Tethys Optimal Execution

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US Equities Market Meltdown Analysis

Introduction:

In this report we study how major US equities security characteristics changed during the "market meltdown" period from February 24 - March 18, 2020 in comparison to the pre-meltdown period of January 27 - February 21, 2020.

This report includes days where the S&P 500 high-low price range was greater than 3%.

We also divided the securities universe in our analysis into the following categories:

- market cap (large>=$10 billion, medium and small<=$2 billion)
- time intervals (30-minute time slots between opening and closing time)

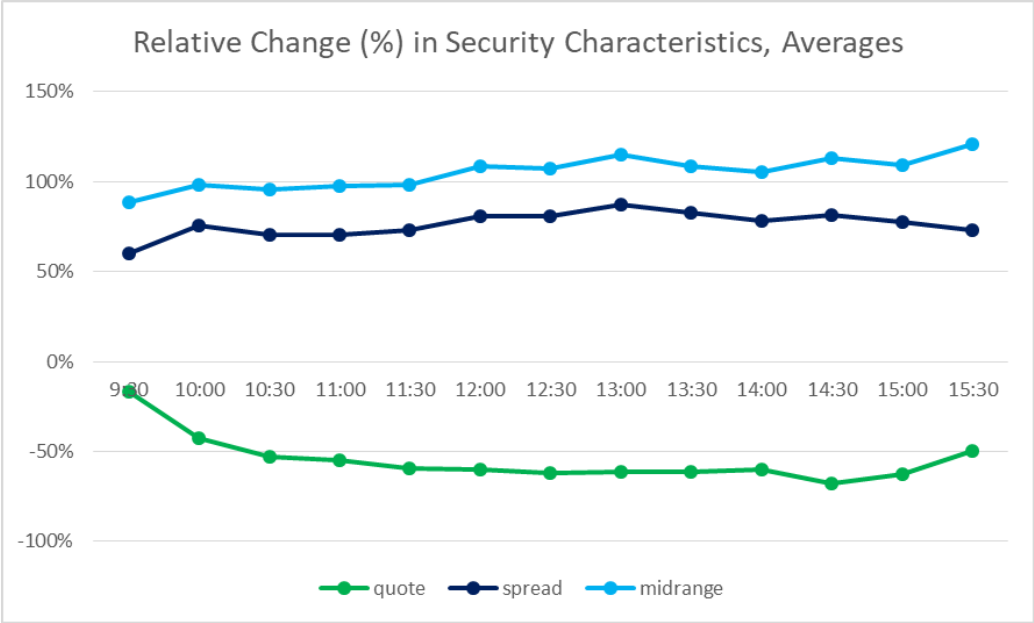
We then calculated descriptive statistics of security characteristics including quote size, spread and midrange change to security price during both time periods. We also looked at averages of daily volume time series within each market cap category.

We use these descriptive statistics in our comparison of how security characteristics were affected by the meltdown. This comparison is visual, in the form of charts in **Section 1** below, as well as supported by hypothesis testing in **Section 2**.

We also constructed a composite index in **Section 3** and calculated what it would have cost to cross the spread across all market cap categories during both time periods.

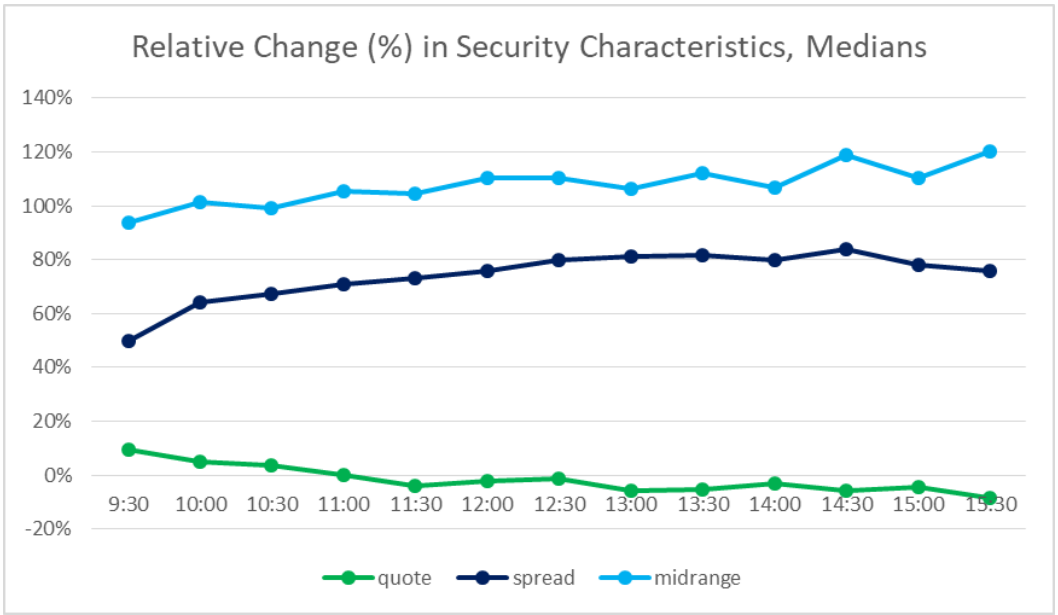
The following patterns were observed during the market meltdown (inclusive of all data):

Chart 1:



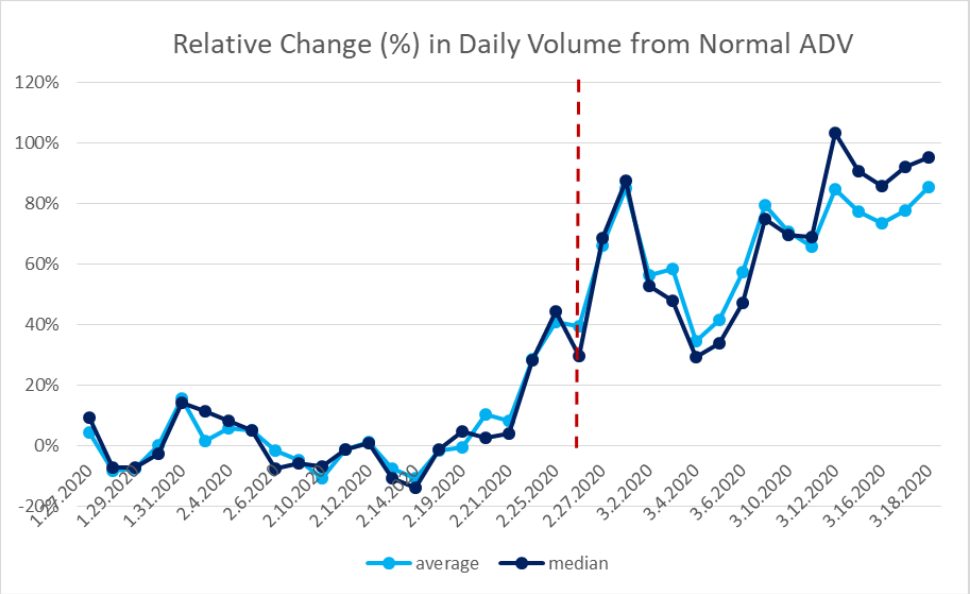
- Limit order books were depleted resulting in average quote sizes that were approximately 55-60% less than the pre-meltdown period levels throughout the trading day,
- Average security spreads and price volatilities increased approximately 75% and 100% respectively with the gap increasing slightly more from open to close.

Chart 2:



- When looking at median data, which is more robust to outliers than averages, these changes were not as drastic, this is particularly relevant for quote sizes,
- However, we still see an increase in relative spread and midrange changes as great as we did on the averages – this is an indication that these security characteristics changed for a high percentage of securities in the dataset.

Chart 3:



- Daily volumes surged and almost doubled on the last day of the meltdown analysis period.

We also estimated the expected cost and fill percentage to sweep at market far-touch NBBO during the pre-meltdown and the meltdown time periods with the following notional values transacted: $1 million for large market cap category, $250,000 for medium cap and $100,000 for small cap.

Table 1: Far-Side Sweep Cost (BPS)

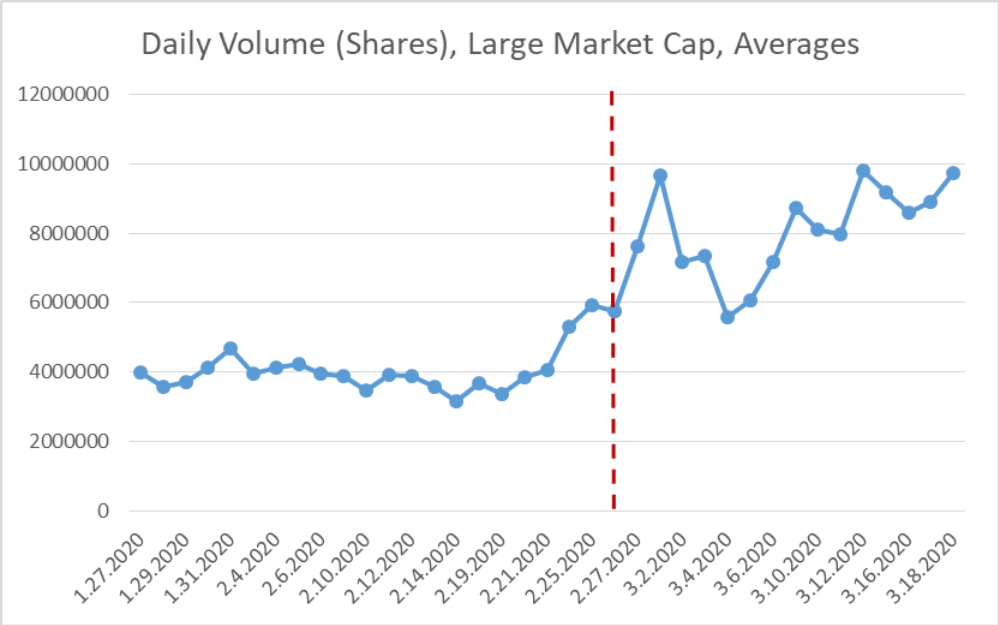
Market Capitalization Category	Far-Side Sweep Cost (BPS), Pre-Meltdown	Far-Side Sweep Cost (BPS), Meltdown	Change (%) from Pre-Meltdown to Meltdown
Large	4.8	11.1	133%
Medium	9.2	20.1	118%
Small	20.3	39.3	94%

Table 2: Far-Side Sweep Fill Percentage (%)

Market Capitalization Category	Far-Side Sweep Fill (%), Pre-Meltdown	Far-Side Sweep Fill (%), Meltdown	Change (%) from Pre-Meltdown to Meltdown
Large	28.5%	19.6%	-38%
Medium	29%	22.5%	-25%
Small	29.5%	23.9%	-19%

- Increase in cross-market far-side slippage cost and decrease in corresponding fill percentages are directly proportional to the market cap category
- Costs are growing by94% for small caps and by 133% for largecaps, while relative drop in fill rates is 19% for small caps and38% for large caps.

