakers were triggered by *trade* prices, so at least one trade outside the specified price band must occur to trigger the circuit breaker. As a result, clearly erroneous trades triggered trading halts throughout the SSCB pilot. Given that trades should not occur outside of the price bands, the LULD mechanism may reduce the number of clearly erroneous trades in comparison to the SSCB. However, the Plan design does allow for clearly erroneous trades to occur.<sup>31</sup>

The calibration of the Pro-Forma Reference Price and the frequent adjustment of the Reference Price throughout the trading day should allow for additional price discovery in response to news while still protecting against large price movements outside the price bands caused by temporary liquidity gaps (i.e., instances in which a temporary depletion of liquidity results in a large price change that reverts quickly with the restoration of liquidity). In addition, the wider LULD price bands during the beginning and end of the trading day (implemented only during Phase II), when volatility is higher, should allow for the flow of fundamental information in the market.<sup>32</sup>

In addition, LULD features a 15-second Limit State that precedes a Trading Pause. In those instances where the movement of, for example, the NBO to the Lower Price Band is due to a momentary gap in liquidity, rather than a fundamental price move, the Limit State allows the market to correct within a 15-second window without a pause in trading. In contrast, circuit breakers would pause trading in many situations when the market might otherwise correct itself during a 15-second limit state. Further, because the price bands in LULD are more finely calibrated than those of the SSCB to accommodate fundamental price movements, a Limit State, rather than a Trading Pause, may be sufficient to resolve temporary liquidity gaps. In particular, while SSCB applied one trigger to all securities it covered, LULD applies different price bands depending on, for example, index inclusion, price, and time of day.

These features of the LULD Plan are designed to restrict disruptive price movements while allowing the market to quickly correct and resume normal trading, without resorting to a Trading Pause, when there are momentary gaps in liquidity rather than a fundamental price move.<sup>33</sup> Moreover, the quote-based triggers in LULD are designed to be more stable and reliable indicators of a significant market event than the single-trade triggers under SSCB.

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<sup>31</sup> See *infra* note 84 and the associated text.

<sup>32</sup> See Lockwood and Linn (1990).

<sup>33</sup> See Approval Order, *supra* note 3, at 40-42.

## B. Prior Rules for Addressing Extraordinary Market Volatility

Since the market break of 1987, equity and options exchanges have designed various automated market-wide and stock-specific trading pauses to address extraordinary market volatility. Among the early rules, NYSE Rule 80A was introduced to address volatility that resulted from index arbitrage.<sup>34</sup> The rule placed certain restrictions on index arbitrage orders when the Dow Jones Industrial Average (DJIA) deviated two percentage points from the previous day's close.

### 1. Market-Wide Circuit Breakers

Market-wide circuit breakers were introduced to promote stability and investor confidence during periods of significant market stress and volatility across the markets, and to ensure that market participants have an opportunity to become aware of, and respond to, significant price movements.<sup>35</sup> Specifically, when market indices experience a rapid and large change, as detailed below, trading pauses provide market participants with the additional time necessary to assess market conditions and fundamental information. After the pause, liquidity suppliers and demanders can engage in more orderly trading.

Historically, NYSE Rule 80B had mandated a market-wide trading halt when the DJIA dropped by 10% (Level 1), 20% (Level 2), or 30% (Level 3).<sup>36</sup> On February 4, 2013, NYSE amended Rule 80B by replacing the DJIA with the S&P 500 index. Specifically, the rule now mandates that market-wide trading pauses of varying lengths occur if the S&P 500 index falls 7% (Level 1), 13% (Level 2), or 20% (Level 3).<sup>37, 38</sup> These market-wide trading pauses have rarely occurred; the equity markets have experienced only one such halt, on October 27, 1997.<sup>39</sup>

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<sup>34</sup> See Notice of Filing and Immediate Effectiveness of Proposed Rule Change Relating to Rule 80A (Index Arbitrage Trading Restrictions), Release No. 34-56726 (October 31, 2007), 72 FR 62719 (November 6, 2007). Rule 80A was originally approved by the Commission in April 1988. See Release No. 34-25599 (April 19, 1988), 53 FR 13371 (April 22, 1988) (SR NYSE-88-02).

<sup>35</sup> See Notice of Filing of Proposed Rule Change Amending Exchange Rule 80B to Revise the Current Methodology for Determining When to Halt Trading in All Stocks Due to Extraordinary Market Volatility, Release No. 34-65427 (September 28, 2011), 76 FR 61422 (October 4, 2011) (File No. SR-NYSE-2011-48), at 3-4.

<sup>36</sup> See Notice of Filing and Immediate Effectiveness of Proposed Rule Change Delaying the Operative Date of A Rule Change to NYSE Rule 80B, Which Provides for Methodology for Determining When to Halt Trading in All Stocks Due to Extraordinary Market Volatility, From the Date of February 4, 2013, Until April 8, 2013, Release No. 34-68784 (January 31, 2013), 78 FR 8662 (February 6, 2013) (File No. SR-NYSE-2013-10).

<sup>37</sup> See *id.*; see also Investor Bulletin: Measures to Address Market Volatility, available <http://www.sec.gov/investor/alerts/circuitbreakersbulletin.htm>.

## 2. *NYSE Liquidity Replenishment Points and Nasdaq Volatility Guard*

When it launched the NYSE hybrid market on October 6, 2006, NYSE introduced liquidity replenishment points (“LRPs”) to address scenarios where a temporary gap in liquidity supply accompanied by a surge in liquidity demand would cause a large price fluctuation in electronic trading. LRPs effectively converted the automated auction market to a manual auction market on a temporary basis, with the intent of moderating volatility in the security.<sup>40</sup> LRPs represented a mechanism for disseminating order imbalances and directly seeking additional liquidity from market participants to help prevent unnecessary price fluctuations. LRPs were stock-specific price bounds, and depended on price and volume.<sup>41</sup> If the quotation for an automated execution was outside of the bounds dictated by the LRP, that quote could not be auto-executed and additional liquidity was sought.<sup>42</sup> LRPs, unlike LULD, applied only to trading on the NYSE while other markets could continue normal trading in the securities, thus causing potential price disparities across exchanges and additional price uncertainty. By 2013, NYSE’s LRP mechanism applied only to a fraction of the overall market because the NYSE and the NYSE MKT (formerly the American Stock Exchange), which also adopted LRPs, had only approximately 12-13% market share of consolidated volume. NYSE and NYSE MKT eliminated LRPs on January 15, 2015.<sup>43</sup>

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<sup>38</sup> On August 2, 2016, the Equity Market Structure Advisory Committee (“EMSAC”) proposed a widening of these thresholds. See Transcript, August 2, 2016 Quarterly EMSAC Meeting, available at <https://www.sec.gov/spotlight/emsac/emsac-080216-transcript.txt>; EMSAC Market Quality Subcommittee Memorandum, Recommendations for Rulemaking on Issues of Market Quality (July 25, 2016), available at <https://www.sec.gov/spotlight/emsac/emsac-market-quality-subcommittee-recomendation-072516.pdf>.

<sup>39</sup> See Trading Analysis of October 27 and 28, 1997: Report by the Division of Market Regulation, U.S. Securities and Exchange Commission (September 1998), available at <http://www.sec.gov/news/studies/tradrep.htm>.

<sup>40</sup> See Order Approving Proposed Rule Change and Amendment Nos. 1, 2, 3, and 5 Thereto and Notice of Filing and Order Granting Accelerated Approval to Amendment Nos. 6, 7, and 8 to the Proposed Rule Change to Establish the Hybrid Market, Release No. 34-53539 (March 22, 2006), 71 FR 16353 (March 31, 2006) (File No. SR-NYSE-2004-05).

<sup>41</sup> See Notice of Filing and Immediate Effectiveness of Proposed Rule Change to Add a Price Protection Mechanism to Prevent the Automatic Execution of Incoming Market Orders and Marketable Limit Orders Outside a Specified Parameter and Eliminate Liquidity Replenishment Points and the Gap Quote Policy by New York Stock Exchange, LLC (“NYSE January 2015 Proposal”), Release No. 34-74063 (January 15, 2015), 80 FR 3269 (January 22, 2015) (File No. SR-NYSE-2015-01), at 3; and <http://www.nyxdata.com/Data-Products/NYSE-LRP>.

<sup>42</sup> See NYSE Liquidity Replenishment Points, Customer Interface Specifications, available at <http://www.nyxdata.com/nysedata/DesktopModules/Bring2mind/DMX/Download.aspx?PortalId=0&EntryId=6093>.

<sup>43</sup> See NYSE January 2015 Proposal, supra note 41, and Notice of Filing and Immediate Effectiveness of Proposed Rule Change to Add a Price Protection Mechanism to Prevent the Automatic Execution of Incoming Market Orders and Marketable Limit Orders Outside a Specified Parameter and Eliminate Liquidity Replenishment Points and the

On March 11, 2011, the Commission approved the Nasdaq Volatility Guard pilot, another exchange-specific single-stock mechanism designed to curb volatility. However, Nasdaq decided to defer implementation of the pilot as the industry-wide LULD proposal moved toward the approval and commencement of Phase I of the LULD pilot.<sup>44</sup> The Nasdaq Volatility Guard pilot expired with the Commission’s approval of the LULD Plan.<sup>45</sup> The Nasdaq Volatility Guard would have applied to 100 Nasdaq-listed securities and would have been triggered if the execution price of a security were to move more than a certain percentage away from a pre-established “triggering price” for that security. The triggering price for each security would have been the price of any execution in that security within the previous 30 seconds. The triggering percentage would have thus varied according to the price of the security. If the Volatility Guard were to trigger for a security, Nasdaq would have suspended trading in that security for a period of 60 seconds but would have maintained all current quotes and orders during that time and would have continued to accept quotes and orders. Following this 60-second period, Nasdaq would have reopened the market using its Halt Cross mechanism.<sup>46</sup>

### 3. *Single-stock Circuit Breakers*

On May 6, 2010, the prices of a large number of individual securities suddenly declined by significant amounts in a very short time period, before suddenly reversing to prices consistent with their pre-decline levels. This severe price volatility led to a large number of trades being executed at depressed prices, including many that were more than 60% away from pre-decline levels.<sup>47</sup> The exchanges and FINRA subsequently broke trades executed at a price more than

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Gap Quote Policy by NYSE MKT LLC, Release No. 34-74064 (January 15, 2015), 80 FR 3273 (January 22, 2015) (File No. SR-NYSEMKT-2015-02).

<sup>44</sup> See Equity Regulatory Alert #2011 – 8, NASDAQ Volatility Guard Pilot Deferred (June 24, 2011), available at <http://www.nasdaqtrader.com/TraderNews.aspx?id=ERA2011-08>.

<sup>45</sup> For more on the history of the Nasdaq Volatility Guard pilot, see Notice of Filing and Immediate Effectiveness of Proposed Rule Change to Remove the Expired Pilot Under Rule 4753(c) from the NASDAQ Rule Book by The NASDAQ Stock Market LLC, Release No. 34-67678 (August 16, 2012), 77 FR 50738 (August 22, 2012) (File No. SR-NASDAQ-2012-094).

<sup>46</sup> For details of the Nasdaq Volatility Guard mechanism, see Notice of Filing of Amendment No. 3 to a Proposed Rule Change and Order Granting Accelerated Approval to the Proposed Rule Change, as Modified by Amendment Nos. 1 and 3, to Adopt Rule 4753(c) as a Six Month Pilot in 100 NASDAQ-Listed Securities by The NASDAQ Stock Market LLC, Release No. 34-64071 (March 11, 2011), 76 FR 14699 (March 17, 2011) (File No. SR-NASDAQ-2010-074); and Notice of Filing and Immediate Effectiveness of Proposed Rule Change to Extend the Pilot Period of Rule 4753(c) by The NASDAQ Stock Market LLC, Release No. 34-65176 (August 19, 2011), 76 FR 53518 (August 26, 2011) (File No. SR-NASDAQ-2011-117).

<sup>47</sup> See Flash Crash Report, *supra* note 10.

60% from the pre-decline price.<sup>48</sup> To avoid the reoccurrence of such a scenario, the exchanges and FINRA introduced SSCBs to the marketplace.<sup>49</sup> SSCBs were designed to provide market participants with additional time to incorporate all available information when assessing the fair value of the security. The trading pauses triggered by SSCBs were followed by procedures similar to the opening price auction, which helped accumulate liquidity on both sides of the market to set new equilibrium prices.

