US EQUITY LIQUIDITY IN THE COVID-19 CRISIS

MARKET ANALYSIS
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INTRODUCTION
In this paper, we study the impact of the ongoing COVID-19 crisis on US equity market liquidity. We compare spread costs, market impact costs, intraday market conditions, and market resilience during the crisis and under normal market conditions. We hope this will help institutional investors and other market participants navigate these challenging conditions more easily. “Liquidity” refers to the difficulty of buying or selling an asset, but investors often confuse liquidity with “volume” (a decent proxy) but there are other factors at play such as volatility, leverage available to liquidity providers, and market resiliency. For smaller trades the cost of liquidity is the bid-offer spread, which an investor can pay to execute up to the shares available at the NBBO (referred to as “NBBO depth” here). Since both spreads and depth are affected in a crisis period, we study the normalized bid-offer spread, comparing the estimated spread for fixed depth before and after the COVID-19 crisis began. For orders larger than the NBBO depth, institutional investors realize market impact costs in addition to the bid-offer spread. We study the market impact costs for varying order sizes and participation rates. We also report on changing intraday liquidity dynamics to help investors optimize execution throughout the day.

EXECUTIVE SUMMARY
1. Spreads have increased significantly and NBBO depth has declined. Normalized spread costs are up 7.2 times for S&P 100 stocks, 4.1 times for Russell 2000 stocks. For a fixed, typically available amount of liquidity in normal trading conditions, the average cost during the COVID-19 crisis period for S&P 100 stocks is 20.5 basis points, compared to the usual 2.9bps.

2. Investors should pay special attention to their speed of execution and order size relative to average daily volume. Realized market impact costs have increased significantly. The realized market impact of trading 2% of volume today is equivalent to trading at 10% of the volume in normal conditions for S&P 100 stocks. These costs come in addition to the higher bid-offer spread costs. Systematic asset managers should review pre-trade cost estimation models used during portfolio construction, and all asset managers should review rule-based order size limits that are typically specified as a percent of average daily volume.
3. Investors should pay special attention to the first thirty minutes of the day. While the first thirty minutes have always been relatively costly to traders, the cost of execution before 10:00am has gone up significantly. For S&P 100 stocks, spreads have increased from 6.8bps to 29.3bps in the first thirty minutes, and for Russell 2000 constituents, spreads have increased from 106.5bps to 378.4bps, on average.

4. The number of times the Limit Up Limit Down mechanism has paused trading in stocks has gone up exponentially. Institutional traders should pay attention to the rules related to LULD and ensure that the execution algorithms handle LULDs well and do not exacerbate poor conditions during the limited execution horizon remaining after stocks trigger these limits.
STUDY PERIOD AND DATA

We present market behavior in three time periods. First, we use January 2020 to represent a “normal” period of trading under “normal” liquidity conditions; during that time, the implied volatility index of the S&P 500, VIX, averaged 13.94. The second period we study is February 24-March 6, during which the VIX Index more than doubled to an average of 34.35, we call the “transition” period. Finally, the current period is included, March 9th to March 27th, where the VIX Index averaged 65.3—almost doubling again, and we call that the “COVID-19 crisis” period.

We have also broken the universe of stocks into liquidity buckets to more clearly illustrate the behaviors traders are seeing. We label the constituents of the S&P 100 “mega cap” stocks. Stocks within the S&P 500—excluding the S&P 100—are referred to as “large cap” stocks. Constituents of the Russell 1000 Index—excluding members of the S&P 500—are labeled “mid cap” stocks, and the Russell 2000 constituents are included in a “small cap” group.

For these 3,000 stocks, we study every quote change in the best bid and offer—price or size—and every trade across all of US equity exchange from January 1st to March 27th.

VOLATILITY AND VOLUME

The volatility during COVID-19 crisis period has been historically high. VIX reached its highest weekly average, 74.92, on March 24, 2020—higher than at the peak of the financial crisis in October 2008—rising from a record low, as shown in Figure 1AB.

As is typically the case when volatility rises and portfolio managers begin reallocating assets to navigate changes in the market, the total market volume increased in response. The notional volume grew dramatically starting on February 24th, the beginning of the transition period in this study, as is illustrated in Figure 2AB.

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1 Source: Yahoo Finance.
2 Source: CBOE Global Markets.
3 While notional volume appears to remain steady, prices were declining, so total shares traded daily continued to increase throughout periods 2 and 3, the transition period and the COVID-19 crisis period.
MARKET HALTS

From a technology perspective, the US electronic equity and futures markets have fared admirably well. Not a single outage has been reported across any of the electronic exchanges. The only manual function at NYSE, related to opening and closing auctions, also became electronic after a couple of COVID-19 cases were reported at NYSE but this does not seem to have impacted the auction process\(^4\).