Chart 4:



Section 1: Volume, Quote Size, Spread and Mid- Range Comparison

- During the turbulent periods in the market, when stocks plunge and rebound rapidly, daily volumes are normally higher than average.
- The charts below plot daily volume averages time series per market capitalization categories (pre-meltdown period is separated from the meltdown one by the red dotted line):

Chart 4:

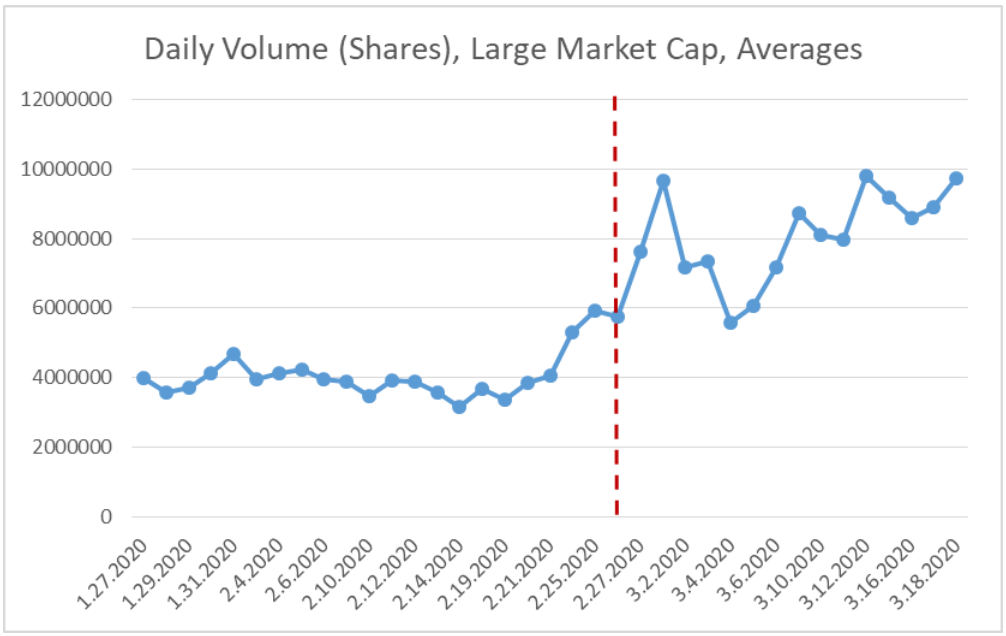


Chart 5:

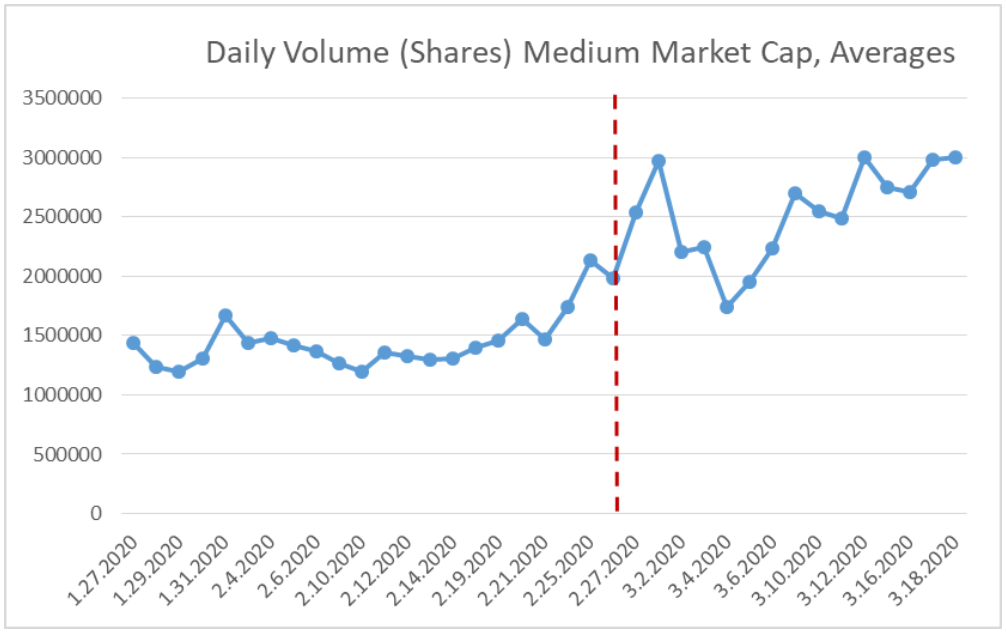
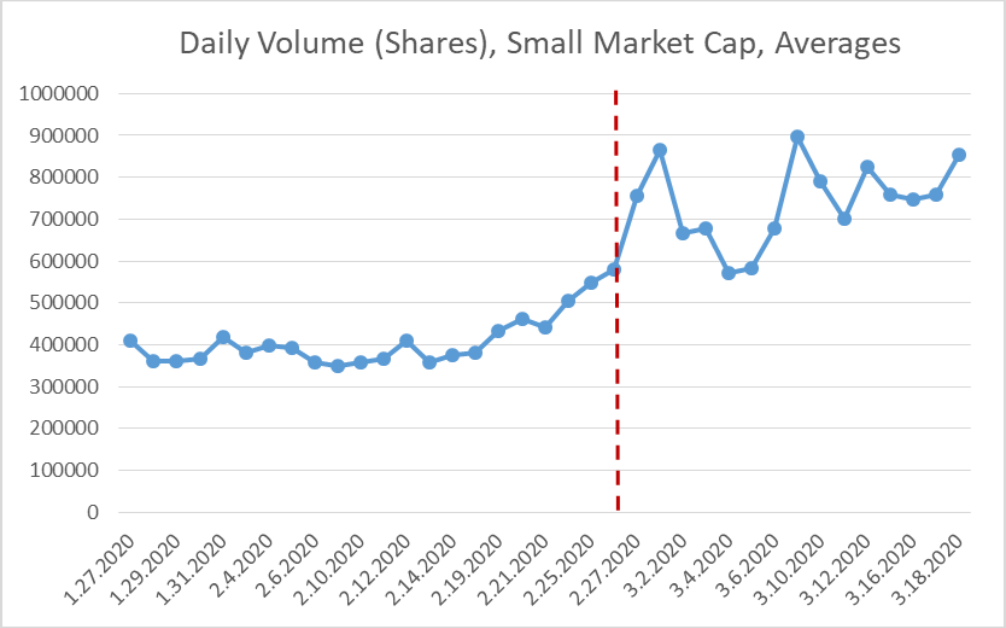


Chart 6:



- Daily volumes during the recent market meltdown increased for securities within small and medium market cap category by about 80% on average from the levels during the pre-meltdown period, while for securities within large caps the volume nearly doubled.

In the charts below we plot averages and medians of quote size, spread and midrange before (PRE) and during the meltdown (MELT) across the whole trading day divided into half-hour time intervals and various levels of market capitalization:

Quote Size:

Chart 7:

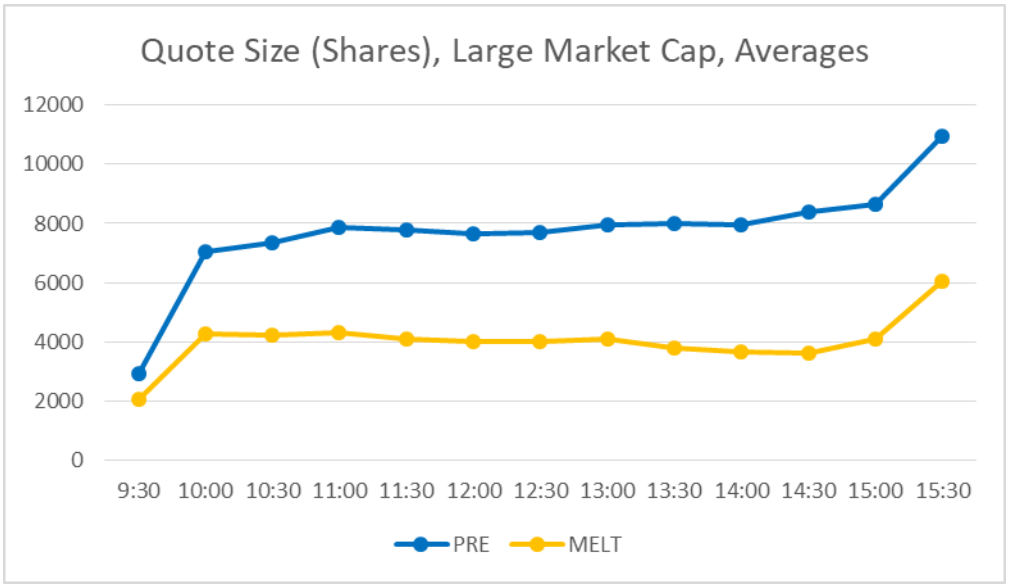


Chart 8:

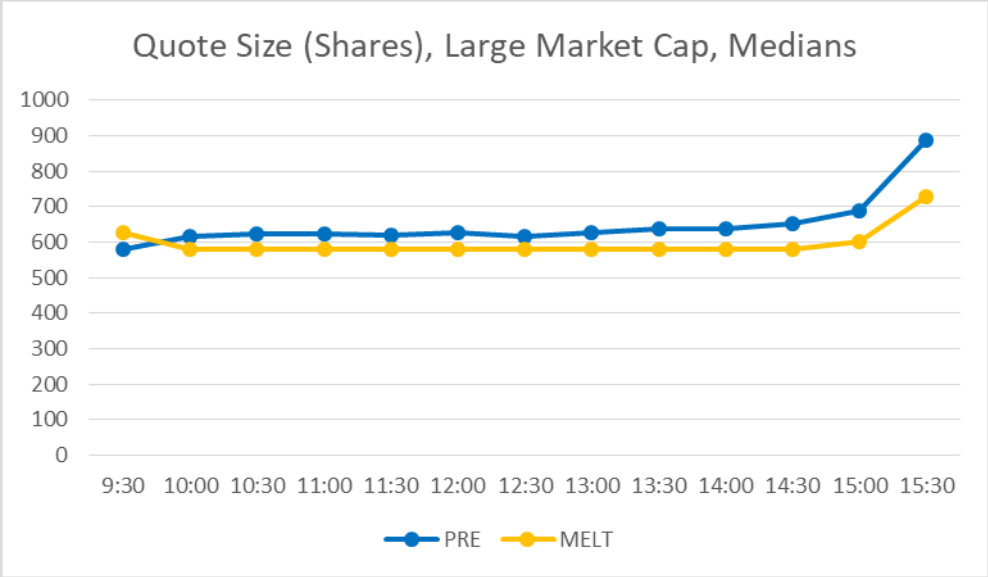


Chart 9:

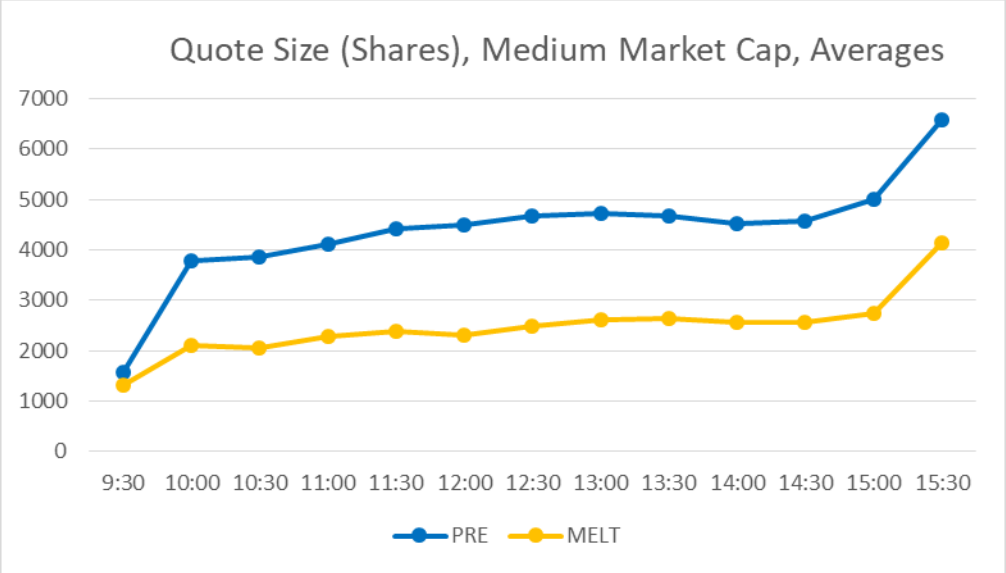


Chart 10:

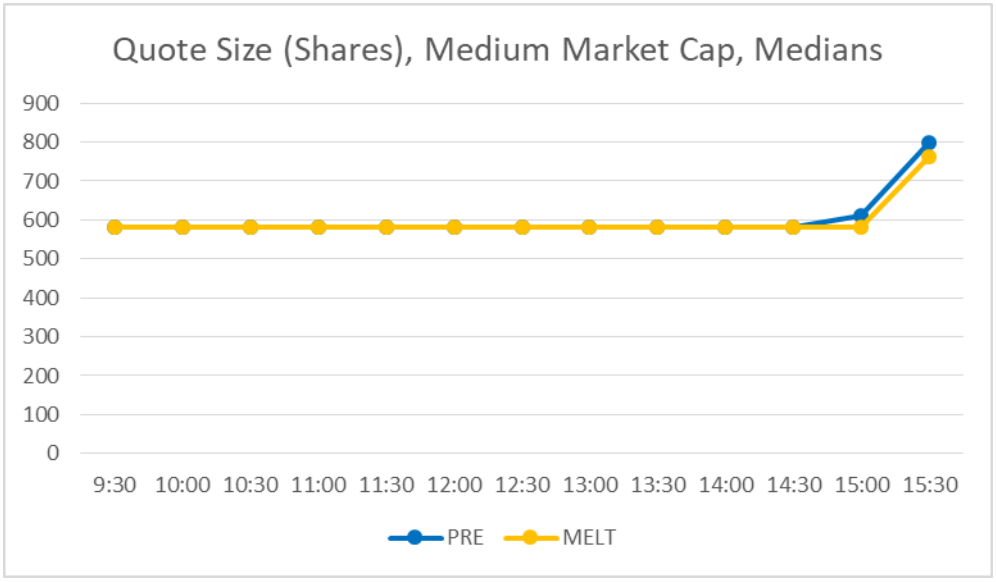


Chart 11:

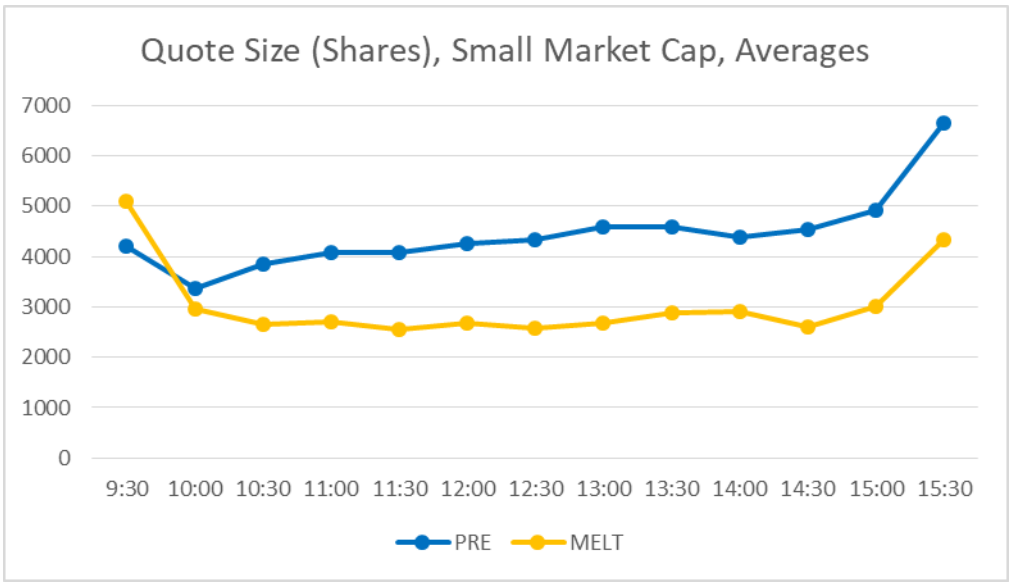
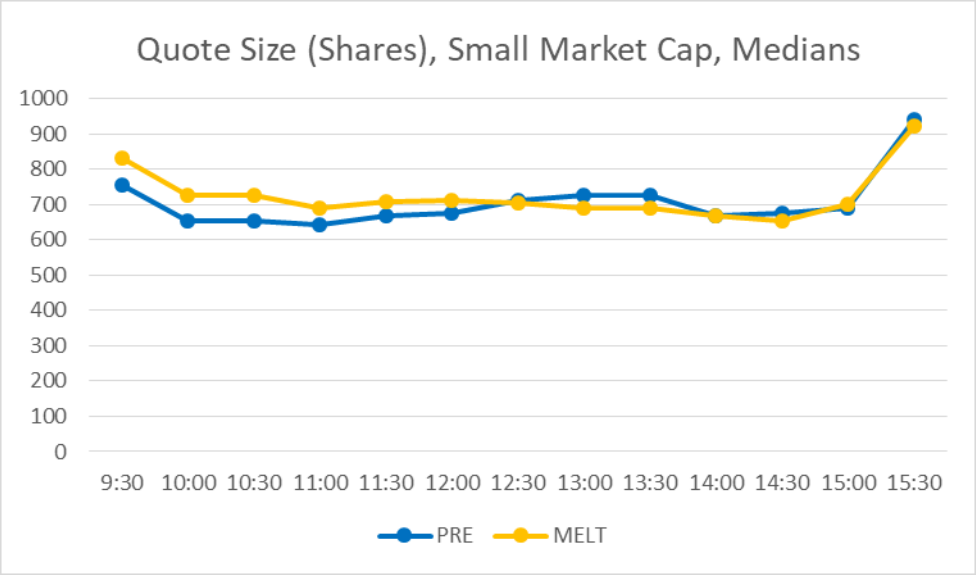


Chart 12:



- Average quote sizes went down during the market meltdown from the pre-meltdown levels
- The difference between corresponding quote size medians was not as pronounced as it was for the averages

Spread:

Chart 13:

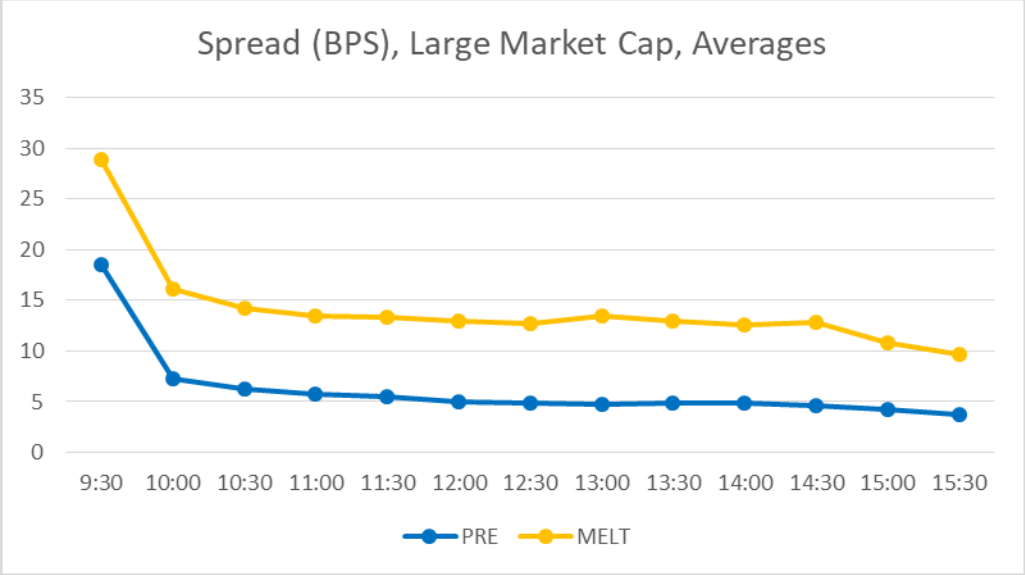


Chart 14:

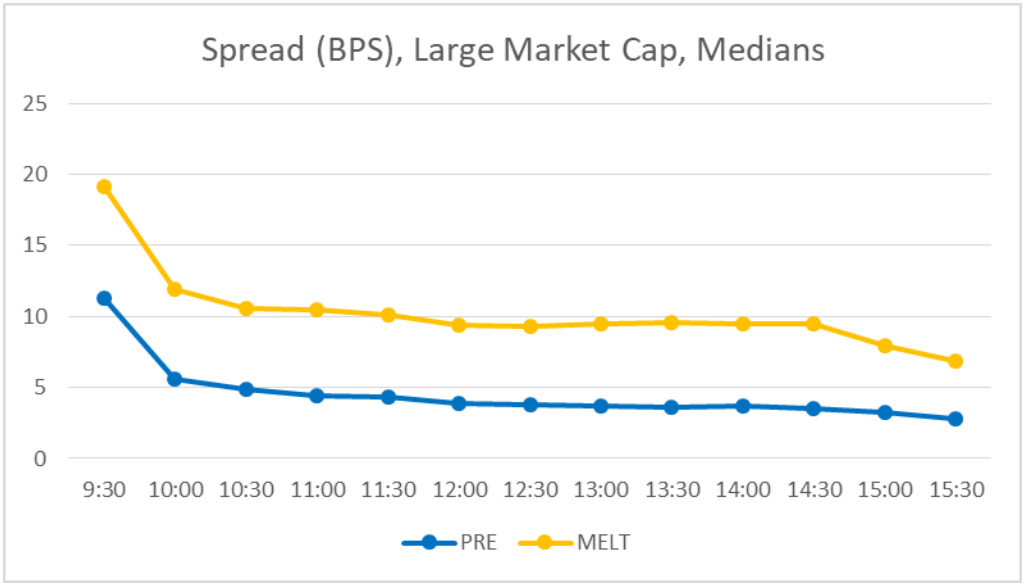


Chart 15:

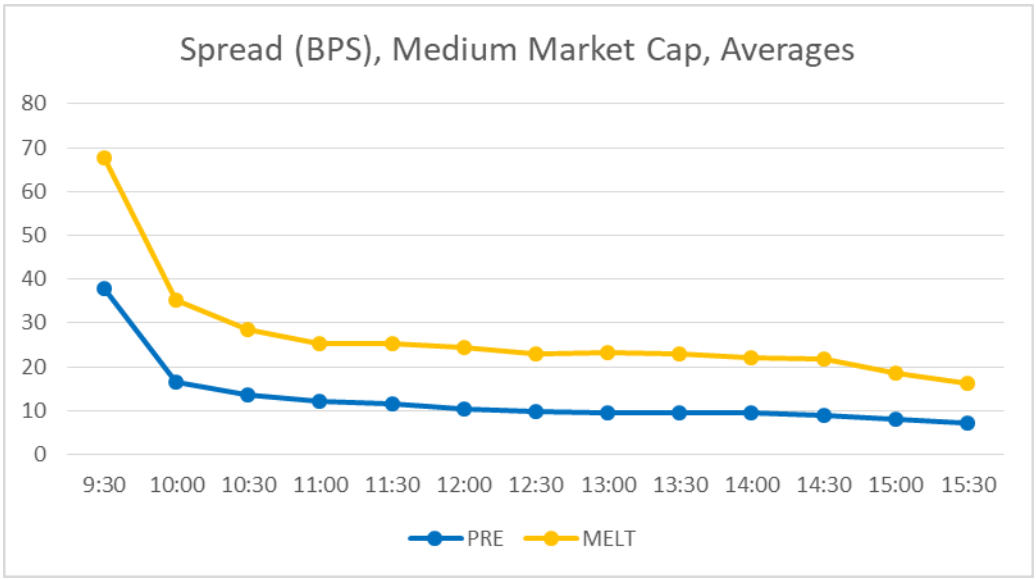


Chart 16:

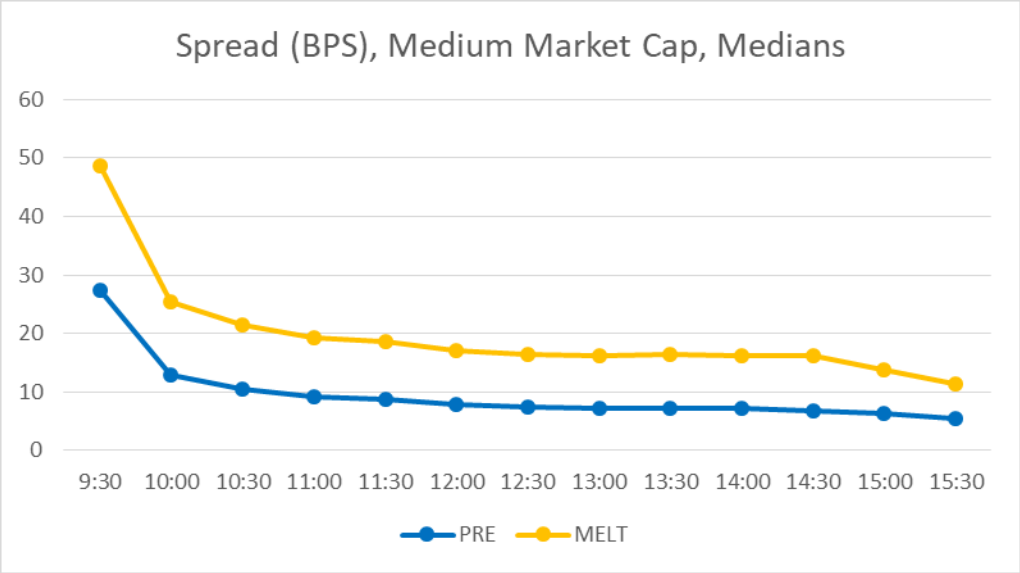


Chart 17:

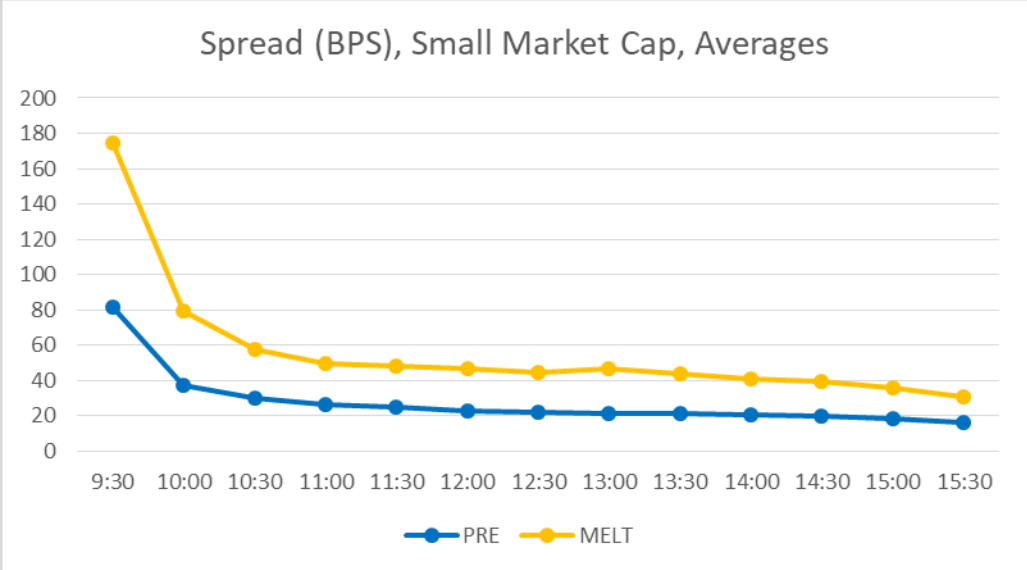
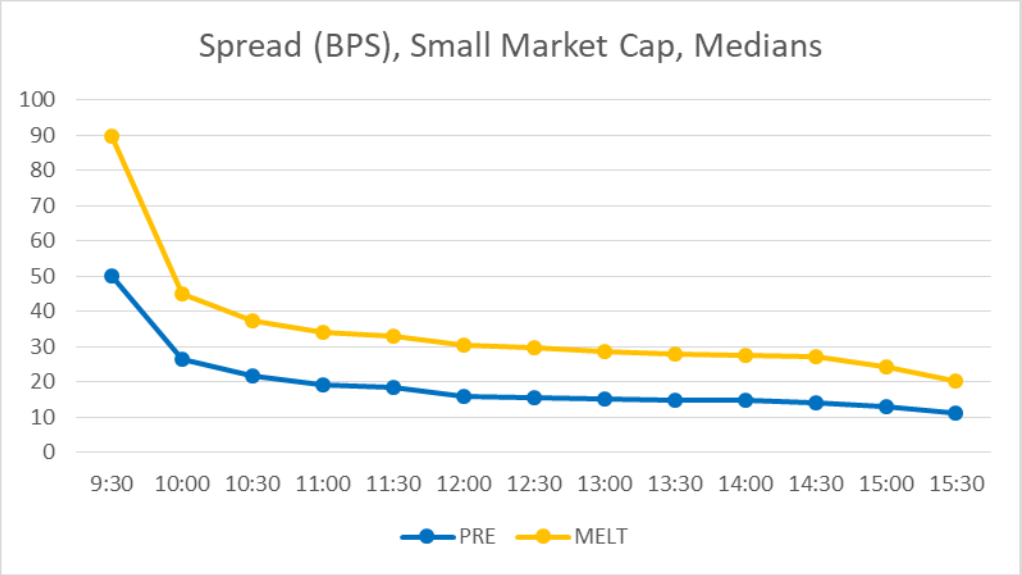


Chart 18:



- Meanwhile, average and median spreads went up during the market meltdown from their pre-meltdown levels
- The trend of spreads shrinking over the course of the trading session persisted in both periods

Midrange:

Chart 19:

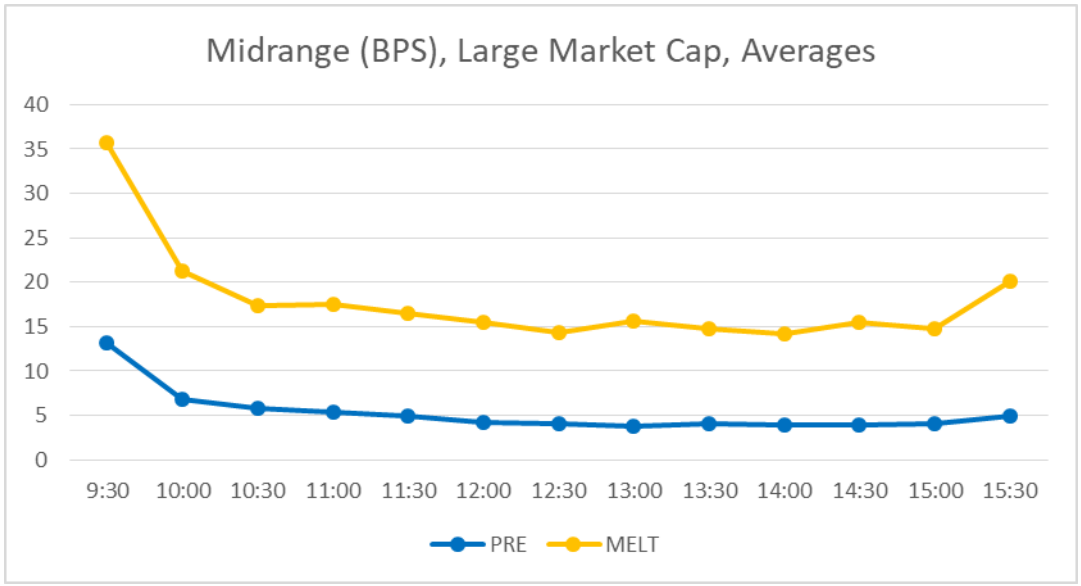


Chart 20:

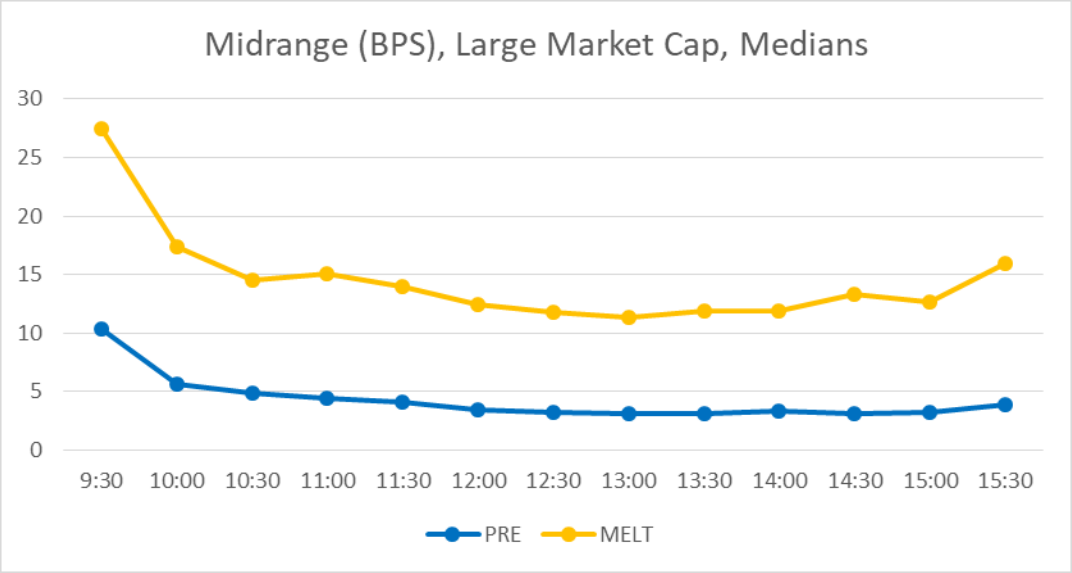


Chart 21:

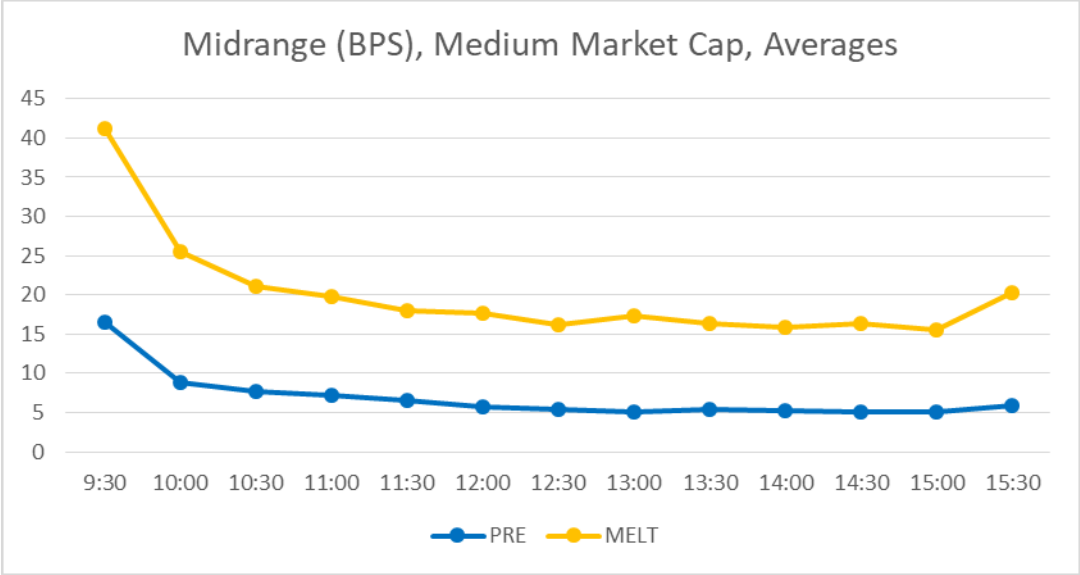


Chart 22:

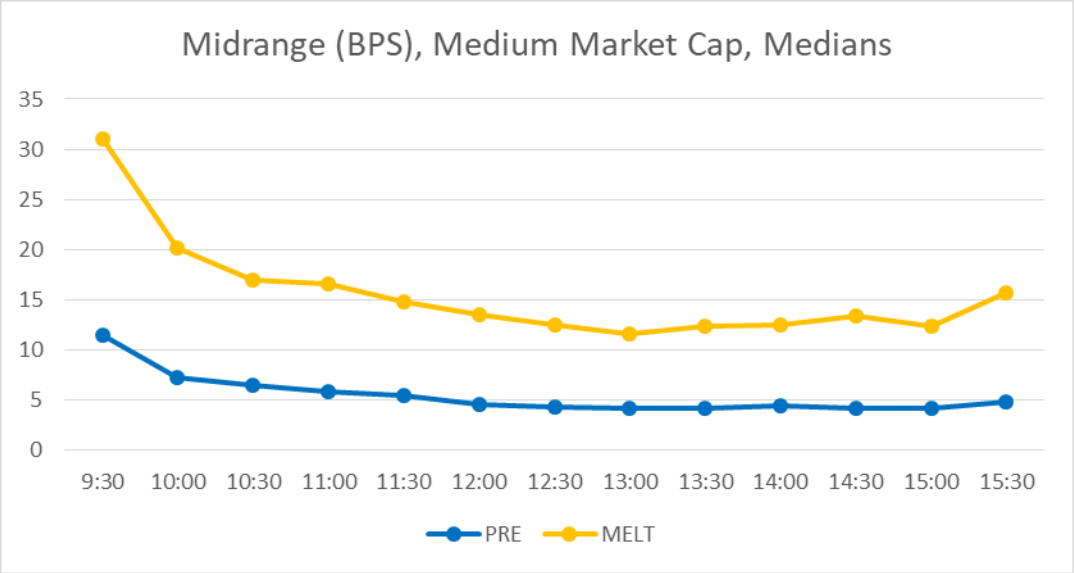


Chart 23:

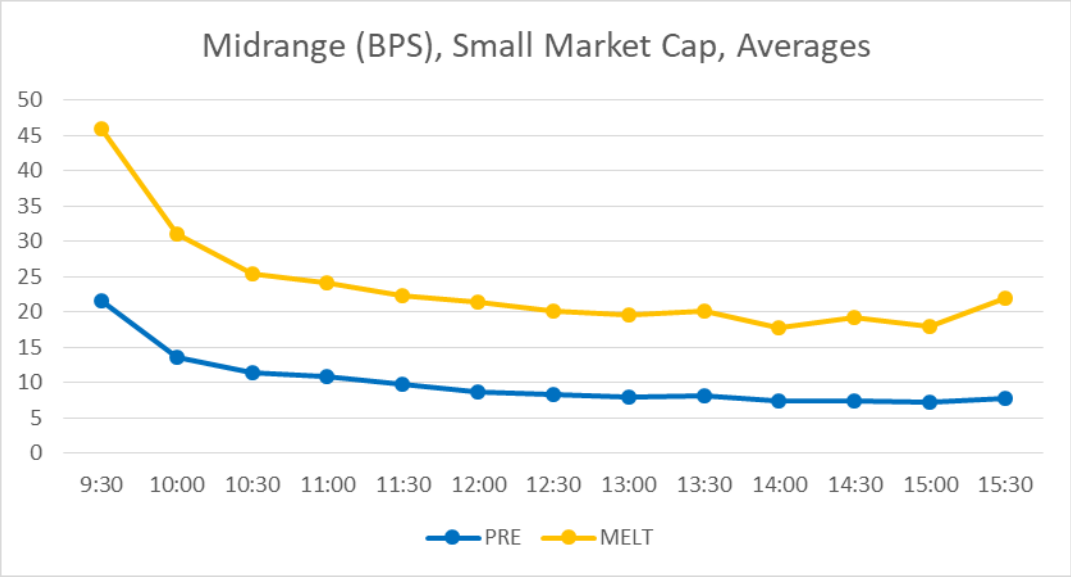
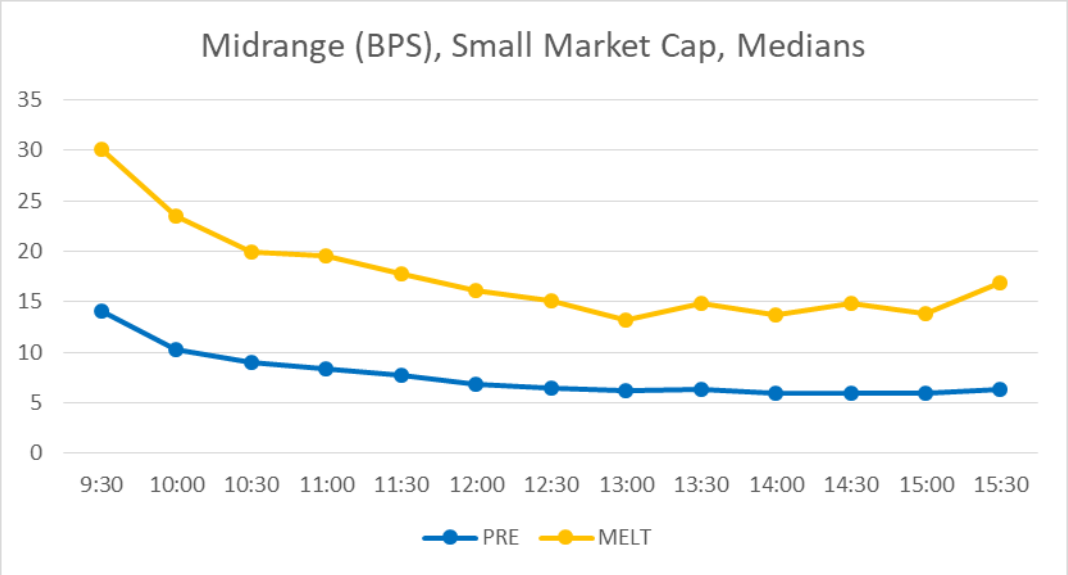


Chart 24:



- The Midrange change statistic (this is a proxy of price variability/volatility), was also higher during the meltdown period than the prior period both for averages and medians
- Price volatility trend patterns remained similar during both periods: A decrease from open, flat during the mid-day and slight increase right before close.

Below we examine relative change in averages and medians of each of the security characteristics.

Quote Size:

Chart 25:

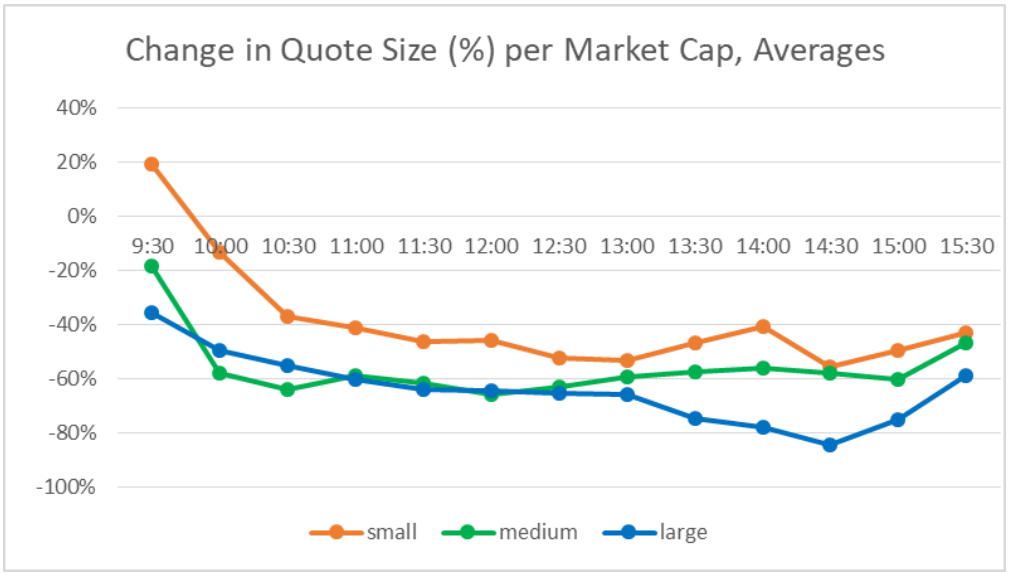
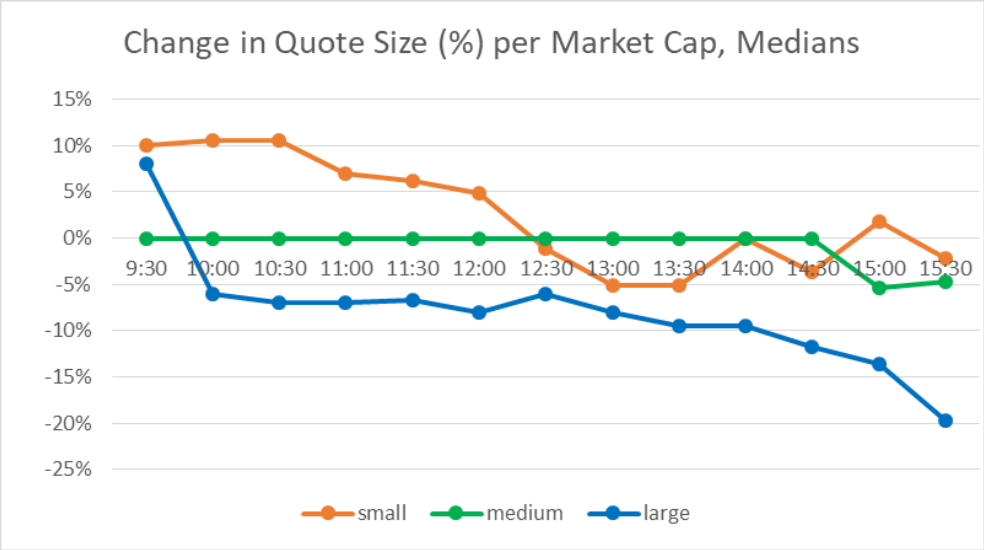


Chart 26:



- As one might expect, the larger the market cap, the lesser the decline in average and median quote sizes.
- For large and medium market cap securities, the gap between the averages was approximately constant across all time intervals, while for small market cap securities the gap grew throughout the trading period.
- In terms of medians, the gap was much smaller in magnitude than for averages.