The SSCBs were implemented in three phases between June 10, 2010, and June 23, 2011. On June 10, 2010, the SEC approved the implementation of SSCB on a pilot basis for the S&P 500 stocks. The SSCB program was extended to stocks in the Russell 1000 as well as certain ETPs on September 10, 2010, and to the remainder of NMS stocks on June 23, 2011. SSCBs were in effect from 9:45am to 3:35pm and they did not operate outside of trading hours. If a stock moved up or down by 10% within a five-minute intraday period, the listing exchange for that symbol would pause trading in the stock for at least five minutes. After five minutes, the listing exchange could extend the pause if there were significant share imbalances prohibiting an orderly reopen. If the listing exchange was unable to reopen the stock in ten minutes, other exchanges and OTC were free to begin trading that symbol. The SSCBs were phased out for a particular tier when the LULD Plan was phased in for that tier.<sup>50</sup>

### C. Related Academic Research

Academics have studied changes in market quality metrics resulting from the introduction of circuit breakers, trading pauses, and price limits<sup>51</sup> — mechanisms designed to address unwarranted large fluctuations in prices that could lead to increased uncertainty in securities valuation.<sup>52</sup>

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<sup>48</sup> See *id.* at 7.

<sup>49</sup> See Approval Order, *supra* note 3, at 4-5.

<sup>50</sup> While SSCB may have dampened extraordinary volatility, there are several well-publicized accounts of erroneous trades triggering trading pauses during that regime. See, e.g., Tom Lauricella, Scott Patterson, and David Benoit, “Trading Firm IPO Fizzles in Seconds,” *The Wall Street Journal* (March 25, 2012), available at <http://online.wsj.com/article/SB10001424052702304636404577299560502440118.html>.

<sup>51</sup> The price limits referenced in the academic literature are similar in nature to the price bands introduced by the Plan.

<sup>52</sup> The References section below provides citations for the academic papers referenced in this section.

## 1. *Market-Wide Circuit Breakers*

Since market-wide circuit breaker events are rare, there has been little empirical research on this topic. Fama (1989) conjectures that traditional circuit breakers delay price discovery and interfere with trading by restricting supply when demand for trading is high. Santoni and Liu (1993) find that a market-wide circuit breaker does not reduce the conditional variance of stock returns. Harris (1997) states that, while circuit breakers will slow price changes related to fundamentals (i.e., they will decrease fundamental volatility), their effect on transitory volatility is uncertain. On one hand, circuit breakers may decrease transitory volatility by restraining the trading of uninformed traders and bluffers. On the other hand, circuit breakers may increase transitory volatility by restraining the trading of informed speculators, dealers, and arbitrageurs. Ackert, Church, and Jayaraman (2001) find that a circuit breaker rule has the unintended consequence of accelerating trade, while the price discovery process is not affected. In a follow-up paper, Ackert, et al. (2002) argue that circuit breakers do not play a useful role in asset markets. They point out that the triggering of a circuit breaker could exacerbate price movements because certain market participants might assume that other market participants are acting on better information, and those participants might then make irrational decisions on the basis of that assumption. Goldstein and Kavajecz (2004) study a single instance of an activation of a circuit breaker in 1997 and find that liquidity was present in the limit order book up to the trading pause but that this liquidity was removed after the initiation of the pause. They conclude that, as the probability of a market-wide circuit breaker increased, market participants accelerated their activity, which is consistent with the “magnet effect” suggested by Subrahmanyam (1994). Subrahmanyam (2013) argues that there is no evidence that circuit breakers reduce either the volatility after trade recommences or the panic-driven selling. He points out that there is some evidence in an experimental setting that circuit breakers lead to “magnet effects.” Goldstein (2015) finds that Rule 80A led to a small but statistically significant decline in intraday U.S. equity market volatility, with volatility being reduced to a larger degree during a rising market.

## 2. *Price Limits for Individual Securities*

Compared to the market-wide circuit breaker, the SSCB implements price limits for individual securities. This mechanism uses fixed parameters for halting individual stocks; the parameters are a function of the stock’s price movement within a certain amount of time.

The mechanism of a price limit has been previously implemented in some countries. For instance, price limits have been used on the Taiwan Stock Exchange, Tokyo Stock Exchange, Korea Stock Exchange, Kuala Lumpur Stock Exchange, Shanghai Stock Exchange and Shenzhen Stock Exchange, Athens Stock Exchange, and Spanish Electronic Market, among others. The price limits that have been implemented in other countries are constant throughout the day, with price limits representing a daily boundary that security prices must lie in. Price limits have been typically expressed as a percentage of the closing price on the previous trading day. While

the price limit concept is similar in nature to LULD, there are differences in how the LULD mechanism works. Under the LULD mechanism, the price bands are continuously updated throughout the day to allow for the incorporation of fundamental information in the market. Further, the price bands under LULD are based on quotes, and there is a Limit State introduced in the LULD set-up that precedes the actual halt.

Using data from both U.S. and international markets, the academic literature has not reached a consensus on the effectiveness of price limits. Some studies argue that price limits can moderate excessive volatility and mitigate panic behavior. For instance, using data from the U.S. futures market after the introduction of price limits, Ma, Rao, and Sears (1989a and 1989b) document that following a limit event, prices tend to stabilize or reverse and that volatility decreases substantially. Lee and Kim (1995) find that price limits reduce price volatility in the Korean stock market. Chowdhry and Nanda (1998) argue that price limits might enhance market stability by eliminating potentially destabilizing market prices. Finally, Kim and Park (2010) derive a model where price limits may deter stock market manipulators, and they present empirical evidence consistent with their model.

Meanwhile, other studies argue that price limits impede market efficiency and have no effect on reducing extraordinary volatility. Kim and Rhee (1997) document that daily price limits do not decrease volatility for the Tokyo Stock Exchange; rather, they delay price discovery and lead to increased activity the following day. Phylaktis, et al. (1999) also find that price limits delay price discovery and do not decrease volatility for the Athens Stock Exchange market, a thinly traded market. Kim et al. (2004) find that price limits lead to higher volatility in the Spanish Electronic Market. Using data from the Kuala Lumpur Stock Exchange, Chan, Kim, and Rhee (2005) find that price limits on individual securities do not improve price discovery; instead, price limits impose serious costs even when the limit band is as wide as 30%, such as a delay in the arrival of informed traders and an exacerbation in order imbalances. Using data from the Chinese stock market, Wang, Chong, and Chan (2014) find that price limits delay price discovery and significantly increase volatility during a downward price movement.<sup>53</sup> In a recent study of the U.S. markets over the period 2009-2012, Brogaard and Roshak (2016) find that the introduction of SSCBs enhances market stability by reducing extreme events; however, this comes at the cost of reduced price efficiency in the market. Finally, Draus and van Achter (2016) argue that both U.S. and China have experienced market runs due to badly calibrated (i.e., having arbitrarily set price triggers) circuit breakers. The authors argue that price-triggered mechanisms such as circuit breakers cannot distinguish the source of excessive selling volume, and therefore, they might in fact restrain legitimate liquidity demand in the market. The authors propose in their study a forward-looking circuit breaker, designed to capture the uncertainty of future liquidity needs and thus, be welfare optimal.

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<sup>53</sup> See Baker and Kiyamaz (2013) and the references therein.

### 3. *Trading Pauses*

Using data prior to the implementation of the LULD and the SSCB, some academic research has found that trading pauses may adversely affect market quality. For instance, Lee, et al. (1994) find that trading pauses increase volatility. Gerety, et al. (1992) provide evidence that, when individuals know that they will be unable to trade, they adjust positions, sometimes significantly, in response to expectations of substantial overnight market volatility. Using Tel-Aviv Stock Exchange data from the 1987 market crash, Lauterbach and Ben-Zion (1993) find that trading halts smooth the price adjustment by reducing next-day opening order imbalance, but they do not stop an overall decline in the market. In more recent work, Jiang, et al. (2009) find spillover effects of trading pauses, where a trading pause in one security is associated with an increase in volume, spreads, and price impact in informationally related securities. The latter findings are consistent with the trading pause model of Spiegel and Subrahmanyam (2000) and with the informed trading model of Tookes (2008).

On the other hand, trading pauses have also been shown to allow market participants additional time to assess new information and, therefore, help reduce volatility. For instance, Corwin and Lipson (2000) find that orders are canceled during single stock trading pauses and that the order book is “renewed” with revised limit orders submitted during the pause to reflect the current environment.<sup>54</sup> Further, they find that quoted spreads are wide immediately after the pause as market participants protect themselves from excess volatility.

In other work, Christie, et al. (2002) compare the effects on market quality of two alternative pause and reopening mechanisms within the Nasdaq exchange, using data from 1997 to 1998. Under the first alternative, trading reopens after a five-minute regulatory pause; under the second alternative, trading reopens the following morning, after a 90-minute regulatory halt. They find an inverse correlation between the duration of the regulatory pauses and post-halt market quality metrics (i.e., shorter pauses are followed by higher volatility and larger transaction costs, and longer pauses by lower volatility and lower transaction costs).

#### **D. Data and Sample Selection**

For our analyses, we use both SRO-provided data and publicly available data from the Center for Research in Security Prices (“CRSP”) and the Trade and Quote (TAQ) database. CRSP provides daily and monthly trading volume and trading price data, while TAQ provides intraday information on trading activity, such as canceled trades, trading prices, quotes, and clearly erroneous trades. The SRO data provides records of each individual Limit State, Trading Pause, Straddle State, and orders that arrived during each Limit State, according to Appendix B of the

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<sup>54</sup> Corwin and Lipson (2000) also document that stale orders submitted before pauses are mostly canceled.

Plan. On the basis of these data, we build statistics on Limit States, Trading Pauses, and Straddle States.<sup>55</sup>

Our analyses span different time periods. First, we cover the two time periods during which the LULD was fully implemented, namely Phase I (June 3 – August 2, 2013) and Phase II (May 12 – August 29, 2014).<sup>56</sup> During Phase I, LULD applied only from 9:45am to 3:30pm and only to Tier 1 securities. Phase II applied LULD to all securities (Tier 1 and Tier 2) and extended its application to the full day. For comparison purposes, we also employ data recorded during periods that represent different rule regimes (prior to the implementation of the LULD): Pre-SSCB (January 4 – May 6, 2010) and SSCB (December 3, 2012 – April 5, 2013).<sup>57</sup> For the Pre-SSCB period, we report results both with and without the Flash Crash day of May 6, 2010, as this is an outlier data point in some analyses. Panel B in Appendix A lists these different periods (collectively, the “sample periods”). In addition, we report in one table the characteristics for the complete set of securities using an extended LULD period, which starts when LULD rollout began (see Panel B in Appendix A for these periods).

Our analyses cover Tier 1 securities and Tier 2 securities.<sup>58</sup> We analyze the events associated with LULD, specifically the frequency of Limit States, Trading Pauses, and Straddle States, as well as the causes and duration of those events. Further, in the approval order for LULD the Commission discussed the potential for LULD to reduce, relative to SSCB, the frequency of Trading Pauses, which could potentially affect extraordinary volatility.<sup>59</sup> Therefore, we examine whether the number of Trading Pauses declines under LULD relative to SSCB. Finally, we analyze the incidence of canceled trades as a proxy to assess the occurrence of clearly erroneous trades before and after the implementation of LULD.

## E. Results

In this section we assess the frequency of Limit States, Straddle States, Trading Pauses, and clearly erroneous trades (as captured by canceled trades) that occurred before and after the

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<sup>55</sup> Appendix C discusses the data in greater detail.

<sup>56</sup> Note Phase II extended beyond the sample period used in this paper.

<sup>57</sup> To capture the immediate impact of LULD in terms of Limit States, Trading Pauses, and Straddle States, we also looked at statistics for these LULD events during two extended periods that began when Phase I and Phase II of the LULD started rolling out but were not fully implemented, as follows: Extended Phase I (April 8 – August 2, 2013) and Extended Phase II (August 5, 2013 – August 29, 2014). These extended periods include LULD Phase I and LULD Phase II, respectively. For brevity, these results are not tabulated.

<sup>58</sup> See LULD FAQs, *supra* note 17.

<sup>59</sup> See Approval Order, *supra* note 3, at 41.

implementation of the LULD mechanism. The Plan assigns wider price bands to Tier 2 securities than to Tier 1 securities. In addition, within each tier, the Plan assigns wider price bands to lower priced securities. To find whether the price bands result in a uniform potential for LULD events across the two groups of securities, we perform our analyses while stratifying them by tier group. Furthermore, under the LULD Plan, all the band sizes double during the first 15 minutes (9:30am - 9:45am) and the last 25 minutes (usually 3:35pm - 4:00pm) of trading.<sup>60</sup> The Participants designed the differences in the size of the price bands to appropriately reflect differences in trading characteristics and volatility among different types of securities and at different times of the trading day.<sup>61</sup> Therefore, we also stratify our analysis by time of day.

