Designated Market Makers Still Matter: Evidence from Two Natural Experiments

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Abstract

Independent technological glitches forced two separate trading halts on different exchanges during the week of July 6, 2015. During each halt, all other exchanges remained open. We exploit exogenous variation provided by this unprecedented coincidence, in conjunction with a novel proprietary dataset, to identify the causal impact of Designated Market Maker (DMM) participation on liquidity. Whereas removing the voluntary liquidity providers on one exchange has negligible effects, removing DMMs substantially reduces liquidity market-wide. Contrary to conventional wisdom, we find that DMMs—liquidity providers with formal obligations—significantly improve liquidity in the modern electronic marketplace. Seemingly tiny obligations elicit enormous effects.

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1 Introduction

In decades past, designated market makers (DMMs) were central fixtures of the trading landscape. However, since the advent of Reg. NMS and electronic trading, voluntary "de facto" market makers have supplanted DMMs as the primary providers of liquidity. In contrast to DMMs, voluntary liquidity providers have no formal obligations to maintain fair and orderly markets in their stocks. Nevertheless, modern electronic markets rely almost entirely on voluntary liquidity provision, and the markets generally seem to function well. The 2010 Flash Crash rekindled interest in market-maker obligations at times of extreme market turmoil, but otherwise, DMMs are widely dismissed as irrelevant relics—their obligations seemingly too small to differentiate them from voluntary liquidity providers. We find strong evidence to refute this dismissive view. DMMs, as distinguished from voluntary liquidity providers, continue to exert an economically significant influence on modern markets.

To identify the causal impact of DMMs' presence in the market, we begin by exploiting a natural experiment that arose on July 8, 2015, when a computer glitch forced the New York Stock Exchange (NYSE) to halt trading from 11:32 AM to 3:10 PM. This unexpected, exogenous event provides a unique opportunity to examine the impact of DMMs on market quality. The NYSE is the only major exchange that still has DMMs (formerly called the "specialists"), so the trading halt exogenously removed all DMMs from the market.[1] Moreover, non-NYSE-listed stocks do not trade on the NYSE, so they were not directly affected by the exchange's trading halt—even if the NYSE had remained open, these stocks would not have been traded there. For the first stage of our analysis, NYSE-listed stocks serve as our treatment group, and non-NYSE-listed stocks serve as our control group. A difference-in-differences test reveals that the liquidity of NYSE-listed stocks fell dramatically relative to that of non-NYSE-listed stocks after the trading halt began. Compared to the control group, the average NBBO (national best bid and offer) proportional quoted

[1] NYSE MKT, the former American Stock Exchange, also has DMMs, but its market share is less than 1% in our sample, and it, too, closed during the NYSE shutdown.

spreads for the NYSE-listed stocks widened by a factor of 1.22 during the halt, and the proportional effective spreads widened by a factor of 1.17 during the halt! Almost immediately after trading resumed on the NYSE, spreads for the NYSE-listed stocks narrowed to their pre-halt values.

On July 6, 2015, two days before the NYSE event, the Direct Edge X platform (EDGX) experienced an unrelated technological difficulty that forced the exchange to halt trading for part of the day. Both the control-group stocks and the treatment-group stocks trade on EDGX, so we can directly observe the impact of a trading-venue shutdown that affects both groups of stocks simultaneously. We find that this impact for stocks in both groups is negligible and insignificant, as is the difference in impact between the two groups.

The basis on which stocks were assigned to the control vs. treatment groups was not random, so we can't dismiss, *ex-ante*, the possibility that the non-NYSE-listed stocks in our control group might differ systematically from the NYSE-listed stocks in our treatment group. In particular, the fundamental concern is that our treatment stocks might be more sensitive to an arbitrary "shutdown shock" than are the control stocks. However, the EDGX results alleviate this concern.