Despite a dramatic reduction in liquidity, we have not experienced an event similar to the Flash Crash in May 2010 when liquidity simply disappeared or an outage as in 2012 that eviscerated a leading market maker and electronic trading broker, Knight Securities. While market liquidity is currently at a record low, we attribute the market’s operational resilience in part to market-wide and single-stock circuit breakers. The market-wide circuit breaker kicks in if the S&P 500 Index declines by 7% or more; in that case, market activity across all stocks is halted for 15 minutes. The market-wide circuit breaker kicked in for the first time in 1997, and during the COVID-19 crisis it has already been triggered four times\(^5\) on March 9\(^th\), 12\(^th\), 16\(^th\) and 18\(^th\).

Critically, we have also seen an increase in the automatic temporary pauses for individual stocks experiencing volatility required by the “limit up-limit down” (LULD) mechanism\(^6\). On April 5, 2011, national securities exchanges and the Financial Industry Regulatory Authority (FINRA) filed a proposal to establish a “limit up limit down” (LULD) mechanism as a reaction to the Flash Crash. The rule went into effect market-wide in 2013, pausing trading in a stock for five minutes if the price goes above or below an average reference price in the immediately preceding five-minute period by 5%, 10%, or 20% depending on the liquidity of the stock and time of day.

While this rule is triggered occasionally, the number of times a single-stock market has halted has increased exponentially, to as many as 1500 times per day\(^7\) during the COVID-19 crisis. Figure 3 shows the dramatic change.

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\(^4\) Closing auction volume at NYSE decreased slightly, but we believe this is due to DMMs not being able to accept d-quote orders after the floor shut down. Even then, volume in the last fifteen minutes have changed only slightly, likely not impacting investors. The d-quote is a special order type DMMs use to submit orders for themselves and their clients after the standard cutoff time.

\(^5\) https://graphics.reuters.com/USA-MARKETS/0100B5L144C/index.html

\(^6\) https://www.nasdaqtrader.com/content/MarketRegulation/LULD_FAQ.pdf

\(^7\) https://www.nasdaqtrader.com/Trader.aspx?id=TradingHaltSearch
Figure 3. Number of triggers of the Limit Up Limit Down mechanism, single-stock market halts based on price volatility. The number of LULD triggers is typically very low, but during the COVID-19 crisis period, this value has risen to over 1500 triggers on a given day.

SPREAD AND DEPTH

During a time of increased volatility, investors experience changes as the cost of liquidity increases. The cost of liquidity is related to both the bid-offer spread set by liquidity providers (and in some part by investors placing limit orders) and the depth, indicating their willingness to trade. In this section, we consider both the spread and the depth and how these components together point to ongoing changes in trading cost during the COVID-19 crisis.

Bid-offer spread is the distance between the national best bid (NBB) and national best offer (NBO) across exchanges. For each stock we analyze a time-weighted average of the bid-offer spread throughout each trading day. Depth is the time-weighted average of the total size posted in limit orders to buy and sell in USD across all exchanges at the NBB and NBO.

Please note that we have removed the first five minutes of the trading day in calculating all daily statistics (not intraday statistics in later sections) for more robust representation of realized spreads, as the first five minutes of the day contain disproportionately more volatility for relatively less volume than later periods. We have also removed market-wide trading halts from all calculations in the remainder of this study.

CHANGES IN SPREAD

Since the onset of the COVID-19 crisis in the US, we’ve seen dramatic changes in spreads. As is illustrated in Figure 4A, spreads in S&P 100 stocks nearly doubled during the transition period in late February/early March as COVID-19 spread to the United States. But as COVID-19 has spread wildly and impacted our economy, S&P 100 spreads have climbed from a typical 2.9bps in January to 12.0bps today—an increase of almost 4 times. In Figure 4B, you can see the same behavior exhibited by Russell 2000 stocks, where spreads have also widened in response to increased volatility.

For comparison we have included the S&P 100 and Russell 2000 in this section; results for all indices are included in tables within the Appendix for reference.
Figure 4AB. Average spread in basis points across stocks in the S&P 100 Index (A) and Russell 2000 Index (B) over three periods in 2020, including the COVID-19 crisis period, shown in navy blue.