Spread:

Chart 27:

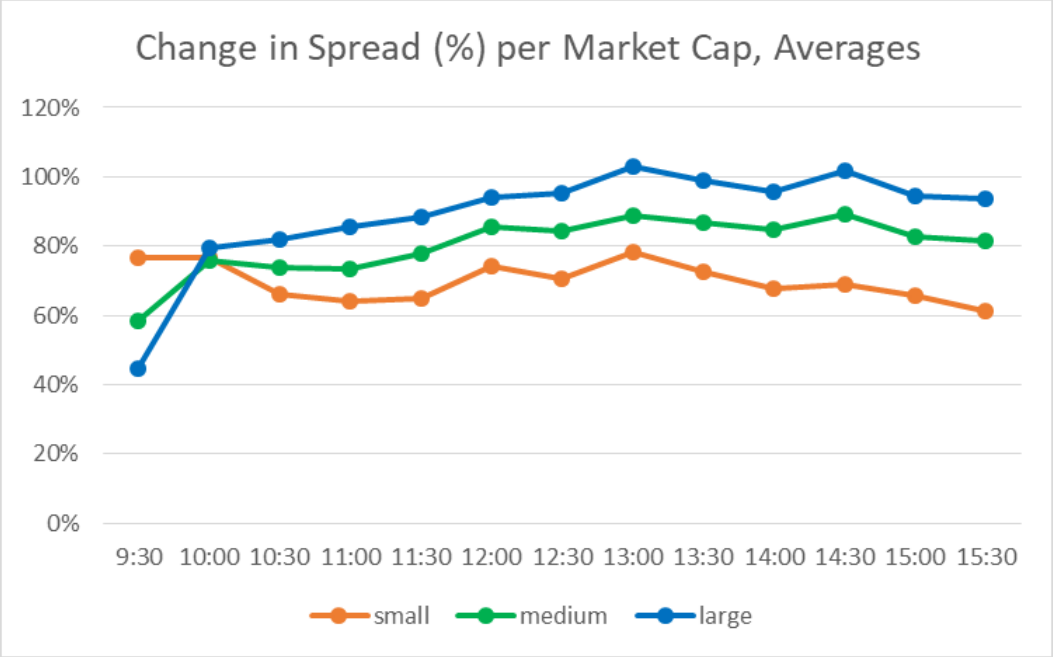
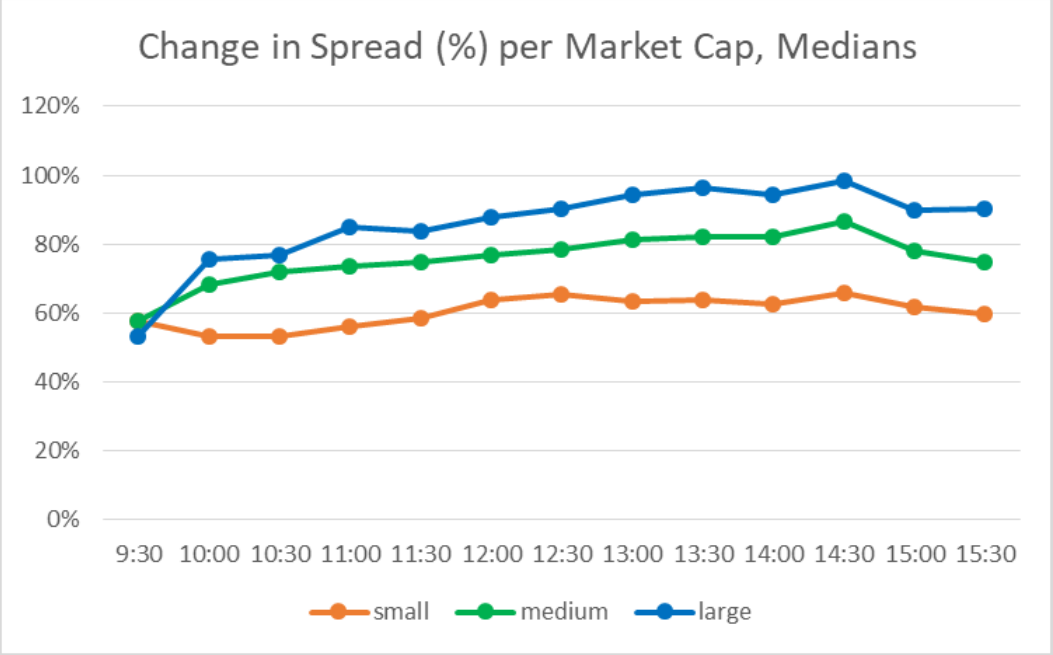


Chart 28:



- The larger the market cap, the greater the increase in average and median spreads
- The gap between average spreads grew throughout the day for medium and large market cap securities and was approximately level for small market cap.

The gap between corresponding median spreads also grew throughout the day for all market cap categories, including the small market cap. **Midrange:**

Chart 29:

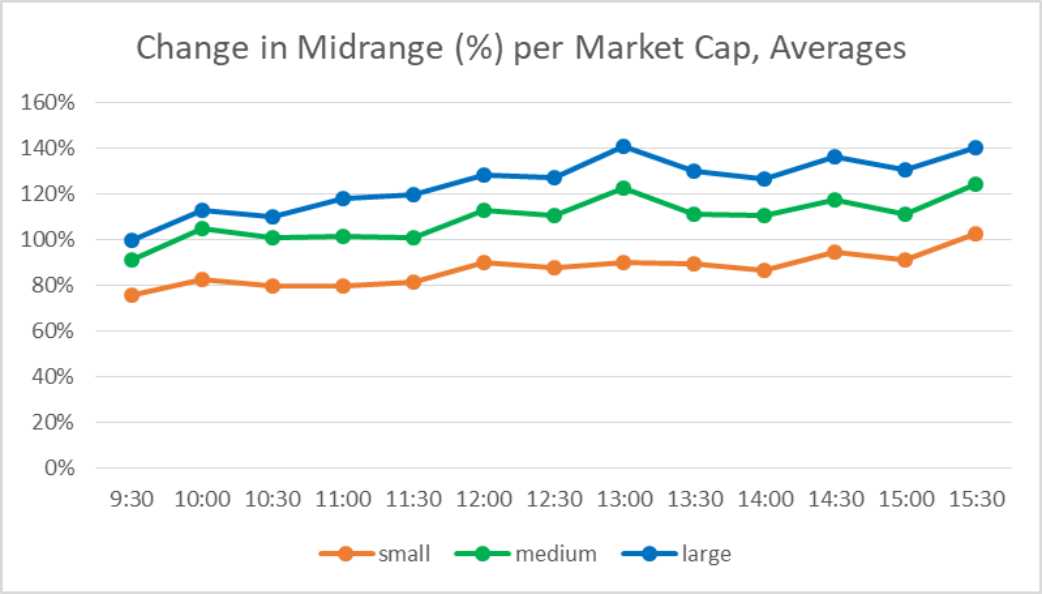
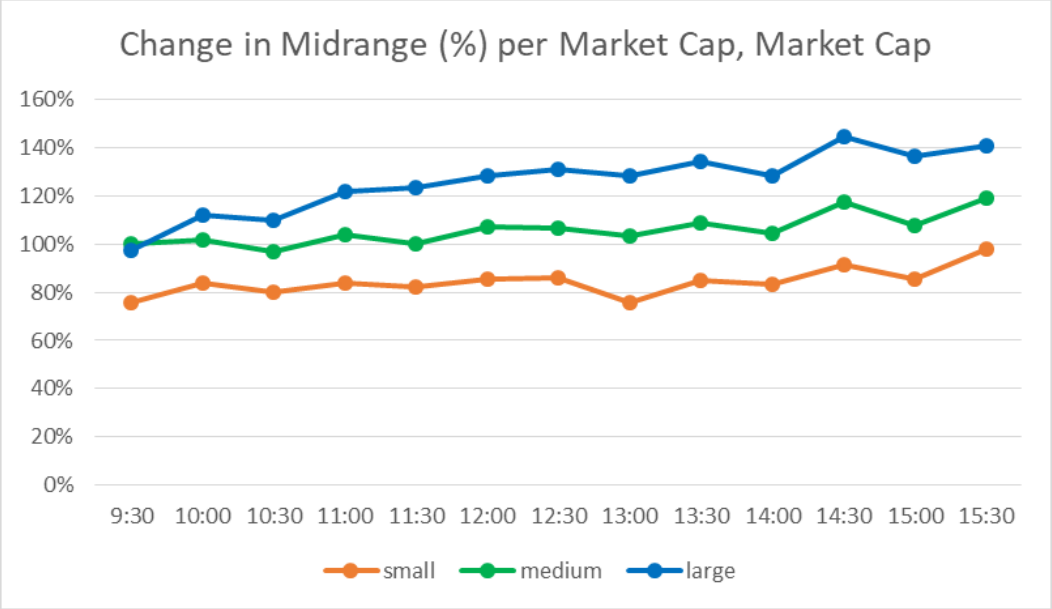


Chart 30:



- The gap between pre-meltdown and meltdown average and median midrange change statistics was wider for securities with larger market capitalization
- This gap grewin magnitude through the trading day.

Section 2: Comparison & Hypothesis Testing

In this section, we are going to do "pairwise" comparison of security characteristics for each symbol by utilizing hypothesis testing.

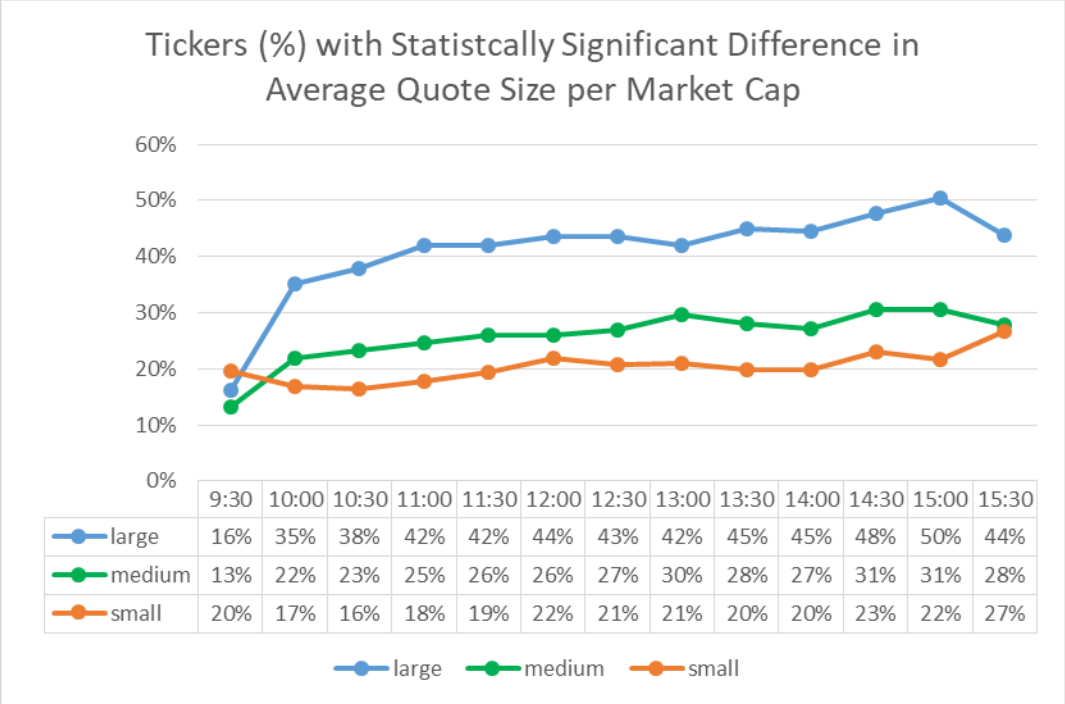
We we are looking to determine if the difference in daily volume, quote size, spread and midrange foreach symbol was statistically significant, i.e. not due to the randomness of data.

We utilize two different tests: the two-sample Student t-test and the Wicoxon nonparametric test, which is robust to outliers, and compare averages and medians of security characteristics.

The charts and tables below illustrate the percentage of securities per market capitalization category for which change in quote size, spread and midrange statistic during the meltdown period was statistically significant from the pre-meltdownperiod.