For each tier group, we start by reporting in Table 1 descriptive statistics, such as the price group, listing venue, average market capitalization, average trading volume, and average closing spread for the securities included in the Plan. We also include statistics on the Limit States, Straddle States, and Trading Pauses. We report results for Tier 1 securities in both phases because they were included in the LULD Plan during Phase I and continued to be included during Phase II. On the other hand, because LULD only applied to Tier 2 securities during Phase II, we only report Tier 2 results for that period. Note that we report in this table results recorded during an extended LULD period, which starts, in each case, when LULD rollout began (see Panel A of Appendix A for rollout dates). The rest of our analysis only covers the time periods when LULD rollout was completed.

The data includes 986 Tier 1 stocks and 458 Tier 1 ETPs in Phase I and an additional 6,163 stocks, 365 ETPs, and 183 leveraged ETPs in Phase II. Almost all of the Tier 1 stocks and over three-quarters of the Tier 1 ETPs have options traded on them. Less than one-half of the Tier 2 securities and half of Tier 2 ETPs have options traded on them. As expected, Tier 1 securities, which are components of the S&P 500 Index or the Russell 1000 Index, have larger market capitalization than Tier 2 securities. Specifically, Tier 1 stocks have an average market capitalization of almost \$21 billion, which is almost 10 times bigger than the average market capitalization of just over \$2 billion for Tier 2 stocks. Even among ETPs, Tier 1 securities have much higher average market capitalization than Tier 2 securities (almost \$4 billion versus \$78 million).

Tier 1 stocks also have an average monthly share volume of almost 66 million, compared to 11 million for Tier 2 stocks. The average quoted spread (recorded at the close of the trading day) at the end of the month for a Tier 1 stock is \$0.02 per share, while for Tier 2 stocks the average quoted spread is \$0.36 per share. Thus, using average volume and quoted spread as metrics for liquidity, relative to large Tier 1 stocks, the smaller capitalization Tier 2 stocks are less liquid.

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<sup>60</sup> See The Plan, *supra* note 3, at Section V(A)(1); see also Appendix A, which provides further details on the size of LULD price bands for different types of securities and at different times of the day.

<sup>61</sup> See Approval Order, *supra* note 3, at 24, 26, 43.

As shown in Panels C and D of Appendix A, the percentage limits for calculating the price bands change with two price breakpoints, \$0.75 and \$3.00. Table 1 shows that almost all Tier 1 securities have prices greater than \$3.00 and are thus subject to price bands of at least 5%. For Tier 2, the majority of securities are priced above \$3.00, some stocks have prices between \$0.75 and \$3.00 and some are below \$0.75, and one leveraged ETP is priced below \$3.00. The Tier 2 securities have price bands greater than 10%. However, LULD events such as Limit States, Straddle States, and Trading Pauses occur for a much lower proportion of Tier 1 securities. Specifically, we find that Limit States only occurred in approximately 6% (=57/986) of Tier 1 stocks over the sample time period (as specified above). In contrast, Limit States occurred in approximately 15% (=905/6,163) of Tier 2 stocks. We also find that Straddle States occurred in approximately 12% (=115/986) of Tier 1 stocks and 43% (=2,660/6,163) of Tier 2 stocks, while Trading Pauses occur in approximately 2% (=22/986) of Tier 1 stocks and 11% (=703/6,163) of Tier 2 stocks.

Thus, despite their wider price bands, a larger number of Tier 2 securities experience LULD events, a result that we attribute to their lower liquidity characteristic. The next sub-section discusses in further detail the frequency with which LULD events occur, their distribution across stocks and time (intraday), their motivation, and their exit method.

### 1. *The Frequency of Limit States, Straddle States, and Trading Pauses*

Table 2 provides statistics on Limit States, Straddle States, and Trading Pauses, by tier. As stated above, one of the key innovations of the LULD was the creation of the Limit State. As seen in Panel A, the bulk of the 960,000 LULD Limit States occurred in Phase II and in Tier 2 securities. For Tier 1 securities, 200 Limit States occurred in Phase I and 181 Limit States occurred in Phase II. For Tier 1 securities, a Limit State occurs in at least one stock on 18% (28%) of all trading days in LULD Phase I (Phase II). In contrast, a Limit State occurs in at least one Tier 2 security on every day of the LULD Phase II period. Overall, the daily average number of Limit States per Tier 1 security during Phase I (Phase II) equals 0.005 (0.002), and the average number of Limit States per Tier 2 security during Phase II is 2.001. Finally, most of the Limit States occurred in stocks and very few occurred in ETPs, both in overall counts and per security.<sup>62</sup>

If a Limit State does not end within 15 seconds, the stock enters a Trading Pause for five minutes. Panel B of Table 2 provides statistics on the total number of Trading Pauses during

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<sup>62</sup> To capture immediate changes in the LULD events after the implementation of the LULD Plan, we also look at extended time periods that begin with the initial phase of the implementation, when not all of the stocks in the tier are subject to LULD. Results are qualitatively similar using these extended time periods. For brevity, the tables and figures include only the selected time periods when all stocks in the tier were subject to LULD.

the LULD time periods (also broken down by tier) and the number and percentage of days with at least one pause. During the LULD Phase I (Phase II), a LULD Trading Pause occurs in at least one Tier 1 security on 11% (18%) of trading days, and during Phase II, a LULD Trading Pause occurs in at least one Tier 2 security every day (i.e., on 100% of trading days). Tier 1 securities average 0.0001 Trading Pauses per security per day during the all-day implementation period (i.e., Phase II). In contrast, Tier 2 securities average 0.004 Trading Pauses per security per day during Phase II, despite their wider bands.

Because bids or offers can be non-executable during a Straddle State (without entering a Limit State),<sup>63</sup> we also examine the frequency of Straddle States. Panel C of Table 2 reports statistics on Straddle States across different tiers. Straddle States are extremely common for Tier 2 stocks. While there are 455 (302) Straddle State events for Tier 1 stocks in Phase I (Phase II), there are over two million such events for Tier 2 stocks in Phase II. The average daily number of Straddle States per security equals 0.01 (0.004) for Tier 1 in Phase I (Phase II), which translates into one Straddle State occurring in a Tier 1 security every 250 trading days during Phase II; on average, Tier 2 stocks experience 4.27 Straddle States per day during Phase II.

Overall, the above findings show a larger average occurrence of LULD events for Tier 2 securities, which is consistent with LULD price bands that do not result in a uniform potential for LULD events across the two tiers of securities.<sup>64</sup> The Supplemental Joint Assessments shows evidence that the many LULD events for Tier 2 result from “Bad Reference Prices.”<sup>65</sup>

## 2. *The Timing of Limit States, Straddle States, and Trading Pauses*

During Phase II, the LULD price bands extended to the open (9:30am - 9:45am) and close (3:35pm – 4:00pm). During these time periods, which are characterized by higher volatility, the price band parameters had double the value used for the middle of the day price bands. Therefore, we next address the question of whether this feature of LULD affects the frequency of LULD-associated events over the course of the day, including Limit States, Straddle States,

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<sup>63</sup> See Approval Order, *supra* note 3, at 17-18 and 43.

<sup>64</sup> The large number of Limit States, Straddle States, and Trading Pauses in Tier 2 securities documented here is consistent with the findings in the Supplemental Joint Assessment.

<sup>65</sup> The issues with bad references prices at the open (for stocks that have not traded in the opening auction), documented in the Supplemental Joint Assessment, may play a significant role in the differences between the frequency of LULD events in Tier 1 and Tier 2 securities. We believe, however, that the opening reference price issue, which has been documented for thinly traded securities, cannot fully explain the differences, because some of these differences also occur later in the day (see Table 3). Notably, Amendment 10, which was approved after our sample period, modified the definition of the Opening Price in certain circumstances to address the reference price issue. See Amendment 10, *supra* note 19. Further analysis, using updated data, would be needed to determine if these differences persist since the implementation of Amendment 10.

and Trading Pauses. To answer that question, we turn our attention to the LULD-associated events stratified by time of day.

Table 3 Panel A reports the frequency of Limit States by time of day. In Phase I, LULD did not apply during the first 15 minutes and the last 25 minutes of the trading day. In Phase II, the first 15 minutes of the trading day account for 4.4% (9.2%) of the overall Limit States for Tier 1 (Tier 2) stocks, even though the first 15 minutes represent only 3.85% of the 390 minutes in a trading day. In addition, the five minute period starting at 9:45am (after the price bands contract) accounts for 1.7% (2.1%) of the number of Tier 1 (Tier 2) Limit States in a time period accounting for only 1.2% of the day's trading time. The occurrence of Limit States shortly after 9:45am during Phase II may be an operational function of the price bands contracting, which can induce Limit States by making quotes fall outside of the narrower price bands at that time.<sup>66</sup> Despite wider price bands at the close in Phase II, we record 22.7% of Limit States for Tier 1 occurring from 3:35pm – 4:00pm. In contrast, only 4.1% of Tier 2 Limit States occur during that time window.

Panel B of Table 3 provides a summary of the time of day of Trading Pauses. In Phase II, despite the wider price bands, the open accounted for 18.7% of the overall LULD Trading Pauses for Tier 1 securities and 24.3% for Tier 2 securities. Note that, when compared to the percentage of Limit States reported above, the opening period accounts for a much higher percentage of overall Trading Pauses for both Tier 1 securities (18.7% Trading Pauses versus 4.4% Limit States) and Tier 2 securities (24.3% Trading Pauses versus 9.2% Limit States). In Phase II of LULD, the five minute period starting at 9:45am accounts for 18.7% of Tier 1 and 36.4% of Tier 2 Trading Pauses within a time window lasting only 1.2% of the day's trading time. Further, the same five minute period accounts only for 1.7% of Limit States in Tier 1 and 2.1% of Limit States in Tier 2. Finally, despite the high percentage of Limit States in the last 25 minutes of regular trading hours, very few Trading Pauses occur during this time of day and only in Tier 2 securities.

Panel C of Table 3 reports results on the time of day when Straddle States occur. In Phase II, the market opening trading period accounted for 12.2% of the overall Straddle States for Tier 1 stocks and 9.5% for Tier 2 stocks. Again, this represents a large percentage given the length of the time period over which they are recorded (i.e., 3.85% of the trading day). Also, despite wider price bands at the close in Phase II, we record 20.2% of Straddle States for Tier 1 occurring from 3:35pm – 4:00pm, but only 4.2% for Tier 2.

Overall, these findings show large accumulation of LULD events during the first 15 minutes of the trading day during Phase II. Also, a large percentage of Limit States, Straddle States, and especially Trading Pauses occur during the following five minutes, from 9:45am to 9:50am.

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<sup>66</sup> During Phase I, the price bands were not in effect during the first 15 minutes. While Tier 1 securities experienced no Limit States during the 9:45am – 9:50am period of that phase, they instead experienced Straddle States, which precede the Limit States.

Finally, while Limit and Straddle States occur during the last 25 minutes of regular trading hours, there are very few Trading Pauses at that time.

### 3. *Reasons, Duration, and Exits of Limit States, Straddle States, and Trading Pauses*

In this subsection we present data on the duration of LULD events, the reasons they occur, and the way they end, as provided by the SROs. We note that the SROs provided the data on the reasons for LULD events, and how the events end, in the form of summary statistics, which are difficult to interpret. Specifically, the terminology used by the various exchanges in defining the “reasons” for a Limit State or Trading Pause is not uniform among the SROs. For example, the various SROs identify “liquidity gap” as a reason for a Limit State or Trading Pause under different circumstances.<sup>67</sup> Therefore, we present the statistics below for completeness but caution against drawing any definitive conclusions as to the specific reasons for either LULD events initiating or ending based on these SRO data.