CHANGES IN DEPTH

Oppositely, when we see spreads widen depth tends to decline. Figures 5A and B show the corresponding decline in the total depth available at the NBBO in S&P 100 stocks (5A) and Russell 2000 stocks (5B).

Figure 5AB. Average depth in USD across stocks in the S&P 100 Index (A) and Russell 2000 Index (B) over three periods in 2020, including the COVID-19 crisis period, shown in navy blue.

HOW TICK SIZE IMPACTS SPREAD AND DEPTH

NBBO depth is generally related to the minimum tick size (one cent for stocks with price greater than $1) acting as a constraint for bid offer spread. If the stock’s natural unconstrained spread is below the minimum tick size, then there is competition among liquidity providers for queue position which increases the NBBO depth. The bigger the difference between the minimum tick size and a stock’s natural spread, the higher the NBBO depth will be. Even though we observe that spreads have increased on average during the COVID-19 crisis and on average depth has declined, that does not apply to all stocks.

For stocks constrained at a spread of the minimum tick size, the spread does not necessarily increase but the depth declines; for stocks unconstrained by the minimum tick size, the depth does not change but the spread increases. In Figure 6ABCD, we illustrate with examples of two stocks, GOOG (Alphabet, Inc.) and SIRI (Sirius Satellite). GOOG trades at a price of over $1,000, while SIRI trades at a price of around $5. For GOOG, the minimum tick size of one cent is less...
than .1 basis point, so tick size is not a constraint. For SIRI, the minimum tick size of one cent is 20 basis points, thus acting as a constraint that does not allow the stock to achieve its natural spread below one cent.

Figure 6A illustrates SIRI’s daily spread, unchanged even through the crisis period, while its depth declines during the COVID-19 crisis (Figure 6B). Figure 6C and 6D illustrate the same features of GOOG, showing that the depth of this high-priced stock did not decline but its spread increased in response to volatility during the crisis period.

Figure 6ABCD. Spread and depth changes in a stock constrained by the minimum tick size of one cent (SIRI) and an unconstrained stock (GOOG), emphasizing the need for a normalized metric that better represents true liquidity.

CHANGES IN NORMALIZED SPREAD

When we see increasing spreads and decreasing depth, we know they lead to increased trading costs. But in order to estimate the real cost of liquidity available at the NBBO, one needs to consider both spread and depth in concert. If an investor wants to execute a trade including the full amount of liquidity available at the touch, the cost of that transaction will be half of the bid-offer spread. During the current liquidity regime created by COVID-19, both the bid-offer spread (cost) and depth (availability) have changed, so we cannot directly compare the periods before and after the epidemic. For example, in the pre-crisis period, about $180,000 was available at the touch at any given time for S&P 100 constituents on average, but in the COVID-19 period only $62,000 is available. In order to trade $180,000, investors will have to pay more than just the bid-offer spread, pushing prices beyond the ask to purchase shares or below the bid to sell shares.
To estimate a normalized cost of liquidity we use the square root rule, projecting the cost of liquidity increasing by the square root of the increase in liquidity required. In other words, if an investor wants four times the liquidity available at the NBB or NBO, the investor will have to pay twice the bid-offer spread. For larger amounts, sized at percentages of daily volume, we share a market impact analysis in later sections.

For example, in the previous section we see that the spread of SIRI stays the same but the depth declines, and the spread of GOOG increases while its depth remains the same. The normalized spread for a fixed depth of $100,000 goes up for both stocks in a similar fashion, as shown in Figure 7.

![Average Normalized Spread](image)

Figure 7. Normalized spread for SIRI and GOOG, constrained and unconstrained by minimum tick size, respectively. While the two stocks’ spread and depth behavior are very different, their normalized behavior is very similar, indicating the need for such metrics.

The same analysis at the index level is illustrated in Figure 8A. Here, the normalized bid-offer spread for S&P 100 constituents is up more than 7 times, increasing from a value of 2.9bps in January to 20.5bps for the same amount of executed liquidity in the current period. The same metric for Russell 2000 constituent stocks (Figure 8B) is up more than 4 times, increasing from January’s average of 44bps to the current 180bps. The changes in this measure of the true cost of liquidity are more dramatic than they appear when we look only at absolute changes in spread, illustrated in Figure 8AB.