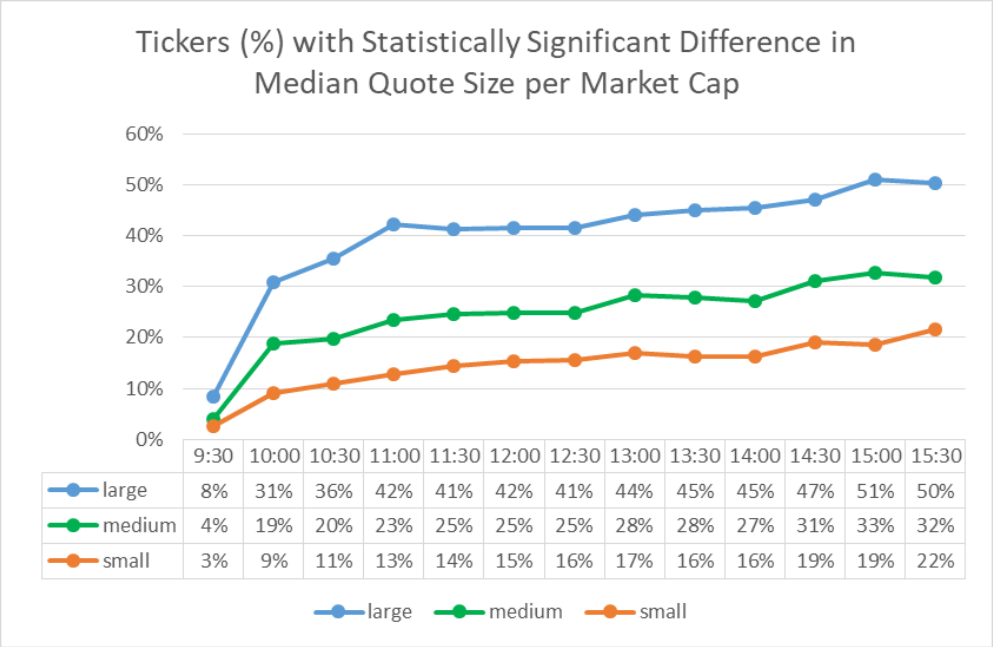
Quote Size:

Chart 31:



	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30
large	16%	35%	38%	42%	42%	44%	43%	42%	45%	45%	48%	50%	44%
medium	13%	22%	23%	25%	26%	26%	27%	30%	28%	27%	31%	31%	28%
small	20%	17%	16%	18%	19%	22%	21%	21%	20%	20%	23%	22%	27%

Chart 32:

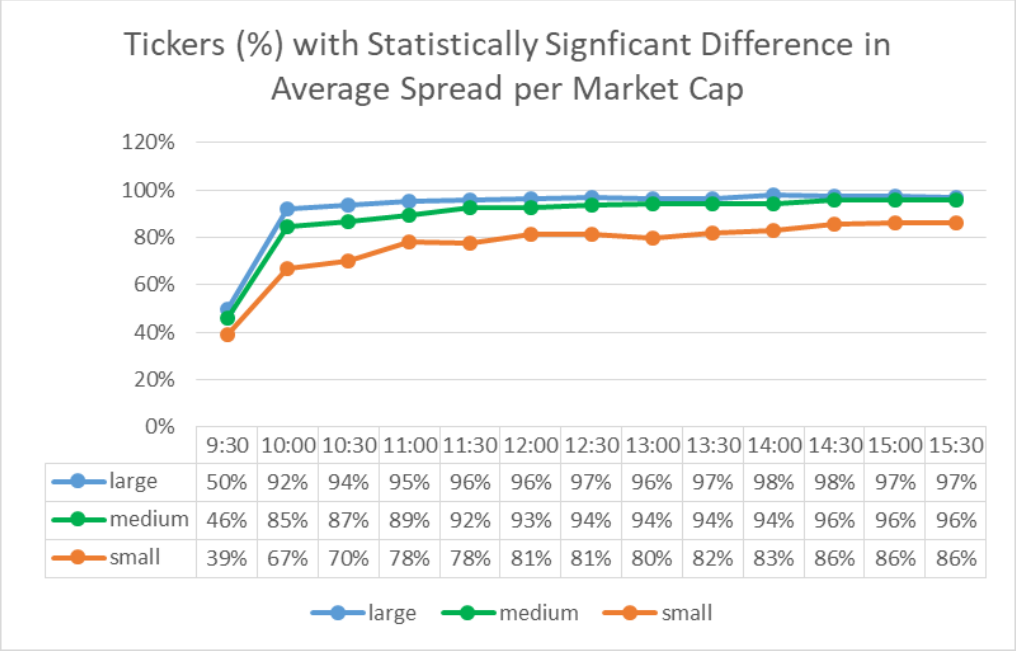


	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30
large	8%	31%	36%	42%	41%	42%	41%	44%	45%	45%	47%	51%	50%
medium	4%	19%	20%	23%	25%	25%	25%	28%	28%	27%	31%	33%	32%
small	3%	9%	11%	13%	14%	15%	16%	17%	16%	16%	19%	19%	22%

- The number of securities for which the average quote size was signifcantly lower during the meltdown period than for pre- meltdown level is increasing throughout the day.
- The increase in the number of such securities through-out the day is quite steep: from around 15% in the morning up to 45% in the evening for large market cap securities.
- The larger the market cap, the steeper the increase.

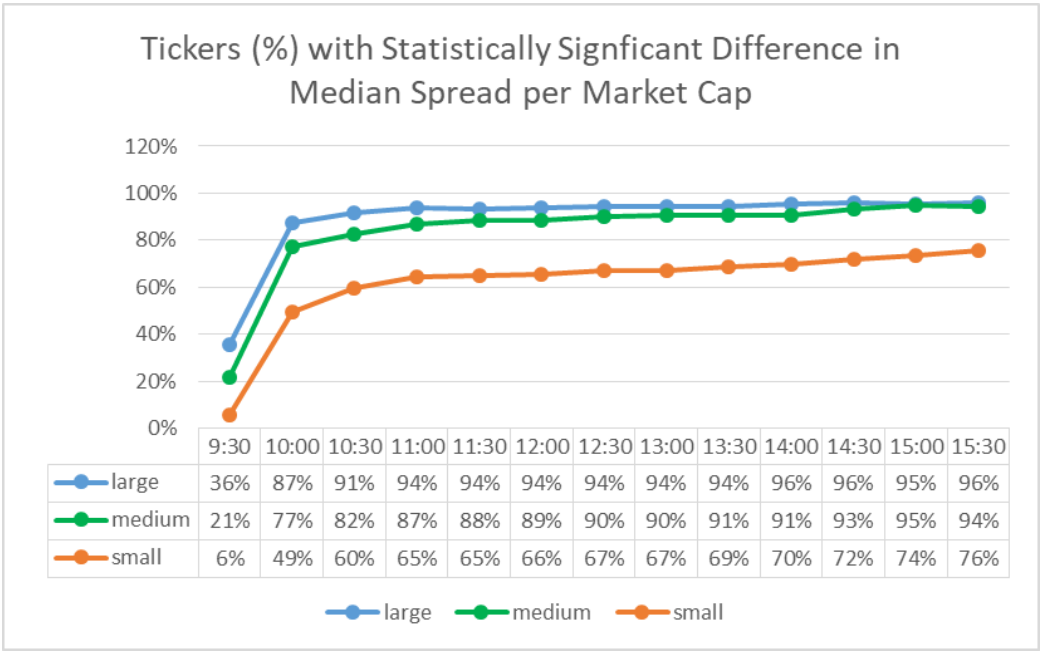
Spread:

Chart 33:



	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30
large	50%	92%	94%	95%	96%	96%	97%	96%	97%	98%	98%	97%	97%
medium	46%	85%	87%	89%	92%	93%	94%	94%	94%	94%	96%	96%	96%
small	39%	67%	70%	78%	78%	81%	81%	80%	82%	83%	86%	86%	86%

Chart 34:



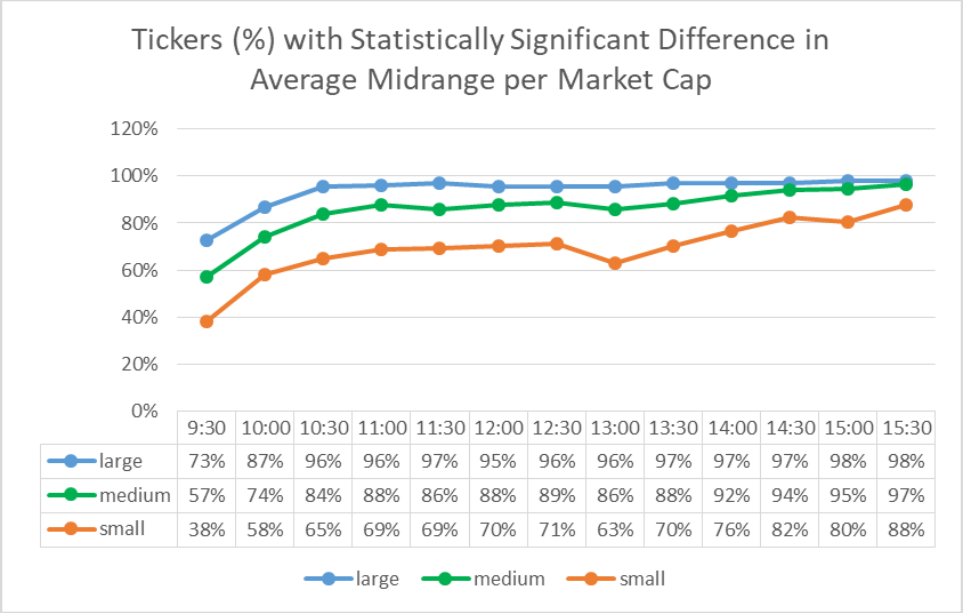
	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30
large	36%	87%	91%	94%	94%	94%	94%	94%	94%	96%	96%	95%	96%
medium	21%	77%	82%	87%	88%	89%	90%	90%	91%	91%	93%	95%	94%
small	6%	49%	60%	65%	65%	66%	67%	67%	69%	70%	72%	74%	76%

- The number of securities for which average and median spread was considerably wider during the meltdown period is increasing throughout the day
- The increase in the number of such securities is quite steep: from around 50% in the morning up to almost 100% right before the close for large market cap securities

- The rate of increase is approximately the same for medium and large cap categories and slightly lesser for small caps.
- The portion of such securities is higher, the higher the market cap category.