Table 4 Panel A provides statistics on the reasons the Limit States occur, the duration of the Limit States, and the way the Limit States end, as reported by the SROs. The SROs identify “liquidity gaps” as the reason for almost all Limit States, though, as noted above, the SROs apply this term in different circumstances. Other reasons for Limit States identified by the SROs include canceled trades and narrowing of bands at 9:45am. The vast majority of Limit States reverse within 15 seconds, with most doing so within five seconds (> 90%), as documented in the top part of Panel A. In Phase II of the LULD, only 8.8% of the Limit States for Tier 1 stocks and 0.2% of those for Tier 2 stocks last for the maximum duration of 15 seconds, necessitating a Trading Pause. That number is even lower for Tier 1 in Phase I (3.5%). As the bottom part of Panel A shows, 30.4% of Tier 1 Limit States and over 99% of Tier 2 Limit States in Phase II end in a reversal, while in Phase I, 79% of Tier 1 Limit States do so. The rest of the Limit States end with “other conditions,” such as a Straddle State, per the SROs’ descriptions: 17.5% of Tier 1 in Phase I, 60.8% of Tier 1 in Phase II and 0.1% of Tier 2 in Phase II.<sup>68</sup> As for the cause of the Limit States, the SRO data shows that they were almost all due to SRO-defined liquidity gaps.

Panel B of Table 4 shows that, according to the exchanges, SRO-defined liquidity gaps were the most common reason for Trading Pauses in both the Tier 1 (81.3%) and Tier 2 (76.7%) securities

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<sup>67</sup> Specifically, the various SROs use this term as a “reason” for a Limit State in a variety of circumstances including: (1) when the Limit State ends without a Trading Pause; (2) when the Limit State is caused by a wide pre-market book, wide spreads, or large orders; and (3) when the Limit State was not attributable to narrowing price bands.

<sup>68</sup> The various SROs associate different scenarios with the category of “other conditions” including (1) when the Limit State ends in a Trading Pause; (2) when the Limit State is caused by narrowing price bands; and (3) when the Limit State resulted from quote dissemination issues at other exchanges.

in Phase II. In Phase I, “SRO-defined liquidity gap” was the only reason for a Trading Pause (i.e., 100%) cited by the exchanges. Canceled trades account for no Trading Pauses, according to exchanges. In addition, Primary Listing Exchanges have not used the manual pause feature to end a Straddle State. Finally, for 18.7% (23.3%) of the Phase II Trading Pauses for Tier 1 (Tier 2), the data does not indicate the specific reason for the pause (labeled as “others”).<sup>69</sup> The Plan couples a limit up-limit down mechanism with Trading Pauses to accommodate fundamental price moves (as opposed to momentary gaps in liquidity).<sup>70</sup> We note, however, that the large number of Trading Pauses caused by “SRO-defined liquidity gaps” raises questions about the degree to which the Trading Pauses are, in fact, accommodating fundamental price moves, which should not result from temporary liquidity gaps.

Unlike Limit States, which have a maximum duration of 15 seconds, Straddle States can, in theory, last “an indefinite period of time.”<sup>71</sup> As noted in the Approval Order, the Participants responded to concerns about Straddle States lasting an indefinite period of time by stating that Limit States would generally follow Straddle States immediately or that the Reference Price may be recalculated within five minutes due to transactions occurring in the previous five minutes, thus ending the Straddle State.<sup>72</sup> The Approval Order stated that the further addition of a manual override, as proposed by the Participants in the First Amendment to the Plan, may, at least partially, alleviate this concern.<sup>73</sup>

Panel C of Table 4 shows that over 95% of Tier 1 Straddle States and 98% of Tier 2 Straddle States have durations of less than five seconds in Phase II of the LULD. Over 99% of Tier 1 Straddle States have a similarly short duration in Phase I. During Phase II, less than 1% of either tier Straddle States last between five and 15 seconds. Further, 0.9% of Tier 1 Straddle States last between 15 seconds and five minutes in Phase I. Meanwhile, 3% of Tier 1 Straddle States and 0.9% of Tier 2 Straddle States last between 15 seconds and five minutes in Phase II. Also during Phase II, less than 1% of Straddle States (for either tier) lasts beyond 30 minutes. However, given the high number of total Tier 2 Straddle States reported in Panel C of Table 2, these percentages translate into more than 4,000 Tier2 Straddle States lasting between five

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<sup>69</sup> As with the use of this term in the context of identifying Limit State reasons, the SROs identify “other” as the reason for Trading Pauses in different circumstances, including: (1) when the Trading Pause is due to the narrowing of price bands; and (2) when the Trading Pause is attributable to quote dissemination issues at other exchanges.

<sup>70</sup> See Approval Order, *supra* note 3, at 6, 9.

<sup>71</sup> A Straddle State can end in any of four ways: (1) when both quotes are inside price bands, (2) when the stock enters a Limit State, (3) when trading closes, or (4) when the Primary Listing Exchange declares a Trading Pause. See the Plan, *supra* note 3, at Section VII(A)(2). See also Approval Order, *supra* note 3, at 18-19 (describing commenter’s concerns about the possibility that Straddle States could restrict trading on one side of the market for an “indefinite period of time”).

<sup>72</sup> See Approval Order, *supra* note 3, at 18, footnote 74 (citing Response Letter at 5).

<sup>73</sup> See Approval Order, *supra* note 3, at 45, footnote 181.

minutes and 30 minutes, and more than 4,000 Tier 2 Straddle States lasting more than 30 minutes.

The majority of Straddle States (61% for Tier 1 in Phase I, and 60% for Tier 1 and 54% for Tier 2 in Phase II) reverse to normal quotes. During Phase II of LULD, 37% of Tier 1 Straddle States and 46% of Tier 2 Straddle States end in a Limit State. During Phase I of LULD, 38% of Tier 1 Straddle States end in a Limit State. Further, the Straddle State database that the SROs provided indicates that the remaining of 1.5% of Tier 1 Straddle States recorded during Phase I, and 3.2% of Tier 1 Straddle States and 0.1% of Tier 2 Straddle States recorded during Phase II, end in a Trading Pause following an intermediate Limit State. The database suggests that Primary Listing Exchanges have not used the manual pause feature of LULD to end the Straddle States.

Overall, these results indicate that the majority of Limit and Straddle States end quickly. However, there is a large number of Tier 2 straddle states that last more than 30 minutes. While the data indicate that SRO-defined liquidity gaps cause most Limit States and that Trading Pauses trigger for reasons other than to accommodate fundamental price moves, as noted above, terminology usage among the SROs was not uniform.

#### 4. *Price Behavior After Trading Pauses*

As stated above, the SRO data suggest that Trading Pauses trigger for reasons other than to accommodate fundamental price moves. To learn more about what triggers Trading Pauses, we examine the securities' price evolution after the event. Specifically, we investigate whether, after a Trading Pause, the price reverts back toward the pre-pause level and stabilizes, or whether it continues to move in the direction it moved before the Trading Pause, as in a fundamental price move. In the former scenario, a liquidity gap would be the reason behind the security entering a Trading Pause, while in the latter one a fundamental price move would trigger the Trading Pause.

To this end, we compare the last sale price before the first Trading Pause of a day to the end-of-minute stock price after the last Trading Pause of the day.<sup>74</sup> After reopening, a price that continues to deviate at least 5% (Tier 1 securities) or at least 10% (Tier 2 securities) from the last sale price before the first Trading Pause may be indicative of the Trading Pause being triggered by the arrival of new fundamental information in the market, because the price does not revert to the previous level. Note that this price pattern could also result from liquidity gaps that persist for more than a minute past the last Trading Pause of the day, which could delay the price reversal. In contrast, observing that the stock price reverts to its level within the

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<sup>74</sup> Because some stocks had multiple, related Trading Pauses within a day, the prices used in our comparison were the last sale price before the first Trading Pause and the end-of-minute trade price after the final Trading Pause.

5% (respectively 10% for Tier 2) range could mean that the LULD Limit State, triggered by a temporary liquidity gap, was not able to avert a Trading Pause.

Table 5 documents our findings. We separate in our analysis the Trading Pauses recorded in low volume securities, which are highly illiquid. While there were no Trading Pauses recorded in Phase I following low volume periods, in Phase II, 13% of Tier 1 and 53% of Tier 2 Trading Pauses followed low volume periods. For Tier 1 stocks, 83% of Phase I Trading Pauses and 87% of Phase II Trading Pauses are followed by a price reversal to the pre-Limit State price level within 1 minute after trading resumes. For Tier 2 stocks, 46% of Phase II Trading Pauses are followed by a price reversal. Thus, the Limit States were not able to avert Trading Pauses due to momentary gaps in liquidity, despite the eventual price reversals. The remaining 17% of Tier 1 Trading Pauses recorded during Phase I and 1% of Tier 2 Trading Pauses recorded during Phase II reflect instances where there is a price continuation following the Trading Pause, which would be indicative of a fundamental price move.

## 5. *The Impact of LULD on the Number of Trading Pauses*

LULD is designed to accommodate fundamental price movements (as opposed to price movements resulting from erroneous trades or momentary gaps in liquidity), albeit in a manner that should slow the velocity of such movements relative to unrestricted trading. Specifically, it allows for the stock to enter a Trading Pause after spending 15 seconds in the Limit State and to reopen at a price unrelated to the price bands at the time the security entered the Limit State.<sup>75</sup> Thus, using quote-based triggers and allowing the market to quickly correct during a Limit State and resume normal trading, without resorting to a Trading Pause, the Plan should ultimately reduce the number of Trading Pauses compared to SSCB.<sup>76</sup> Therefore, our next step consists of comparing the number of Trading Pauses during the SSCB with those during the LULD.

For Tier 1 securities, Table 6 shows that the average daily number of Trading Pauses declines from 0.44 during SSCB to 0.16 during LULD Phase I and to 0.21 during LULD Phase II.<sup>77</sup> This is a decline from just under one Trading Pause every other day during SSCB to less than one Trading Pause every five days. For Tier 2 securities, the average daily number of Trading Pauses increases from 0.49 in the SSCB period to 29.19 during the LULD Phase II.

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<sup>75</sup> See Approval Order, *supra* note 3, at 42.

<sup>76</sup> See Approval Order, *supra* note 3, at 40-41.

<sup>77</sup> The analysis reported in Table 6 does not have any data from the BATS-Z exchange because there were no SSCB pauses at that trading venue. Additionally, most BATS tickers that experienced LULD halts were Tier 2 securities in Phase II; therefore, the inclusion of BATS LULD halts would further increase the distributional difference between the Phase II and SSCB samples, which is already at 1% statistical significance.

To gauge whether these changes are statistically significant, we next estimate a Poisson regression model.<sup>78</sup> The coefficient estimates in this model are all highly statistically significant, as seen in Table 6. These estimates indicate that both the drop in Trading Pauses in Tier 1 securities during LULD and the increase in Trading Pauses in Tier 2 securities during Phase II of LULD are statistically significant.

We consider two possible explanations for the increase in the number of Trading Pauses in the Tier 2 securities. First, the “Bad Reference Price” issue examined in the Supplemental Joint Assessment could result in unnecessary Trading Pauses in securities without robust opening auctions.<sup>79</sup> Second, because LULD has narrower price bands relative to those under the SSCB, especially for Tier 2 securities, the number of Trading Pauses for Tier 2 securities under the LULD can be larger.

## 6. *Clearly erroneous Trades*

Under the SSCB, some trading pauses were triggered by clearly erroneous trades.<sup>80</sup> In addition, clearly erroneous trades can create the perception of greater volatility. They can also be one of the reasons that dissuade participation during high volatility periods because counterparties can lose money if a trade is eventually canceled.<sup>81</sup> In the approval order for LULD, the Commission discussed the potential for LULD to reduce, relative to SSCB, the number of clearly

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<sup>78</sup> We use dummy variables to capture the two phases of LULD, and we consider the SSCB period as the basis for our Poisson regression model. We assume that the daily number of Trading (or scaled Trading) Pauses for day  $i$  has a Poisson probability distribution and that its mean,  $\mu$ , is related to the LULD Phase of the Plan according to:  $\log(\mu_i) = \beta_0 + X_i' \beta_i$ . Here,  $X$  is a vector that includes the dummy variables representing Phase I and Phase II of the LULD Plan.

<sup>79</sup> See *supra* note 65 and related text. Also, the Fifth Amendment to the LULD Plan addressed a similar concern that certain thinly traded ETPs with wide quotes had triggered LULD Trading Pauses despite the lack of trading in these securities. See Order Approving the Fifth Amendment to the National Market System Plan to Address Extraordinary Market Volatility by BATS Exchange, Inc., BATS Y-Exchange, Inc., Chicago Board Options Exchange, Incorporated, Chicago Stock Exchange, Inc., EDGA Exchange, Inc., EDGX Exchange, Inc., Financial Industry Regulatory Authority, Inc., NASDAQ OMX BX, Inc., NASDAQ OMX PHLX LLC, The Nasdaq Stock Market LLC, National Stock Exchange, Inc., New York Stock Exchange LLC, NYSE MKT LLC, and NYSE Arca, Inc., Release No. 34-70530 (September 26, 2013), 78 FR 60937( October 2, 2013) (File No. 4-631) at 8. Our results raise the possibility that the issue may apply to a broader set of illiquid securities.