![S&P 100 Normalized Spread Cost](image)

![Russell 2000 Normalized Spread Cost](image)

Figure 8AB. Normalized average spread in bpx across stocks in the S&P 100 Index (A) and Russell 2000 Index (B) over three periods in 2020, including the COVID-19 crisis period, shown in navy blue. The spread has been normalized to account for purchase or sale of a fixed amount of liquidity (the average available at the touch in January), as depth has declined over time.
INTRADAY DYNAMICS
The charts above illustrate the changes investors are experiencing, but in order to develop strategies to abate the impact on trading costs we must review intraday dynamics.

INTRADAY VOLUME
As is shown in Figure 9AB, there is surprisingly little change to the intraday volume distribution—for mega cap and small cap stocks alike—except for minor adjustments in the opening and closing 15 minutes of the trading day. The figures do indicate a bit of flattening in the volume distribution across the bins—less liquidity in the opening and closing bins relative to normal periods—and the effect is somewhat stronger for mega caps than less liquid stocks.

**Figure 9AB.** Average percentage of total daily volume traded in each 15-minute time bin throughout the trading day for S&P 100 (A) and Russell 2000 (B) constituent stocks. Both include January 2020 in blue and the COVID-19 crisis period in navy blue.

INTRADAY SPREAD AND DEPTH
While the overall volume distribution does not show much change, there are major differences in the intraday spread distribution. Figure 10AB shows a comparison of intraday spreads from January to the COVID-19 crisis period. Time-weighted average spreads for each 15-minute period within the trading day are illustrated, for both S&P 100 stocks (10A) and Russell 2000 stocks (10B).

As one would expect follows the daily analysis, each figure shows spreads elevated throughout the day in the COVID-19 crisis period. As is typical, spreads are more elevated early in the day, but the magnitude of differences in spread should give pause to investors if they are trading during the first thirty minutes. For S&P 100 stocks, spreads have increased from 6.8bps to 29.3bps in the first thirty minutes, and for Russell 2000 constituents, spreads have increased from 106.5bps to 378.4bps, on average.
Figure 10AB. Average spread in basis points in each 15-minute time bin throughout the trading day for S&P 100 (A) and Russell 2000 (B) constituent stocks. Both include January 2020 in blue and the COVID-19 crisis period in navy blue.

Figure 11AB shows the corresponding changes to intraday depth, where available displayed liquidity has declined. Within Figure 11AB across intraday time bins, we can also see that the depth curve is unusually flat, not sustaining the usual growth over the trading day, but still increasing in the last 45 minutes of the day as expected.

Figure 11AB. Average available depth at the NBBO in USD in each 15-minute time bin throughout the trading day for S&P 100 (A) and Russell 2000 (B) constituent stocks. Both include January 2020 in blue and the COVID-19 crisis period in navy blue.

Here again, while we know costs will increase as spreads widen, it is important to consider the normalized spread when taking a fixed amount of liquidity to analyze the true scale of change in the cost of liquidity.

Figure 12AB illustrates the spread normalized by order size to estimate the real cost of liquidity intraday, comparing conditions during the COVID-19 crisis to normal trading conditions in January. For S&P 100 stocks, we fixed the traded depth at $100,000 as was typically available to trade at the touch in January, so this Figure 12A indicates the spread cost associated with trading this typically available size in these stocks, then and now, for a fairer comparison. For Russell 2000 stocks, we similarly fixed the traded depth at $10,000, shown in Figure 12B.

Again, Figure 12AB show that the actual cost of trading the same amount of liquidity is more dramatically increased than spread changes alone would lead traders to believe. For S&P 100 stocks, normalized spreads have increased from 10bps
to more than 45bps in the first fifteen minutes, and for Russell 2000 constituents, normalized spreads have increased from 120bps to 500bps, on average.

Figure 12AB. Spread in basis points in each 15-minute time bin throughout the trading day, normalized to account for purchase or sale of a fixed amount of liquidity, $100,000 for S&P 100 stocks (A) and $10,000 for Russell 2000 (B) constituent stocks (the average amount available at the touch in January). Both include January 2020 in blue and the COVID-19 crisis period in navy blue.

**REALIZED MARKET IMPACT**

**TOTAL COST FOR INSTITUTIONAL INVESTORS**

The first sections of this paper cover spread costs, a critical component of trading costs. But investors typically pay two kinds of costs: spread costs and market impact costs. When traders have order sizes larger than what is available at the NBBO, they spread their orders over a longer time horizon and blend into the volume distribution. Such ongoing participation impacts prices, driving prices for buy orders higher (or sell orders lower) as the execution horizon wears on. Here, we present the changes in realized market impact for longer-horizon orders, comparing the COVID-19 crisis period to January’s normal conditions.