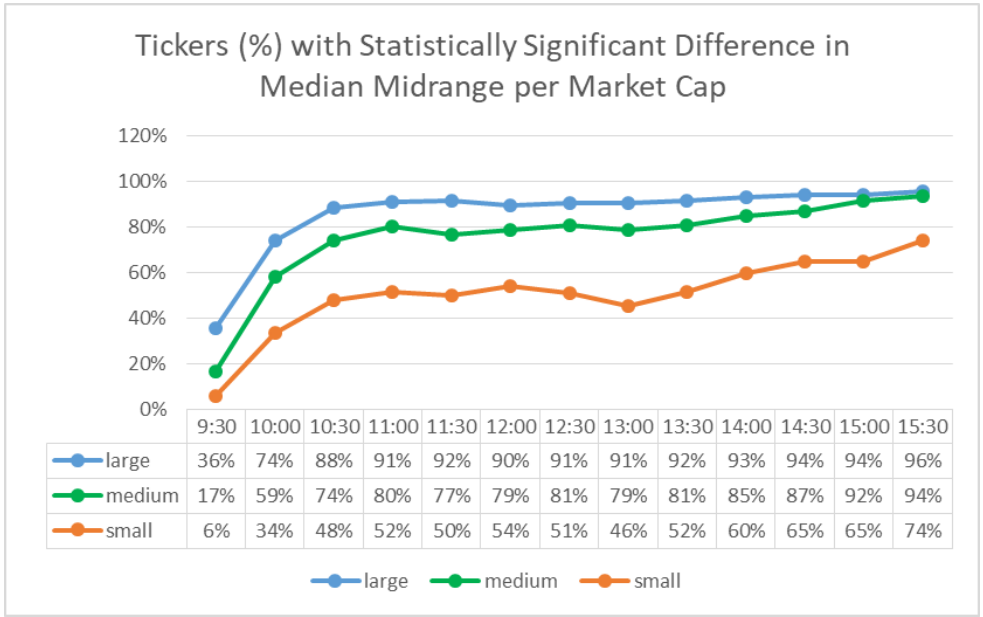
Midrange:

Chart 35:



	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30
large	73%	87%	96%	96%	97%	95%	96%	96%	97%	97%	97%	98%	98%
medium	57%	74%	84%	88%	86%	88%	89%	86%	88%	92%	94%	95%	97%
small	38%	58%	65%	69%	69%	70%	71%	63%	70%	76%	82%	80%	88%

Chart 36:



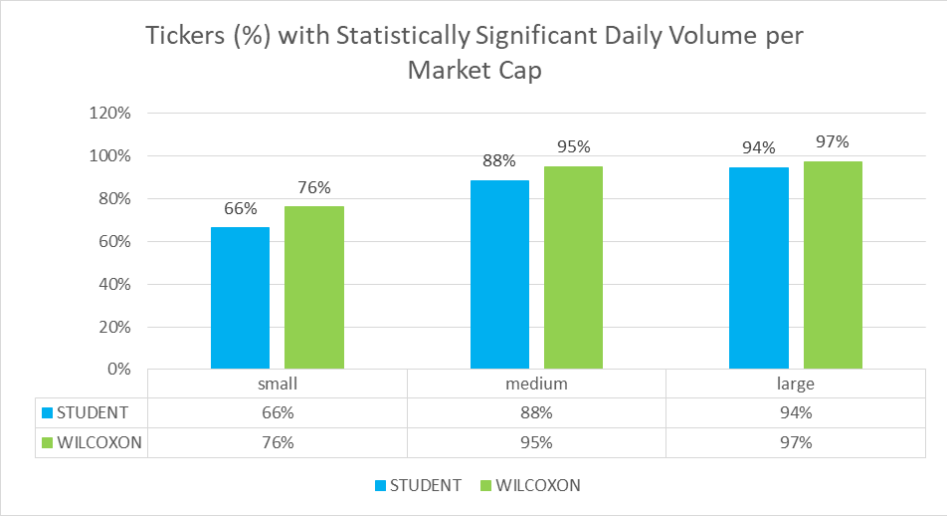
	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30
large	36%	74%	88%	91%	92%	90%	91%	91%	92%	93%	94%	94%	96%
medium	17%	59%	74%	80%	77%	79%	81%	79%	81%	85%	87%	92%	94%
small	6%	34%	48%	52%	50%	54%	51%	46%	52%	60%	65%	65%	74%

- The number of securities for which the average and median midrange statistic was considerably higher during the meltdown period increased throughout the trading day.

- The increase in number of such securities over the day is quite pronounced: from around 20-40% in the morning up to almost 100% before the close for medians
- The rate of increase for medians is approximately the same for medium and large market cap categories and a bit lesser for the small caps.
- The portion of such securities is higher, the higher the market cap.

Daily Volume:

Chart 37:



- The portion of securities for which daily volume was higher with statistical significance during the meltdown period than for the pre-meltdown increases with market cap. It from 66 % - 76% for small cap up to 95% for large caps.

Section 3. Composite Index: Sweep Cost & Available Liquidity at Far-Touch

Finally,we calculated theexpected cost to sweep at cross market far-touch NBBO during the pre-meltdown and actual meltdown time periods. We ran these models with notional value to be transacted: $1 million for large cap category, $250,000 for medium cap and $100,000 for small cap. The liqudity available on far-touch will not always be enough to fullfill such orders, thus we will also provide fill percentage (%) along with cost in basis points per share (bps).

Chart 38:

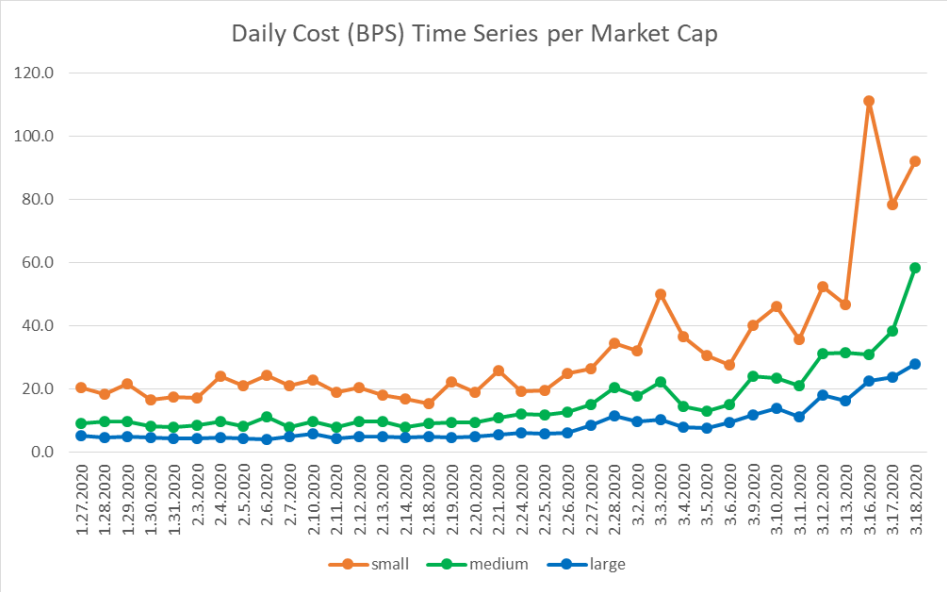
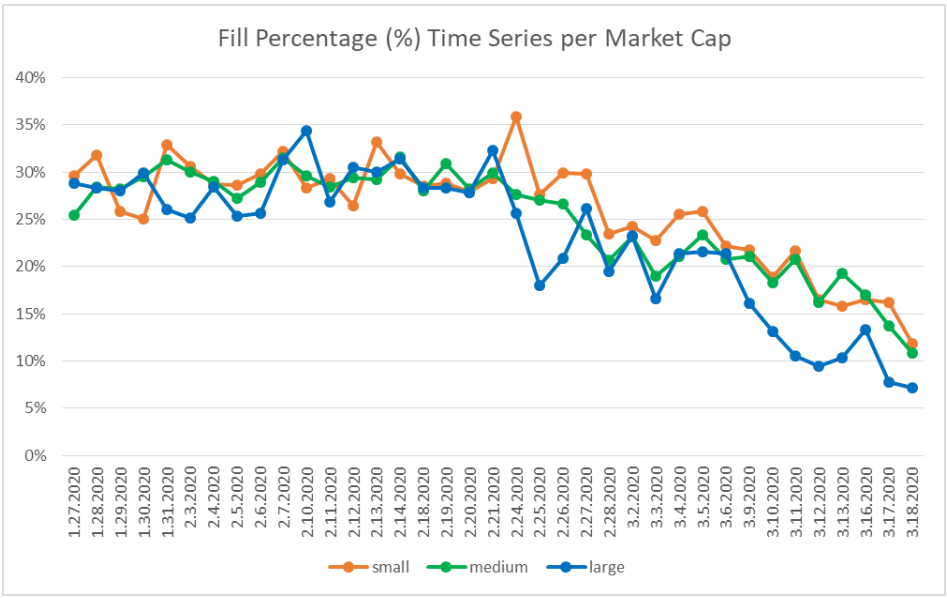


Chart 39:



- Unsurpisingly, the cost of crossing spread increased and fill percentages decreased with respect to the pre-meltdown period

The following charts summarize obtained time series via descriptive statistics: means and medians of cost and fill pre- and during the meltdown period:

Chart 40:

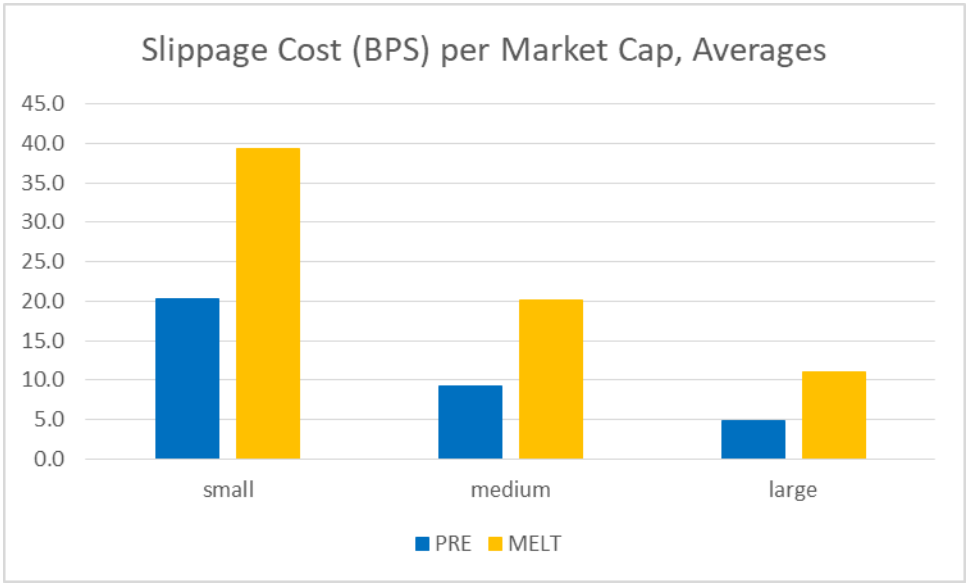
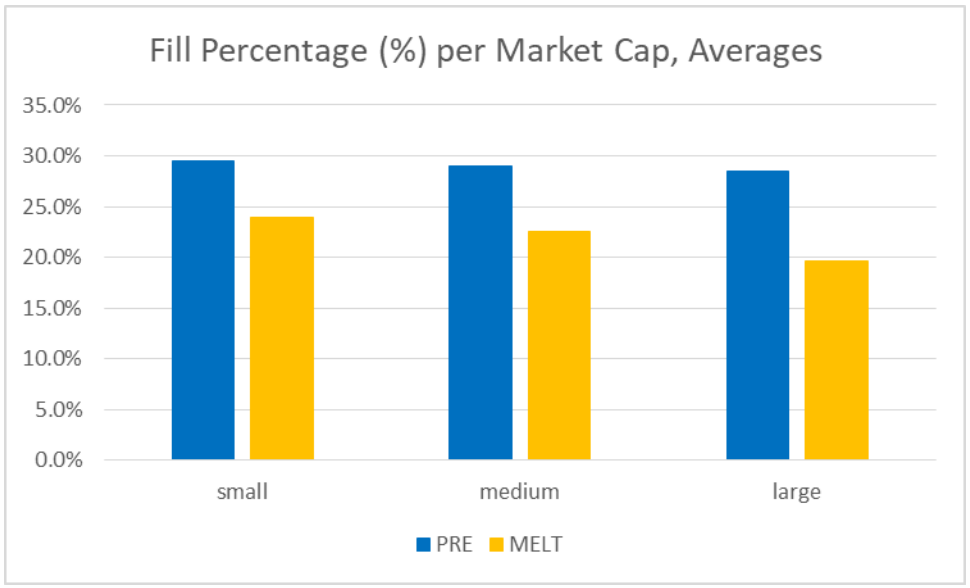


Chart 41:



- The expected increase in slippage cost from crossing the spread was lesser for small cap securities (about 95%), while for medium and large caps, the increase was nearly 120% and 133% respectively.
- At the same time, fill percentage decreased, with relative drop being proportional to market cap category: a decline of nearly 20% for small cap and 40% for large cap.