The reduction of liquidity observed during the NYSE shutdown therefore presents a puzzle. The trading-halt closed down only one exchange out of eleven. Liquidity providers and demanders in equities markets are not directly affected by a technology glitch at a single exchange, and they are still able to submit orders to ten other exchanges and off-exchange trading venues. As we witness during the EDGX shutdown, removing a trading venue without DMMs has essentially no effect. So why would the NYSE shutdown have any meaningful effects? Mechanical explanations based on stock heterogeneity or intraday seasonality can be readily ruled out by placebo tests using adjacent days' data. We're lead to the inevitable conclusion that the NYSE is not redundant—it has some important distinguishing feature. Moreover, whatever the NYSE's magical potion may be, our results indicate that it *causes* a significant increase in liquidity.

The presence of DMMs is unambiguously one of the NYSE's distinctive features, but

attributing the liquidity effects to DMMs (or rather, to DMMs' absence) requires an additional step of analysis. To explicitly test whether our results reflect effects attributable to the presence/absence of DMMs, we analyze a novel proprietary dataset provided by the NYSE that documents the participation rate of DMMs in each NYSE-listed stock. This dataset enables us to isolate the trading on the NYSE where DMMs, as opposed to non-DMMs, provided liquidity. For each stock, we compute the average fraction of total trading volume, across all exchanges and off-exchange trading venues, that executes on the NYSE on days prior to July 8, 2015. We then decompose this NYSE market-share into a DMM component and a non-DMM component.

We find that higher DMM participation before the NYSE trading halt predicts larger increases in quoted and effective spread during the halt, but that the non-DMM participation rate has no such predictive power. In other words, the NYSE market-share doesn't explain any additional cross-sectional variation beyond what is explained by the DMM-participation-rate alone. These findings suggest that our liquidity results are driven by DMM participation, and not some other NYSE-specific mechanism.

In sum, our results demonstrate that the presence of DMMs in the market causes liquidity to increase—markedly. Thirty years ago, when DMMs were sometimes the sole providers of liquidity, this would have been a completely inane finding. However, there are many other liquidity providers in the market now. Our finding is not the simple truism that liquidity providers improve liquidity, but rather that assigning formal obligations to those providers improves liquidity. Qualitatively, the latter statement is no more surprising than the former. Quantitatively, though, the impact of formal market-making obligations is remarkable; seemingly minuscule obligations elicit enormous effects, even outside of the extreme episodes when those obligations would obviously be binding.

Our findings in this paper shed light on some ongoing debates in the microstructure literature on DMMs. In a recent theoretical analysis, Bessembinder, Hao, and Zheng (2015) demonstrate that competitive market liquidity provision can be suboptimal when fundamental uncertainty and information asymmetry are large. They propose that DMMs with

the obligation to enhance liquidity could prevent market failure and increase social welfare. Anand and Venkataraman (2015) find that Endogenous Liquidity Providers (ELPs) enter and exit the stock markets in a correlated manner. ELPs actively participate in liquidity provision when market conditions are favorable, but scale back their participation in unison when market conditions go bad; at such times, DMMs help to mitigate the illiquidity created by ELPs' synchronized withdrawal from the market. However, the literature has not reached a conclusion on whether DMMs improve liquidity. Sabourin (2006) finds that whether DMMs improve liquidity depends on the asset volatility and the differences in valuation among traders. In particular, Sabourin argues that DMMs may degrade liquidity for large stocks.

Our study contributes to the literature by examining the exogenous loss of DMMs, thereby avoiding the pervasive problem of self-selection bias. The extant empirical literature on DMMs focuses on the introduction of the voluntary DMM contracts in Sweden (Anand, Tanggaard, and Weaver 2009), France (Venkataraman and Waisburd 2007), the Netherlands (Menkveld and Wang 2013) and Italy (Nimalendran and Petrella 2003; Perroti and Rindi 2010). Menkveld and Wang (2013), however, point out the self-selection bias across DMM and non-DMM stocks that unavoidably becomes a pivotal element of such studies; Skjeltorp and Odegaard (2015) find that firms that sign the DMM contract differ substantially from firms that do not.