<sup>80</sup> See Approval Order, *supra* note 3, at 40.

<sup>81</sup> For example, a trader that purchases at a low price may sell at a profit before the purchase is canceled as a clearly erroneous trade. The trader may then have to close the sale at an unprofitable price. For further discussion on this topic, see OICV- IOSCO Final Report on Policies on Error Trades, available at <https://www.iosco.org/library/pubdocs/pdf/IOSCOPD208.pdf>, at 8.

erroneous trades, which could potentially affect extraordinary volatility.<sup>82</sup> This is because, unlike SSCBs, the LULD mechanism prevents all trades in individual securities outside of a specified price band. However, a comparison between the clearly erroneous executions numerical guidelines and the LULD parameters shows that the LULD design permits clearly erroneous trades to occur due to, for instance, LULD parameters being in some cases larger than the clearly erroneous guidelines (i.e., for Tier 1 stocks trading above \$50 or for Tier 2 stocks trading above \$25),<sup>83</sup> or due to a slow reference price update under LULD.<sup>84</sup> Thus, our final exercise looks at clearly erroneous trades and their changes during the different periods under analysis.

We use canceled trades as a proxy for clearly erroneous trades.<sup>85</sup> Figure 1 displays the time series of the daily canceled trades across all stocks, presented as a percentage of total trades. While there are some increased values for this series during SSCB, we notice even larger values during Phase II of LULD.

We start by assessing and comparing the occurrence of canceled trades during the two phases of the LULD Plan, and we follow with the comparison to prior periods. Panel A of Table 7 reports the average daily canceled trades stratified by time of day during the LULD period. There is a very large average number of trades canceled at the open (9:30am to 9:45am) for all securities during LULD. We note that once the LULD extended to the open in Phase II, the average number of canceled trades per security, per day more than doubled: for Tier 1 securities it increased from 0.008 to 0.015 and for Tier 2 it increased from 0.002 to 0.007. The

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<sup>82</sup> See Approval Order, supra note 3, at 41.

<sup>83</sup> For numerical guidelines regarding the parameters used by exchanges for breaking trades, see Order Granting Approval of Proposed Rule Changes Relating to Clearly Erroneous Transactions by BATS Exchange, Inc.; NASDAQ OMX BX, Inc.; Chicago Board Options Exchange, Incorporated; Chicago Stock Exchange, Inc.; EDGA Exchange, Inc.; EDGX Exchange, Inc.; International Securities Exchange LLC; The NASDAQ Stock Market LLC; National Stock Exchange, Inc.; New York Stock Exchange LLC; NYSE Amex LLC; NYSE Arca, Inc., Release No. 34-62886 (September 10, 2010), 75 FR 56613 (September 16, 2010) (File Nos. SR-BATS-2010-016; SR-BX-2010-040; SR-CBOE-2010-056; SR-CHX-2010-13; SR-EDGA-2010-03; SR-EDGX-2010-03; SR-ISE-2010-62; SR-NASDAQ- 2010-076; SR-NSX-2010-07; SR-NYSE-2010-47; SR-NYSEAmex-2010-60; SR-NYSEArca- 2010-58) at 4.

<sup>84</sup> See Supplemental Joint Assessment, supra note 9, at 30-31, for additional examples of clearly erroneous trades under the LULD Plan.

<sup>85</sup> A canceled trade may be a clearly erroneous trade but could also be a trade canceled for reasons other than an erroneous price. The TAQ data does not indicate whether a canceled trade is a clearly erroneous trade, so our use of TAQ data may provide an overestimate of the number of clearly erroneous trades. On the other hand, TAQ data does not record all of the clearly erroneous trades, which may lead to an underestimate of the number of clearly erroneous trades. Further, we only consider the canceled trades recorded for securities that survived throughout the study, which also leads to an underestimate of the number of clearly erroneous trades. Also, we do not exclude in our analysis the off-exchange cancellations. We have no reason to anticipate that LULD affected the level of any over- or underestimate.

following five minutes (9:45am to 9:50am) and the close of the trading day (3:35pm to 4:00pm) also register a considerable average number of canceled trades for Tier 1 in Phase II.

Because the LULD Plan mechanism is designed to prevent trades from occurring outside of the specified price bands, we further examine whether there is a decline in the number of canceled trades under this regime compared to prior periods. We use as baseline: the SSCB; the Pre-SSCB with the Flash Crash; and the Pre-SSCB without the Flash Crash. The use of the latter period ensures that the results are not driven by the inclusion of the Flash Crash day, when the exchanges broke thousands of trades.

Panel B of Table 7 reports the average number and percentage canceled trades (out of total trades) during different time periods. For Tier 1, the LULD Phase I time period is associated with a lower average number and percentage of canceled trades per day compared to the prior periods: 0.0008% versus 0.0011% during SSCB and 0.0017% during Pre-SSCB excluding the Flash Crash. However, this percentage increases during Phase II to 0.0011% for this group of securities. For Tier 2, the corresponding percentages are 0.0015% (during LULD Phase II), which is larger than the value of 0.0011% recorded during Phase I (when Tier 2 securities were still under the SSCB regime), but smaller than the values recorded earlier: 0.0018% (during SSCB) and 0.0029% (during Pre-SSCB excluding the Flash Crash).

Panel C of Table 7 reports the distributional differences. Compared to the SSCB and the Pre-SSCB excluding the Flash Crash periods, both tier groups experience a significant decline in the number of canceled trades during Phase I, regardless of whether the LULD mechanism was in place or not. On average, there were 164.35 and 38.69 less canceled trades compared to the SSCB and Pre-SSCB periods, respectively, for Tier 1, and 128.06 and 43.04 less canceled trades for Tier 2 compared to the SSCB and Pre-SSCB periods, respectively. However, we document a significantly larger number of canceled trades during Phase II (when the LULD mechanism applied to all securities) compared to the SSCB period: on average, there were 7.33 more canceled trades in Tier 1 and 9.91 more canceled trades in Tier 2.<sup>86</sup> Therefore, the data suggest that there was no reduction in clearly erroneous trades (as captured by canceled trades) during the LULD Plan period.

## F. Conclusion

This paper examines the incidence of events associated with the implementation of the LULD Plan in the securities market, such as Limit States, Trading Pauses, and Straddle States. Our analysis also examines the frequency of canceled trades during the LULD period.

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<sup>86</sup> Our conclusions regarding the changes in clearly erroneous trades differ from those reported in the Supplemental Joint Assessment. This is because our analysis looks at all the canceled trades, while the latter study groups the multiple daily canceled trades in one security in one canceled trade per day, called a Multiple Cancellation Event, and it reports results for such events.

We find that the LULD events occur much more often in the less liquid, Tier 2 securities. This suggests that, although the LULD price bands are tier specific and larger for the less liquid securities, they do not result in a uniform potential for LULD events across the two tiers of securities. Specifically, Limit States, Trading Pauses, and Straddle States each occur in Tier 2 stocks on every day examined. In fact, we observe over two million Straddle States in Tier 2 stocks in less than four months. Over the same sample period, Tier 1 securities only experienced Limit States on 28% of days, Trading Pauses on 18% of days, and Straddle States on 42% of days.

LULD events also do not occur uniformly across the trading day. The findings show that a disproportionate percentage of LULD events occur during the first 15 minutes of the trading day, despite wider price bands, and the five minutes that follow the first 15 minutes, just after the price bands narrow. A high percentage of Limit and Straddle States in Tier 1 securities occur during the last 25 minutes of regular trading hours, but we observe no Trading Pauses in these securities at that time.<sup>87</sup> We also find that the vast majority of Straddle States reverse within five minutes. Yet, in a period of less than four months, more than 4,000 Tier 2 Straddle States lasted longer than five minutes and more than 4,000 Tier 2 Straddle States lasted longer than 30 minutes.

We find a significant decline in the number of Trading Pauses in Tier 1 securities under LULD versus SSCB. In contrast, we find significantly more Trading Pauses for Tier 2 securities during the second phase of the Plan compared to the SSCB period. Further analysis reveals that, in the majority of cases, prices revert back to within the price bands in place prior to a Trading Pause, suggesting that Trading Pauses do not occur only to accommodate fundamental price moves.

According to the data definitions supplied by the Primary Listing Exchanges, most of the Limit State events result from temporary SRO-defined liquidity gaps and are reversed within 15 seconds, without resulting in a Trading Pause. Still, a small fraction of Limit States results in a Trading Pause, and most of these Trading Pauses result from “SRO-defined liquidity gaps.” We note that the data definitions on the reasons for Limit State and Trading Pause events are not consistent across the different trading venues.

Finally, for both groups of securities, regardless of whether the LULD mechanism was in place or not, we observe a significant reduction in both the number and occurrence of clearly erroneous trades (as a percent of all trades) during Phase I of LULD when compared to the prior periods. We also document a significantly larger number of clearly erroneous trades for both tiers during the second phase of LULD, when LULD applied to all securities, compared to the

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<sup>87</sup> The large number of LULD events in Tier 2 securities, particularly at the beginning of the day, is consistent with the findings in the Supplemental Joint Assessment.

SSCB period. Overall, the data suggest that there was no reduction in clearly erroneous trades (as captured by canceled trades) during the LULD Plan period.

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**Table 1: Characteristics for the Complete Set of Securities**

This table reports characteristics of our complete sample of securities: the total number of NMS securities affected by LULD Limit States, Straddle States, or Trading Pauses from April 2013 through August 2014; the distribution of security characteristics such as optionability, price, and listing venue; and average volume and spread. Tier 1 securities are all securities included in the S&P 500 and the Russell 1000, plus some ETPs.<sup>88</sup> (Tier 2 securities are all NMS stocks that are not in Tier 1.)

We require that the analyzed stocks have valid closing price and volume information in the Center for Research in Security Prices (“CRSP”) within the analysis period. This excludes 0.59% of stocks listed during the analysis period. Each stock’s price is the last available price in CRSP monthly stock files on or before August 29, 2014, depending on when the stock last traded. *Average Market Capitalization* is the average product of the latest closing price and the latest number of shares outstanding in the entire analysis period for each stock. *Average Trading Volume* for each stock is the average of the monthly trading volume (number of shares traded). *Average Closing Spread* is the equal weighted average of the average monthly bid-offer spreads across stocks.

*Data source:* LULD events database provided by the Primary Listing Exchanges, namely, Nasdaq, BATS and NYSE (NYSE, MKT, Arca), under Appendix B of the Plan, CRSP, and OCC data downloaded from <http://www.theocc.com/webapps/daily-delo-download>.

|   | Stocks | Tier 1<br>ETP | Leveraged<br>ETP | Stocks | Tier 2<br>ETP | Leveraged<br>ETP |
|---|--------|---------------|------------------|--------|---------------|------------------|
| <b>Total Securities</b>                 | 986    | 458           | 0                | 6,163  | 365           | 183              |
| <b>Optionable Securities</b>            | 980    | 363           | 0                | 2,839  | 33            | 90               |
| <b>Price</b>                            |        |               |                  |        |               |                  |
| > \$3                                   | 984    | 458           | 0                | 5,547  | 365           | 182              |
| \$0.75 - \$3                            | 1      | 0             | 0                | 514    | 0             | 1                |
| < \$0.75                                | 1      | 0             | 0                | 102    | 0             | 0                |
| <b>Securities with Events</b>           |        |               |                  |        |               |                  |
| Limit States                            | 57     | 12            | 0                | 905    | 107           | 18               |
| Straddle States                         | 115    | 24            | 0                | 2,660  | 180           | 60               |
| Trading Pauses                          | 22     | 8             | 0                | 703    | 104           | 18               |
| <b>Listing Venue</b>                    |        |               |                  |        |               |                  |
| Nasdaq                                  | 242    | 27            | 0                | 2,720  | 72            | 4                |
| NYSE                                    | 742    | 0             | 0                | 2,360  | 0             | 0                |
| NYSE MKT                                | 2      | 0             | 0                | 450    | 0             | 0                |
| NYSE Arca                               | 0      | 429           | 0                | 618    | 285           | 179              |
| BATS                                    | 0      | 2             | 0                | 15     | 8             | 0                |
| <b>Avg Market Cap (\$ Millions)</b>     | 20,826 | 3,808         | 0                | 2,135  | 78            | 158              |
| <b>Avg Trading Volume (1000 Shares)</b> | 65,815 | 39,077        | 0                | 11,360 | 431           | 14,852           |
| <b>Avg Closing Spread (c)</b>           | 2.47   | 4.95          | 0.00             | 35.57  | 32.10         | 156.09           |

<sup>88</sup> See The Plan, *supra* note 3, at Appendix A.