We define the realized market impact as an order’s side-adjusted difference in volume-weighted average price over a fixed execution horizon and the midpoint price at the beginning of the order

\[ \text{Realized Market Impact} = \text{sign(side)} \times \frac{(\text{Interval VWAP} - \text{Order Arrival Midpoint Price})}{\text{Order Arrival Midpoint Price}} \]

where \( \text{sign(sell)} = -1 \) and \( \text{sign(buy)} = 1 \).

**PARTICIPATION RATE, ORDER SIZE, AND REALIZED MARKET IMPACT**

As one would expect, higher participation rate yields higher market impact for a fixed order size. An order of $1M to buy will have higher market impact costs when executed over 10 minutes than executed over 30 minutes. Similarly, for a fixed participation rate, longer order duration yields higher impact. An order with the participation rate of 5% over 10 minutes will have less market impact than an order trading at 5% over 30 minutes. The reason for this is that the second

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8 Realized Market Impact = sign(side) * (Interval VWAP – Order Arrival Midpoint Price) / Order Arrival Midpoint Price where sign(sell) = -1 and sign(buy) = 1

9 In our experience the slippage versus VWAP generally ranges from 10% to 70% of bid-offer spread depending on the skill of the algorithmic trading provider.
order is larger, and a portion of the market impact accumulates over time increasing prices (for a buy order) in the latter part of the order. A robust transaction cost model takes all of these considerations into account and provides institutional portfolio managers with an estimate of cost for varying order sizes and participation rates in varying market conditions. In this section, we analyze the effects of executing at varying participation rates and order sizes during the unique market conditions of the COVID-19 crisis.

CALCULATING PARTICIPATION RATE AND ORDER SIZES

In calculating participation rate and order size, we use TAQ data including quotes and trades across exchanges from January 1, 2020 through March 27, 2020 for Russell 3000 stocks. We classify each trade as buyer-initiated or seller-initiated using the Lee-Ready algorithm—trades occurring at the NBO are buyer-initiated and trades occurring at the NBB are seller-initiated.

We divide the data into 15-minute, 30-minute, 60-minute, and 2-hour bins to study the effect of large order sizes traded over varying durations. For each stock, date, and bin, we calculate the total trade imbalance, summing the dollar volume of buy-initiated trades and subtracting sell-initiated trades. We divide the trade imbalance by the volume in each bin to calculate participation rate. A negative participation rate of 10% means that the volume from buy-initiated trades was 45% while the volume from sell-initiated trades was 55% of the total volume during that time. These calculated participation rates serve as proxy for institutional orders of corresponding size executed at the same participation rate. For example, an observation with a $1M trade imbalance and a negative 10% participation rate serves as a proxy for a sell order of $1M executed at a 10% participation rate.

REALIZED MARKET IMPACT AND THE COVID-19 CRISIS

We study the data by keeping the bin size fixed. We present our analysis of S&P 500 constituent stocks (totaling 97,500 observations during the COVID-19 crisis period) and Russell 2000 (780,000 observations) over 30-minute intervals.

Just as the bid offer spread costs are high, the realized market impact is much higher during the COVID-19 crisis period, as shown in Figure 13AB. The effect is exacerbated as order sizes increase (and thus the participation rate increases over the same time horizon). More specifically, a basket of orders in S&P 500 stocks with orders sized at 10% of average daily volume in January 2020 has roughly the same market impact on average as orders sized at 2% of average daily volume during the crisis period (Figure 13A). Similarly, a basket of orders in Russell 2000 stocks with orders sized at 10% of average daily volume in January has roughly the same market impact on average as orders sized at 3% of average daily volume during the crisis period (Figure 13B).

Many institutional traders use participation rate as a constraint while rebalancing their portfolios; if current volatility conditions persist, we recommend reevaluating the usual constraints thoughtfully. Similarly, many systematic asset managers use pre-trade cost models within their portfolio optimization process, and those models often do not estimate costs well under varying market conditions. Systematic managers should verify their cost estimates against the empirical observations we provide here.

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10 BestEx Research provides its clients with a transaction cost model allowing them to estimate cost of execution prior to executing a basket with varying speeds of urgency. Our model allows portfolio managers to size the orders appropriately during the portfolio construction process, thus implementing more efficient portfolios.

11 Inferring Trade Direction from Intraday Data; Charles M. C. Lee, Mark J. Ready; The Journal of Finance Vol. 46 (2): 733-746.