Our results also connect and contribute to the literature on high-frequency trading. In particular, our paper indicates the relevance of preserving market-making obligations in a world of fast trading. The large majority of the six DMMs in our sample—Barclays, Brendan E. Cryan & Co., IMC Financial Markets, J Streicher & Co. LLC, KCG, and Virtu Financial Capital Markets LLC—meet the definition of "high-frequency trader" (HFT) set forth in the U.S. Securities and Exchanges Commission's 2010 Concept Release. The NYSE also has HFTs with minimal or no market-making obligations.[2] We find that the

[2]Each security has only one NYSE DMM, but can have multiple Supplemental Liquidity Providers (SLPs), who have no formal obligations to provide liquidity. Other traders can also provide liquidity by placing limit orders.

loss of voluntary HFT liquidity-providers in the NYSE does not harm liquidity, whereas the loss of DMMs causes spreads to widen substantially and very much *does* harm liquidity. Our empirical results complement the theory work of Bessembinder, Hao, and Lemmon (2011), who identify underlying economic mechanisms that explain how and why DMMs' maintenance of narrow spreads can improve market efficiency and social welfare.

The remainder of this paper is organized as follows: Section 2 describes the institutional details, data, and our methodology for addressing intraday-seasonality effects. Section 3 presents difference-in-differences analyses, placebo tests from the days before and the day after the NYSE glitch, and compares effects of the NYSE shutdown to those of the EDGX shutdown. Section 4 uses the proprietary dataset to examine the cross-sectional relationship between pre-halt DMM participation rates and changes in liquidity during the halt. Section 5 exploits the exogenous variation provided by the NYSE halt, in conjunction with the proprietary dataset, to analyze cross-sectional patterns in the participation and impact of DMMs. Section 6 discusses the issue of *why* DMMs improve liquidity to the extent that they do. Section 7 concludes.

2 Data and Institutional Details

2.1 Institutional Details

According to the NYSE, designated market-makers are the cornerstone of the exchange's market model. DMMs are the successors of the so-called "specialists" on the NYSE. Each stock has one DMM, whom the issuer selects. Like the specialists, DMMs have affirmative obligations to maintain a fair and orderly market in their stocks, quote at the NBBO a specified percentage of the time, and facilitate price discovery throughout the day as well as at the open, close, and in periods of significant imbalances and high volatility.

However, DMMs do not face the negative obligations that the specialists once did. NYSE removed the "public order precedence rule," and thereby allowed DMMs to compete for order-priority on parity with floor traders and electronic limit order books. In 2008,

the NYSE also exempted DMMs from the "public liquidity preservation principle," which had discouraged specialists from taking liquidity from the public limit order book.

DMMs also receive privileges, as the specialists did, but those privileges are now quite modest. In Section 6 we discuss DMMs' privileges and their (ir)relevance to our results; Appendix A provides a detailed discussion of DMMs' privileges.

2.2 Data and Sample

Our data are drawn from TAQ, CRSP, I/B/E/S, and a set of proprietary data on DMM participation provided to us by the NYSE. We postpone detailed description of the proprietary dataset until Section 4, when it enters our analysis. Our preliminary sample of stocks consists of all common stocks that are present in the Daily TAQ master file for both July 6, 2015 and July 8, 2015, and that are listed in the CRSP database on December 31, 2014. We then restrict attention to only those stocks whose monthly share volume for December 2014 exceeded 10,000 shares, and whose closing price on December 31, 2014 exceeded \$5.00.

We divide this sample of stocks into a treatment group and a control group, based on the data field "TradedOnNYSE" in the DTAQ Master File Data for July 8, 2015. The treatment group consists of sample stocks that are traded on the NYSE ($TradedOnNYSE = 1$), and the control group consists of stocks that are not traded on the NYSE ($TradedOnNYSE = 0$). We check listing-exchanges and prior historical data to verify that the control-group stocks never trade on the NYSE, but that the treatment-group stocks do. We obtain 980 treated stocks, and 922 control stocks. Table 1 presents the summary statistics for the two groups of stocks.