## Table 2: LULD Events by Tier

This table summarizes the counts of LULD events using LULD data that the SROs provided. LULD events are identified by the Primary Listing Exchanges, namely, Nasdaq, BATS, and the NYSE (NYSE, MKT, Arca). The time periods examined include LULD Phase I (June 3 – August 2, 2013) and LULD Phase II (May 12 – August 29, 2014).

Tier 1 securities are all securities included in the S&P 500 and the Russell 1000, plus some ETPs.<sup>89</sup> Tier 2 securities are all NMS stocks that are not in Tier 1. We separately analyze Tier 1 securities during Phase II of the LULD. Apart from the total number of events and the number and percentage of days when events occur, the table shows the daily average number of events separately for stocks, ETPs, and leveraged ETPs.

*Data source:* LULD events database provided by the Primary Listing Exchanges, namely, Nasdaq, BATS, and NYSE (NYSE, MKT, Arca), under Appendix B of the Plan.

**Panel A: Limit States by Tier**

|   | Tier 1  |          | Tier 2   |
|---|---------|----------|----------|
|   | Phase I | Phase II | Phase II |
| <b>Total number of Limit States</b>                         | 200     | 181      | 962,919  |
| <b>Total number of Trading Days in the Period</b>           | 44      | 78       | 78       |
| <b>Number of days with at least one Limit State</b>         | 8       | 22       | 78       |
| <b>Percentage of Trading Days when a Limit State occurs</b> | 18%     | 28%      | 100%     |
| <b>Avg per Security per Day for Stocks</b>                  | 0.00461 | 0.00225  | 2.00122  |
| <b>Avg per Security per Day for ETPs</b>                    | 0.00000 | 0.00022  | 0.00625  |
| <b>Avg per Security per Day for Leveraged ETPs</b>          | 0.00000 | 0.00000  | 0.05086  |

<sup>89</sup> See The Plan, *supra* note 3, at Appendix A.

**Panel B: Trading Pauses by Tier**

|   | Tier 1  |          | Tier 2   |
|---|---------|----------|----------|
|   | Phase I | Phase II | Phase II |
| <b>Total Number of Trading Pauses</b>                 | 7       | 16       | 2,279    |
| <b>Total Number of Trading Days in the Period</b>     | 44      | 78       | 78       |
| <b>Number of Days with at least one Pause</b>         | 5       | 14       | 78       |
| <b>Percentage of Trading Days when a Pause occurs</b> | 11%     | 18%      | 100%     |
| <b>Avg per Security per Day for Stocks</b>            | 0.00016 | 0.00010  | 0.00432  |
| <b>Avg per Security per Day for ETPs</b>              | 0.00000 | 0.00022  | 0.00365  |
| <b>Avg per Security per Day for Leveraged ETPs</b>    | 0.00000 | 0.00000  | 0.00687  |

**Panel C: Straddle States by Tier**

|  | Tier 1  |          | Tier 2    |
|--|---------|----------|-----------|
|  | Phase I | Phase II | Phase II  |
| <b>Total Number of Straddle Events</b>                         | 455     | 302      | 2,073,497 |
| <b>Total Number of Trading Days in the Period</b>              | 44      | 78       | 78        |
| <b>Number of days with at least one Straddle Event</b>         | 9       | 33       | 78        |
| <b>Percentage of Trading Days when a Straddle Event occurs</b> | 20%     | 42%      | 100%      |
| <b>Avg per Security per Day for Stocks</b>                     | 0.01049 | 0.00421  | 4.26794   |
| <b>Avg per Security per Day for ETPs</b>                       | 0.00000 | 0.00041  | 0.07090   |
| <b>Avg per Security per Day for Leveraged ETPs</b>             | 0.00000 | 0.00000  | 1.47863   |

### Table 3: LULD Events by Time of Day

This table reports the average number of events that occur during the open (9:30am to 9:45am); in the five-minute period following the contraction of price bands (9:45am to 9:50am); during the trading day (9:50am to 3:35pm); and during the final period leading to the market close (3:35pm to 4:00pm). The time periods examined include LULD Phase I (June 3 – August 2, 2013) and LULD Phase II (May 12 – August 29, 2014).

Tier 1 securities are securities included in the S&P 500 and the Russell 1000, plus some ETPs.<sup>90</sup> Tier 2 securities are all NMS stocks that are not in Tier 1.

*Data source:* LULD events database provided by the Primary Listing Exchanges, namely, Nasdaq, BATS, and NYSE (NYSE, MKT, Arca), under Appendix B of the Plan.

#### Panel A: Limit States by Time of Day

|   | Tier 1  |          | Tier 2   |
|---|---------|----------|----------|
|   | Phase I | Phase II | Phase II |
| <b>Avg per Security per Day by Time</b> |         |          |          |
| 9:30 – 9:45                             | 0.00000 | 0.00007  | 0.16907  |
| 9:45 – 9:50                             | 0.00000 | 0.00003  | 0.03946  |
| 9:50 – 3:35                             | 0.00315 | 0.00115  | 1.55493  |
| 3:35 – 4:00                             | 0.00000 | 0.00036  | 0.07607  |
| <b>Percentage by Time</b>               |         |          |          |
| 9:30 – 9:45                             | 0.0%    | 4.4%     | 9.2%     |
| 9:45 – 9:50                             | 0.0%    | 1.7%     | 2.1%     |
| 9:50 – 3:35                             | 100.0%  | 71.3%    | 84.5%    |
| 3:35 – 4:00                             | 0.0%    | 22.7%    | 4.1%     |

<sup>90</sup> See The Plan, *supra* note 3, at Appendix A.

Panel B: Trading Pauses by Time of Day

|   | Tier 1  |          | Tier 2   |
|---|---------|----------|----------|
|   | Phase I | Phase II | Phase II |
| <b>Avg per Security per Day by Time</b> |         |          |          |
| 9:30 – 9:45                             | 0.00000 | 0.00003  | 0.00106  |
| 9:45 – 9:50                             | 0.00000 | 0.00003  | 0.00159  |
| 9:50 – 3:35                             | 0.00011 | 0.00009  | 0.00170  |
| 3:35 – 4:00                             | 0.00000 | 0.00000  | 0.00001  |
| <b>Percentage by Time</b>               |         |          |          |
| 9:30 – 9:45                             | 0.0%    | 18.7%    | 24.3%    |
| 9:45 – 9:50                             | 0.0%    | 18.7%    | 36.4%    |
| 9:50 – 3:35                             | 100.0%  | 62.5%    | 39.0%    |
| 3:35 – 4:00                             | 0.0%    | 0.0%     | 0.3%     |

Panel C: Straddle Events by Time of Day

|   | Tier 1  |          | Tier 2   |
|---|---------|----------|----------|
|   | Phase I | Phase II | Phase II |
| <b>Avg per Security per Day by Time</b> |         |          |          |
| 9:30 – 9:45                             | 0.00000 | 0.00037  | 0.37814  |
| 9:45 – 9:50                             | 0.00003 | 0.00003  | 0.08980  |
| 9:50 – 3:35                             | 0.00713 | 0.00201  | 3.33074  |
| 3:35 – 4:00                             | 0.00000 | 0.00061  | 0.16494  |
| <b>Percentage by Time</b>               |         |          |          |
| 9:30 – 9:45                             | 0.0%    | 12.2%    | 9.5%     |
| 9:45 – 9:50                             | 0.5%    | 0.9%     | 2.3%     |
| 9:50 – 3:35                             | 99.5%   | 66.7%    | 84.0%    |
| 3:35 – 4:00                             | 0.0%    | 20.2%    | 4.2%     |

## Table 4: LULD Events Reasons, Duration and Exits

This table divides the LULD events into various categories on the basis of reason, duration, and how the stock exits the event, as described in the SRO data. The time periods examined include LULD Phase I (June 3 – August 2, 2013) and LULD Phase II (May 12 – August 29, 2014).

Tier 1 securities are securities included in the S&P 500 and the Russell 1000, plus some ETPs.<sup>91</sup> Tier 2 securities are all NMS stocks that are not in Tier 1.

*Data source:* LULD events database provided by the Primary Listing Exchanges, namely, Nasdaq, BATS, and NYSE (NYSE, MKT, Arca), under Appendix B of the Plan.

### Panel A: Limit States

|  | Tier 1  |          | Tier 2   |
|--|---------|----------|----------|
|  | Phase I | Phase II | Phase II |
| <b>Percentage by Duration (Seconds)</b>    |         |          |          |
| 0 to < 5                                   | 95.5%   | 90.1%    | 99.4%    |
| 5 to < 10                                  | 1.0%    | 0.0%     | 0.4%     |
| 10 to < 15                                 | 0.0%    | 1.1%     | 0.0%     |
| 15   | 3.5%    | 8.8%     | 0.2%     |
| <b>Percentage by Reason</b>                |         |          |          |
| SRO-Defined Liquidity Gap                  | 100.0%  | 98.3%    | 99.9%    |
| Canceled Trades                            | 0.0%    | 0.0%     | 0.0%     |
| Other                                      | 0.0%    | 1.7%     | 0.1%     |
| <b>% Limits ends in Trading Pause</b>      | 3.5%    | 8.8%     | 0.2%     |
| <b>% Limits ends in Reversal</b>           | 79.0%   | 30.4%    | 99.6%    |
| <b>% Limits ends with Other Conditions</b> | 17.5%   | 60.8%    | 0.1%     |

<sup>91</sup> See The Plan, *supra* note 3, at Appendix A.

**Panel B: Trading Pauses**

|                                  | Tier 1  |          | Tier 2   |
|----------------------------------|---------|----------|----------|
|                                  | Phase I | Phase II | Phase II |
| <b>Percentage by Reason</b>      |         |          |          |
| <b>SRO-Defined Liquidity Gap</b> | 100.0%  | 81.3%    | 76.7%    |
| <b>Canceled Trades</b>           | 0.0%    | 0.0%     | 0.0%     |
| <b>Manual Pause</b>              | 0.0%    | 0.0%     | 0.0%     |
| <b>Other</b>                     | 0.0%    | 18.7%    | 23.3%    |

**Panel C: Straddle States**

|   | Tier 1  |          | Tier 2   |
|---|---------|----------|----------|
|   | Phase I | Phase II | Phase II |
| <b>Percentage by Duration (Seconds)</b> |         |          |          |
| <b>0 to &lt; 5</b>                      | 99.1%   | 95.6%    | 98.2%    |
| <b>5 to &lt; 10</b>                     | 0.0%    | 0.0%     | 0.4%     |
| <b>10 to &lt; 15</b>                    | 0.0%    | 0.6%     | 0.1%     |
| <b>15 secs to &lt; 5 mins</b>           | 0.9%    | 3.0%     | 0.9%     |
| <b>5 to &lt; 30 mins</b>                | 0.0%    | 0.6%     | 0.2%     |
| <b>&gt; 30 mins</b>                     | 0.0%    | 0.3%     | 0.2%     |
| <b>Percentage by Exit</b>               |         |          |          |
| <b>Trading Pause (after Limit)</b>      | 1.5%    | 3.2%     | 0.1%     |
| <b>Limit State</b>                      | 37.6%   | 36.9%    | 46.3%    |
| <b>Reversal</b>                         | 60.9%   | 59.9%    | 53.6%    |
| <b>Manual Pause</b>                     | 0.0%    | 0.0%     | 0.0%     |

## Table 5: Analysis of LULD Trading Pauses Based on Future Price Behavior

This table analyzes price behavior after the Trading Pause. The first row reports Trading Pauses in low volume securities. (A security is classified as having “low volume” if it has a total dollar volume in the one minute preceding the Trading Pause below \$1,000.) Trading Pauses for the remaining securities are divided into two groups by comparing the price patterns before and after the LULD Trading Pauses. Price reversals are cases where quotes temporarily deviate beyond the percentage parameters set by the LULD but eventually reverse to the price range within LULD price bands immediately after the trading resumes following the Trading Pause. Price continuations are cases where Trading Pauses are followed by prices continuing to levels beyond the percentage parameters set by the LULD from the pre-pause Reference Prices. The time periods examined include LULD Phase I (June 3 – August 2, 2013) and LULD Phase II (May 12 – August 29, 2014). The values are the total daily count of securities with Trading Pauses. We grouped multiple Trading Pauses for the same security into one trading pause because such Trading Pauses were clustered very closely together.