12 We combine the full S&P 500 for our market impact analysis to create more robust results than the smaller sample size of S&P 100 stocks can generate over the fixed period of observation. We include results across all indices and intervals in the Appendix.
Figure 13AB. Realized market impact cost for S&P 500 constituent stocks (A) and Russell 2000 (B). The horizontal axis represents the average participation rate within each group of orders (trade imbalance divided by total volume in each 30-minute bin), and the vertical axis represents the price impact (side-adjusted VWAP performance versus arrival midpoint in each 30-minute bin).

CONCLUSION

As illustrated here, traders are facing unprecedented challenges in availability of liquidity, and there is no telling how long this volatility will last. According to Dr. Anthony Fauci, the director of the National Institute of Allergy and Infectious Diseases, “You don’t make the timeline, the virus makes the timeline.” Investors should pay even more attention to liquidity in these uncertain market conditions.

While we know institutional investors sometimes need to trade quickly and in large quantities, to accommodate the changes to liquidity conditions, investors should carefully evaluate available liquidity when choosing order sizes and execution strategies.

- Normalized bid-offer spread during the COVID-19 crisis period is 7 times higher than usual for S&P 100 stocks and increased similarly in less-liquid stocks.
- Intraday liquidity in the first thirty minutes of the trading has been affected the most. Market impact costs for trading large order sizes are equivalent to trading four to five times more under normal conditions.
- Single-stock and market-wide pauses have also increased dramatically, making the actual trade horizon even shorter for long-duration trades.

Investors should consider each of these factors while planning order execution until conditions improve. Investors should also re-evaluate pre-trade cost estimation models if used in portfolio construction, and they should re-evaluate any rule-based order size caps based on participation rate.
APPENDIX

APPENDIX 1: Daily Analytics for Various Liquidity Groups

These tables show average bid offer spread, NBBO depth, VIX, and normalized bid offer spread for each symbol group in each time period. Normalized bid offer spreads are estimated as the spread cost for acquiring a fixed amount of liquidity available in January 2020 in all periods.

S&P 100

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<tr>
<th>Time Period</th>
<th>Spread (bps)</th>
<th>Depth (USD)</th>
<th>VIX</th>
<th>Normalized Spread (bps)</th>
<th>Realized Volatility</th>
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<td>January</td>
<td>2.86</td>
<td>$187,664</td>
<td>13.9</td>
<td>2.86</td>
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<tr>
<td>Feb 1 – Feb 21</td>
<td>3.03</td>
<td>$193,594</td>
<td>15.2</td>
<td>2.99</td>
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</tr>
<tr>
<td>Feb 24 – Mar 6</td>
<td>4.77</td>
<td>$111,538</td>
<td>34.4</td>
<td>6.19</td>
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<td>Mar 9 – Mar 27</td>
<td>12.00</td>
<td>$64,270</td>
<td>65.3</td>
<td>20.50</td>
<td>95%</td>
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S&P 500 (excluding S&P 100)

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<th>Time Period</th>
<th>Spread (bps)</th>
<th>Depth (USD)</th>
<th>VIX</th>
<th>Normalized Spread (bps)</th>
<th>Realized Volatility</th>
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<tbody>
<tr>
<td>January</td>
<td>4.87</td>
<td>$63,211</td>
<td>13.9</td>
<td>4.87</td>
<td>18%</td>
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<tr>
<td>Feb 1 – Feb 21</td>
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<td>$62,085</td>
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<td>Mar 9 – Mar 27</td>
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<td>$29,110</td>
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Russell 1000 (excluding S&P 500)

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<th>VIX</th>
<th>Normalized Spread (bps)</th>
<th>Realized Volatility</th>
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<td>9.87</td>
<td>$57,039</td>
<td>13.9</td>
<td>9.87</td>
<td>22%</td>
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<td>Feb 1 – Feb 21</td>
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<td>$59,936</td>
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<td>$26,733</td>
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Russell 2000

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<th>VIX</th>
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<td>43.61</td>
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<td>Mar 9 – Mar 27</td>
<td>131.25</td>
<td>$9,505</td>
<td>65.3</td>
<td>180.17</td>
<td>160%</td>
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APPENDIX 2: Market Impact Curves for Various Time Horizons

These charts illustrate the empirical market impact curves for various participation rates and trade durations for S&P 500 and Russell 2000 constituent stocks in two periods: January 2020 and March 9-27. The horizontal axis represents the average participation rates within each range, as described in the market impact section of this paper. Each point represents the average market impact to trade at the average participation rate over durations 15, 30, 60, 90, and 120 minute intervals.