Tier 1 securities are securities included in the S&P 500 and the Russell 1000, plus some ETPs.<sup>92</sup> Tier 2 securities are all NMS stocks that are not in Tier 1.

*Data source:* Daily Trade and Quote files (Daily TAQ) and Trading Pause database provided by the Primary Listing Exchanges, namely, Nasdaq, BATS, and NYSE (NYSE, MKT, Arca), under Appendix B of the Plan.

|                               | Tier 1  |          | Tier 2   |
|-------------------------------|---------|----------|----------|
|                               | Phase I | Phase II | Phase II |
| <b>Low volume</b>             | 0%      | 13%      | 53%      |
| <b>Price Change Reverts</b>   | 83%     | 87%      | 46%      |
| <b>Price Change Continues</b> | 17%     | 0%       | 1%       |

<sup>92</sup> See The Plan, *supra* note 3, at Appendix A.

**Table 6: LULD Impact on Trading Pauses**

This table reports the daily average number of Trading Pauses for Tier 1 and Tier 2 securities. It also reports the estimates from a Poisson regression for the change in number of Trading Pauses between the SSCB period and LULD Phase I and between the SSCB period and LULD Phase II (see text for details). We use the SSCB period as the basis in our Poisson regression model. The time periods examined include SSCB (December 3, 2012 – April 5, 2013), LULD Phase I (June 3 – August 2, 2013), and LULD Phase II (May 12 – August 29, 2014). During the SSCB period, Trading Pauses triggered by the SSCB are from Nasdaq and the NYSE; there were no BATS SSCB halts.

Tier 1 securities are securities included in the S&P 500 and the Russell 1000, plus some ETPs.<sup>93</sup> Tier 2 securities are all NMS stocks that are not in Tier 1.

*Data source:* Trading Pause database provided by the Primary Listing Exchanges Nasdaq and NYSE (NYSE, MKT, Arca), under Appendix B of the Plan and a database compiled from public information on the incidence of SSCB halts. Because there were no BATS SSCB halts, BATS LULD Trading Pauses were excluded from the analysis in order to use the same samples. Additionally, most BATS tickers that experienced LULD halts were Tier 2 securities in Phase II; therefore, the inclusion of BATS LULD halts would have further increased the change in the number of Trading Pauses between the Phase II and SSCB samples, which is already at a 1% statistical significance level.

\*\*\*, \*\*, \* indicate statistical significance at the 1, 5 and 10% levels in a Poisson regression for the change in number of Trading Pauses between the SSCB period and LULD Phase I and between the SSCB period and LULD Phase II.

| Tier 1                         |         |          | Tier 2                                    |                       |                                |          |   |
|--------------------------------|---------|----------|---|-----------------------|--------------------------------|----------|---|
| Daily Avg No of Trading Pauses |         |          | Estimates from a Poisson Regression Model |                       | Daily Avg No of Trading Pauses |          | Estimates from a Poisson Regression Model |
| SSCB                           | Phase I | Phase II | Phase I<br>(vs SSCB)                      | Phase II<br>(vs SSCB) | SSCB                           | Phase II | Phase II<br>(vs SSCB)                     |
| 0.44                           | 0.16    | 0.21     | -1.01**                                   | -0.75**               | 0.49                           | 29.19    | 4.08***                                   |

<sup>93</sup> See The Plan, *supra* note 3, at Appendix A.

## Table 7: Canceled Trades

This table reports in Panel A the average number and the percentage of canceled trades that occur during the open (9:30am to 9:45am); in the five-minute period following the contraction of price bands (9:45am to 9:50am); during the trading day (9:50am to 3:35pm); and during the final period leading to the market close (3:35pm to 4:00pm). Panel B reports, for each period, the average of the daily time series of total canceled trades and the average of the daily percentage canceled trades (out of total trades). Panel C reports the statistical significance of the distributional difference test and the corresponding difference in means between the two phases of LULD and prior periods. The time periods cover: Pre-SSCB with the Flash Crash (January 4, 2010 – May 6, 2010); Pre-SSCB without the Flash Crash (January 4, 2010 – May 5, 2010); SSCB (December 3, 2012 – April 5, 2013); LULD Phase I (June 3 – August 2, 2013); and LULD Phase II (May 12 – August 29, 2014).

Tier 1 securities are securities included in the S&P 500 and the Russell 1000, plus some ETPs.<sup>94</sup> Tier 2 securities are all NMS stocks that are not in Tier 1.

*Data source:* Daily Trade and Quote files (Daily TAQ).

\*\*\*, \*\*, \* indicate statistical significance at the 1, 5 and 10% levels in a Wilcoxon two-sample nonparametric test.

### Panel A: Average and Percentage Canceled Trades by Time of Day

|   | Tier 1  |          | Tier 2  |          |
|---|---------|----------|---------|----------|
|   | Phase I | Phase II | Phase I | Phase II |
| <b>Avg per Security per Day by Time</b> |         |          |         |          |
| <b>9:30 – 9:45</b>                      | 0.00762 | 0.01507  | 0.00215 | 0.00744  |
| <b>9:45 – 9:50</b>                      | 0.00143 | 0.00169  | 0.00022 | 0.00029  |
| <b>9:50 – 3:35</b>                      | 0.06354 | 0.07241  | 0.00683 | 0.00936  |
| <b>3:35 – 4:00</b>                      | 0.00608 | 0.02137  | 0.00083 | 0.00083  |
| <b>Percentage by Time</b>               |         |          |         |          |
| <b>9:30 – 9:45</b>                      | 9.7%    | 13.6%    | 21.4%   | 41.5%    |
| <b>9:45 – 9:50</b>                      | 1.8%    | 1.5%     | 2.2%    | 1.6%     |
| <b>9:50 – 3:35</b>                      | 80.8%   | 65.5%    | 68.0%   | 52.2%    |
| <b>3:35 – 4:00</b>                      | 7.7%    | 19.3%    | 8.3%    | 4.6%     |

<sup>94</sup> See The Plan, *supra* note 3, at Appendix A.

**Panel B: Average and Percentage Canceled Trades by Time Period**

|  | <b>PreSSCB with Flash<br/>Crash</b> | <b>PreSSCB without<br/>Flash Crash</b> | <b>SSCB</b> | <b>Phase I</b> | <b>Phase II</b> |
|--|-------------------------------------|--|-------------|----------------|-----------------|
| <b>Tier 1</b>  |                                     |  |             |                |                 |
| <b>Average Canceled Trades</b>   | 395.34                              | 277.94                                 | 152.28      | 113.59         | 159.62          |
| <b>Average Canceled Trades<br/>as a Percentage of Total<br/>Trades (%)</b> | 0.00202%                            | 0.00174%                               | 0.00108%    | 0.00078%       | 0.00111%        |
| <b>Tier 2</b>  |                                     |  |             |                |                 |
| <b>Average Canceled Trades</b>   | 274.66                              | 195.42                                 | 110.40      | 67.36          | 120.31          |
| <b>Average Canceled Trades<br/>as a Percentage of Total<br/>Trades (%)</b> | 0.00330%                            | 0.00287%                               | 0.00177%    | 0.00105%       | 0.00154%        |

Panel C: Distributional Differences

|  | Distributional Difference<br>between Phase I and  |                                |              |
|--|---|--------------------------------|--------------|
|  | PreSSCB with Flash<br>Crash                       | PreSSCB without Flash<br>Crash | SSCB         |
| <b>Tier1</b>   |   |                                |              |
| Average Canceled<br>Trades   | -281.75***  | -164.35***                     | -38.69***    |
| Average Canceled<br>Trades as a<br>Percentage of Total<br>Trades (%) | -0.00124%***                                      | -0.00096%***                   | -0.00030%*** |
| <b>Tier2</b>   |   |                                |              |
| Average Canceled<br>Trades   | -207.3***   | -128.06***                     | -43.04*      |
| Average Canceled<br>Trades as a<br>Percentage of Total<br>Trades (%) | -0.00225%***                                      | -0.00181%***                   | -0.00072%**  |
|  | Distributional Difference<br>between Phase II and |                                |              |
|  | PreSSCB with Flash<br>Crash                       | PreSSCB without Flash<br>Crash | SSCB         |
| <b>Tier 1</b>  |   |                                |              |
| Average Canceled<br>Trades   | -235.72***  | -118.33***                     | 7.33***      |
| Average Canceled<br>Trades as a<br>Percentage of Total<br>Trades (%) | -0.00091%***                                      | -0.00063%***                   | 0.00003%***  |
| <b>Tier 2</b>  |   |                                |              |
| Average Canceled<br>Trades   | -154.36***  | -75.12***                      | 9.91*        |
| Average Canceled<br>Trades as a<br>Percentage of Total<br>Trades (%) | -0.00176%***                                      | -0.00133%***                   | -0.00023%**  |

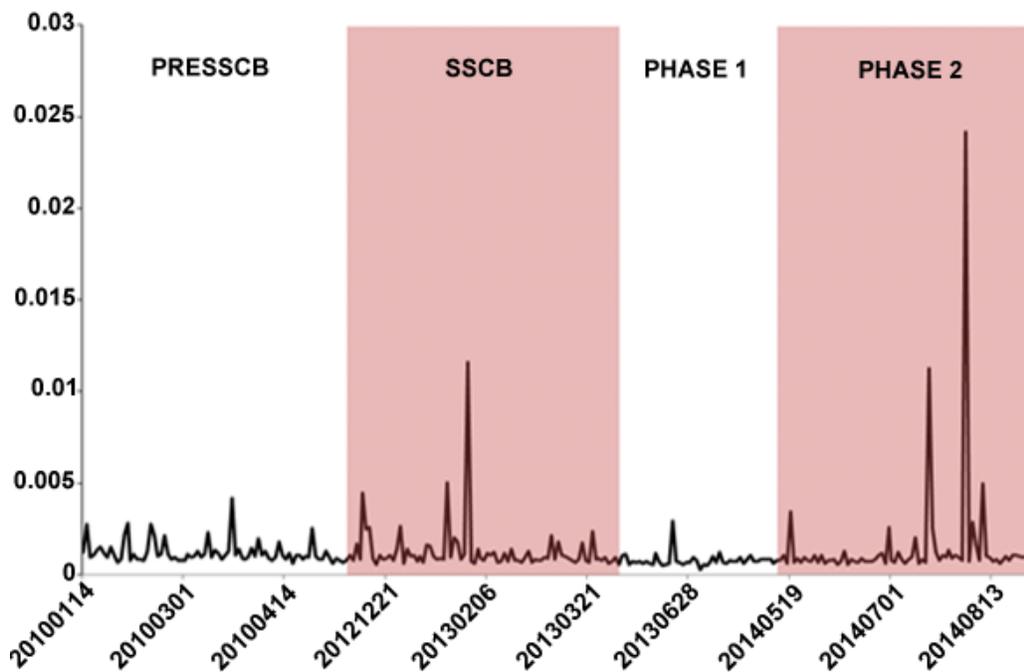
## Figure 1: Canceled Trades

This figure plots the time series of the daily canceled trades across all stocks, presented as a percentage of total trades, over the following four periods:

- Pre-SSCB (January 4 – May 6, 2010);
- SSCB (December 3, 2012 – April 5, 2013);
- LULD Phase I (June 3 – August 2, 2013); and
- LULD Phase II (May 12 – August 29, 2014).

Data excludes two outlier days: April 5, 2010 and the Flash Crash of May 6, 2010.

*Data source:* Daily Trade and Quote files (Daily TAQ).



## Appendix A: LULD Implementation Details

The timeline for the implementation of the LULD is described in Panel A; the periods used in our analyses are described in Panel B; and the parameter bounds for the two groups of securities are in Panels C and D.

Source: The Regulation NMS Plan available at <http://www.finra.org/sites/default/files/regulation-NMS-plan-to-address-extraordinary-market-volatility.pdf>

**Panel A: LULD Rollout Phases**

| Date                                     | Description   |
|--|---|
| May 6, 2010                              | The Flash Crash   |
| Between June 10, 2010, and June 23, 2011 | SSCB was implemented in three phases.   |
| Monday, April 8, 2013                    | LULD Phase I rollout begins. It applies from 9:45am to 3:30pm and covers Tier 1 securities only.          |
| Friday, May 31, 2013                     | LULD Phase I rollout complete.  |
| Monday, August 5, 2013                   | LULD Phase II.A rollout begins. It applies from 9:30am to 3:35pm and covers Tier 1 and Tier 2 securities. |
| On or before December 8, 2013            | LULD Phase II.A rollout complete.   |
| On or before February 24, 2014           | LULD Phase II.B price bands extended to the close (4 pm ET) on all exchanges except for Nasdaq.           |
| Monday, May 12, 2014                     | LULD Phase II.B price bands extended to the close (4 pm ET) on all exchanges.                             |

**Panel B: Representative Periods Used in Our Analyses**

|  |   |
|--|---|
| Pre-SSCB                                       | January 4 through May 6, 2010           |
| Pre-SSCB Without Flash Crash                   | January 4 through May 5, 2010           |
| SSCB   | December 3, 2012, through April 5, 2013 |
| LULD – Phase I (Tier 1 securities only)        | June 3 through August 2, 2013           |
| LULD – Phase II (Tier 1 and Tier 2 securities) | May 12 through August 29, 2014          |

**Panel C: Percentage Parameters for Tier 1 Securities**

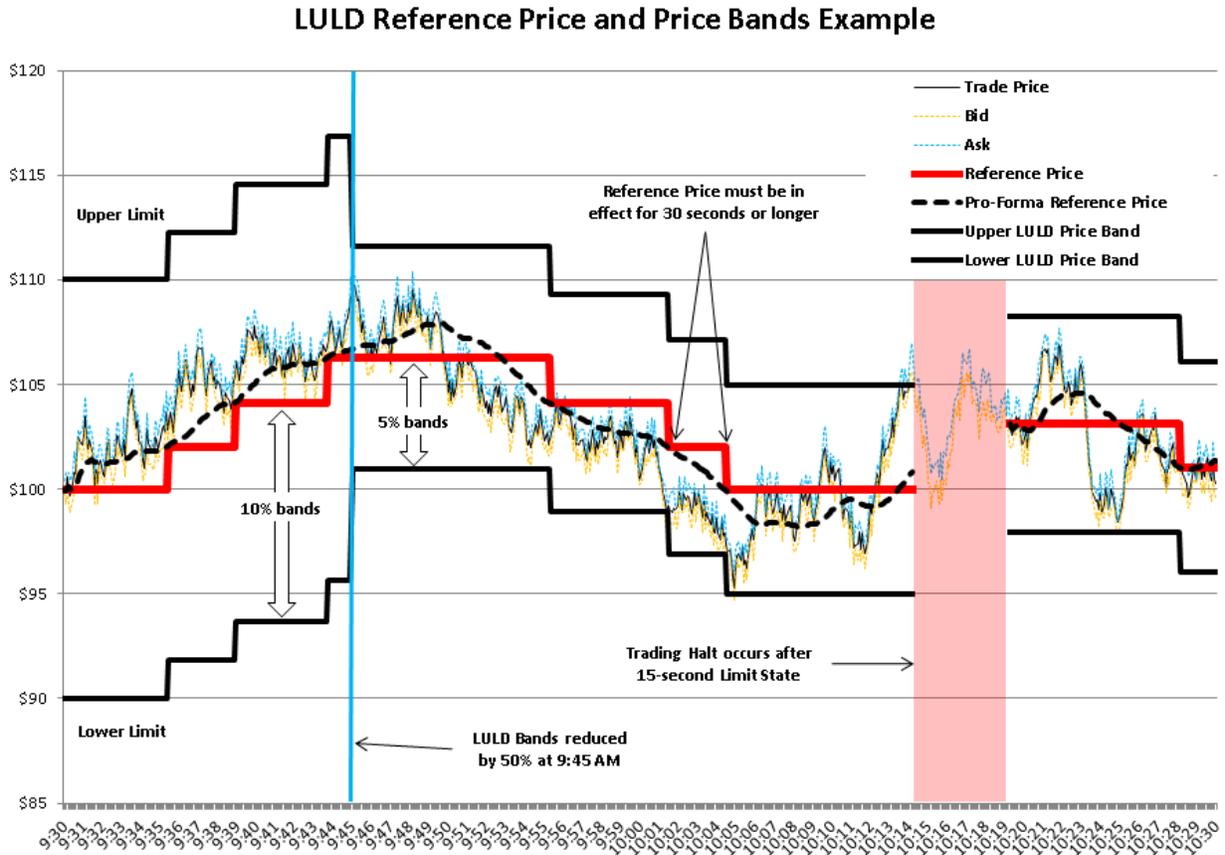
| <b>Previous closing price</b>     | <b>LULD Band Percentages</b> | <b>During open and close (i.e., 9:30-9:45 and 15:35-16:00)</b> |
|-----------------------------------|------------------------------|--|
| Greater than \$3.00               | 5%                           | 10%  |
| \$0.75 up to and including \$3.00 | 20%                          | 40%  |
| Less than \$0.75                  | Lesser of \$0.15 or 75%      | Lesser of \$0.30 or 150%                                       |

**Panel D: Percentage Parameters for Tier 2 Securities**

| <b>Previous closing price</b>     | <b>LULD Band Percentages</b> | <b>During open and close (i.e., 9:30-9:45 and 15:35-16:00)</b> |
|-----------------------------------|------------------------------|--|
| Greater than \$3.00               | 10%                          | 20%  |
| \$0.75 up to and including \$3.00 | 20%                          | 40%  |
| Less than \$0.75                  | Lesser of \$0.15 or 75%      | Lesser of \$0.30 or 150%                                       |

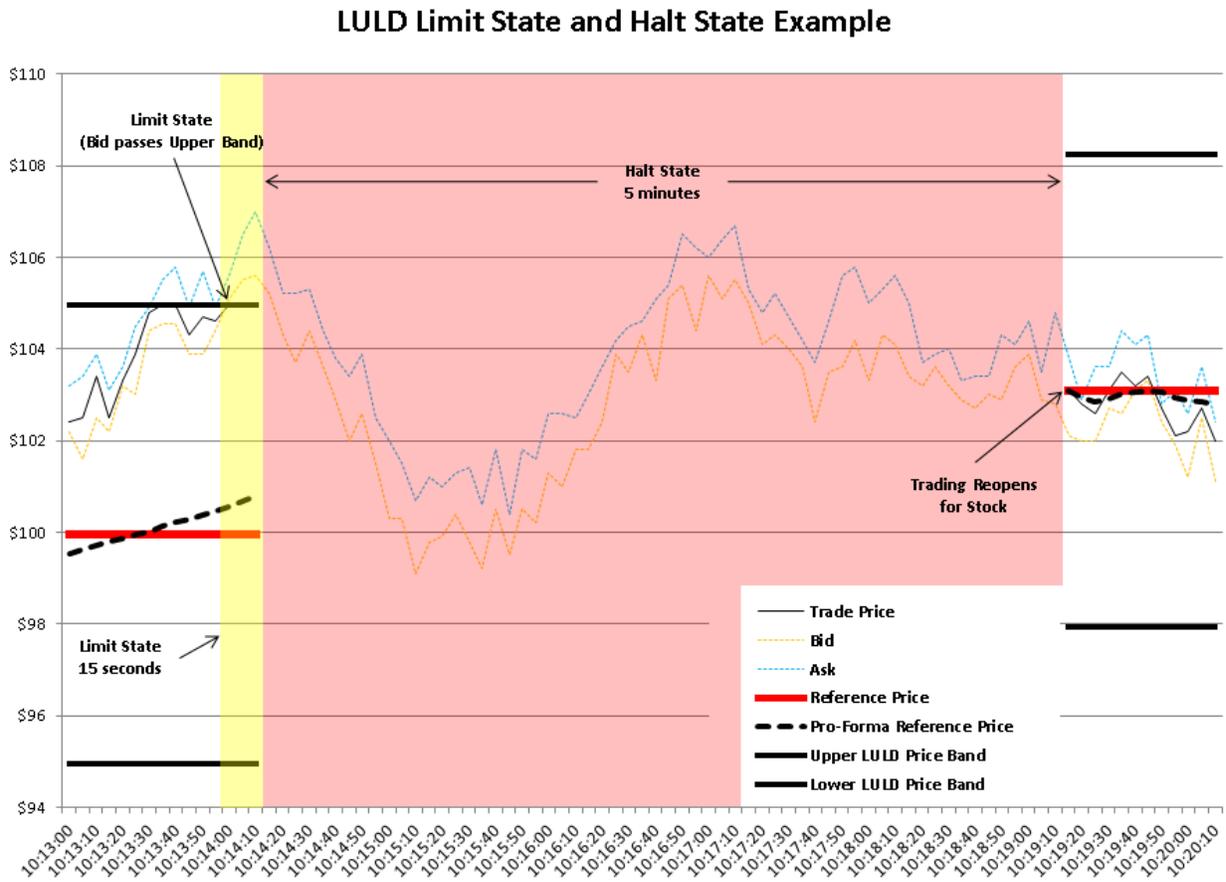
## Appendix B: Simulations

Figure B.1. LULD Reference Price and Price Bands Example



Appendix B – cont.

Figure B.2. LULD Limit State and Trading Pause (Halt) State Example



## Appendix C: Methods and Data

### Using Public Data Sources

For our analysis, we used two sources of publicly available data to augment data that the exchanges provided. The first source is the Trade and Quote (TAQ) database.<sup>95</sup> The second source is the CRSP, which we accessed via Wharton Research Data Services.<sup>96</sup>

Throughout our analysis, we form various subsamples in the following manner:

- according to the types of securities that the LULD affected, e.g., stocks versus ETPs;
- by time period (i.e., pre-SSCB (with and without Flash Crash), SSCB, Phase I of LULD, and Phase II of LULD); and
- by the time of day, because opening, intraday, and closings have different levels of liquidity, volatility, and price bands.

We used only securities with trade and quote data in TAQ or CRSP during the LULD Pilot Plan period.

The Corrected TAQ daily trade files identify canceled trades in the trade correction indicator field with a value of 7 or 8. We downloaded and processed with a lag of two days to allow for all corrections.

We used the SRO-provided data described in Appendix B of the LULD NMS Plan. The three Primary Listing Exchanges (BATS, Nasdaq, and the NYSE) provided the summary statistics specified in Appendix B, Section I and Section II (price bands, Limit States, Trading Pauses, and Straddle States) of the LULD Plan.

The table below lists the data that the exchanges and the SROs provided.

| Exchange | Data   | Starting month of data used in the paper | Ending month of data used in the paper |
|----------|--|--|--|
| ARCA     | All summary statistics; all LULD data                    | April 2013                               | August 2014                            |
| BATS     | Summary statistics of Limit State reasons; all LULD data | April 2013                               | August 2014                            |
| Nasdaq   | All summary statistics; all LULD data                    | April 2013                               | August 2014                            |
| NYSE     | All summary statistics; all LULD data                    | April 2013                               | August 2014                            |
| NYSE MKT | All summary statistics; all LULD data                    | April 2013                               | August 2014                            |

<sup>95</sup> See Daily TAQ (Historical Trades & Quotes-All CTA Participating Markets) at <http://www.nyxdata.com/data-products/daily-taq>.

<sup>96</sup> See Wharton Research Data Services, Welcome to WRDS! at <https://wrds-web.wharton.upenn.edu/wrds/>.

### ***Datasets from the SROs: Names and Descriptions***

|                        |  |
|------------------------|--|
| Limit State dataset    | identifies the stock symbol; the date and times when the Limit State starts and ends; how the stock exits the limit state; and the reason for the Limit State. |
| Trading Pause dataset  | identifies the stock symbol; the date and times when the Trading Pause starts and ends; and the reason for the Trading Pause.                                  |
| Straddle State dataset | identifies the stock symbol; the date and times when the Straddle State starts and ends; and how the stock exits the Straddle State.                           |

### ***Processing and Filtering the SRO Data***

Appendix B of the LULD approval order outlined the type of data feed, components of each feed, and the format of the feed; however, it did not specify the data type and format of each component. Since the data that each SRO provided were in different formats for various components, such as date, time, and Limit State indicators, we cleaned and standardized the SRO data. We applied the following processes and filters to the SRO data:

- All similar data feeds (Limit States, Trading Pauses, Straddle States, orders during Limit States and Trading Pauses, and price bands) from all SROs were merged together into corresponding standardized tables.

We excluded from our analysis:

- Limit States, Straddle States, and orders during Limit States that had start times during an LULD Trading Pause;
- Limit States, extending beyond 15 seconds, that had no corresponding Trading Pause;
- Limit States, Straddle States, and Trading Pauses for securities submitted by exchanges that are not the Primary Listing Exchange for the security; and
- All LULD data for Tier 2 during Phase I of the Pilot Plan (April 8 through August 2, 2013).