We use TAQ data to construct the national best bid and offer (NBBO) prices, and we calculate liquidity measures following Holden and Jacobsen (2014).[3] The *quoted spread* is

[3]DTAQ provides two files that contain official NBBO quotes. If a single exchange has both best bid and offer, then the official NBBO quotes will be recorded in the DTAQ Quotes File. Otherwise, the NBBO quotes will be recorded in the DTAQ NBBO file. We combine the NBBO quotes from both files to construct the complete official NBBO. We exclude quotes with abnormal quote conditions (A, B, H, O, R, and W). We delete quote whose bid is greater than or equal to ask. We also delete cases in which the

Table 1: Summary Statistics for Treated and Control Stocks

Table 1 presents summary statistics for the stocks in our sample. The "treated" group consists of 980 stocks that are traded on the NYSE. The "control" group consists of 922 stocks that do not trade on the NYSE.

	Treated		**Control**	
	Mean	*Std. Dev.*	*Mean*	*Std. Dev.*
Quoted Spread (cent)	5.24	7.46	7.87	11.83
Proportional Quoted Spread (bps)	17.80	19.67	20.97	20.64
Effective Spread (cent)	3.62	5.13	5.84	13.53
Proportional Effective Spread (bps)	12.76	13.96	18.41	59.70
Dollar Depth (thousand)	22.80	42.61	23.86	39.31
Daily Dollar Volume (million)	23.31	51.55	26.68	91.43
Price (dollars)	32.51	22.61	34.67	26.11
Market Capitalization (billion)	2.77	8.47	2.87	9.88

the difference between the best bid and best ask prices. The *effective spread* measures the cost of trading against the actual supply of liquidity; the effective spread is defined for a buy as twice the difference between the trade price and the midpoint of the NBBO price, and for a sell as twice the difference between the midpoints of the NBBO and the trade price. A proportional spread (quoted, effective) is the spread divided by the midpoint of the best bid and best ask prices. Measures of quoted spread and proportional quoted spread are weighted by the time, while measures of effective spread and proportional effective spread are weighted by trade-size. We measure depth as the time-weighted average of displayed depth at the NBBO, and we measure volume based on the consolidated volume in all U.S. stock exchanges and off-exchange trading venues.

2.3 Intraday Seasonality Correction and Normalizations

McInish and Wood (1992) find that liquidity has a reverse J-shaped intraday pattern: spreads are much higher at the beginning of the day relative to mid-day, and moderately higher at the end of the day relative to mid-day. Since the NYSE trading halt occurred

quoted spread is greater than $5.00.

in the middle of the trading day, time-of-day artifacts contaminate direct comparisons of liquidity during the halt to liquidity before and/or after the halt. We adjust intraday seasonality using multiplicative seasonal adjustment, following Harvey (1993). This method divides each value of the time series by a seasonal index that represents the long-run average value typically observed in each season. In our application, we split the trading day into 10-minute intervals—39 intervals in total—and compute the liquidity measures during each interval. To adjust for intraday seasonality, we calculate the monthly average of the indicated measure for each stock during each of the 39 time intervals, then divide the values measured on the day of interest by the corresponding interval-stock monthly averages. The averages are taken over all trading days in July 2015, except for the two event dates (July 6 and 8). We refer to the resulting adjusted measures as the "normalized" measures.

Figure 1 provides a concrete illustration of how this intraday-seasonality adjustment normalizes the data, here in the case of proportional effective spreads on the day of the NYSE shutdown, July 8. For a given 10-minute interval, the vertical axis represents the ratio of the spread in that interval on July 8 to the average spread in that interval during the rest of of the month. The dark dashed line with triangular markers reflects the cross-sectional average among the 980 treatment stocks, while the light solid line with circular markers reflects the cross-sectional average among the 922 control stocks. So, for example, during the interval 12:00:00 PM - 12:09:59 PM on July 8th, effective spreads on the control stocks were roughly 10% above their (respective) typical levels, while effective spreads on the treatment stocks were roughly 35% above their (respective) typical levels.

To a first approximation, for both quoted spreads and effective spreads, the normalized spread and the normalized *proportional* spread will be equal. Algebraically, the division by the midpoint price approximately washes out in the normalization, provided that the price doesn't vary too wildly over the course of the month. The same remarks apply to dollar-depth versus depth. For brevity, we omit results on non-proportional spreads, but the results are nearly identical to those reported for the proportional spreads.

Figure 1: Normalized Proportional Effective Spreads on July 8th (NYSE Halt)

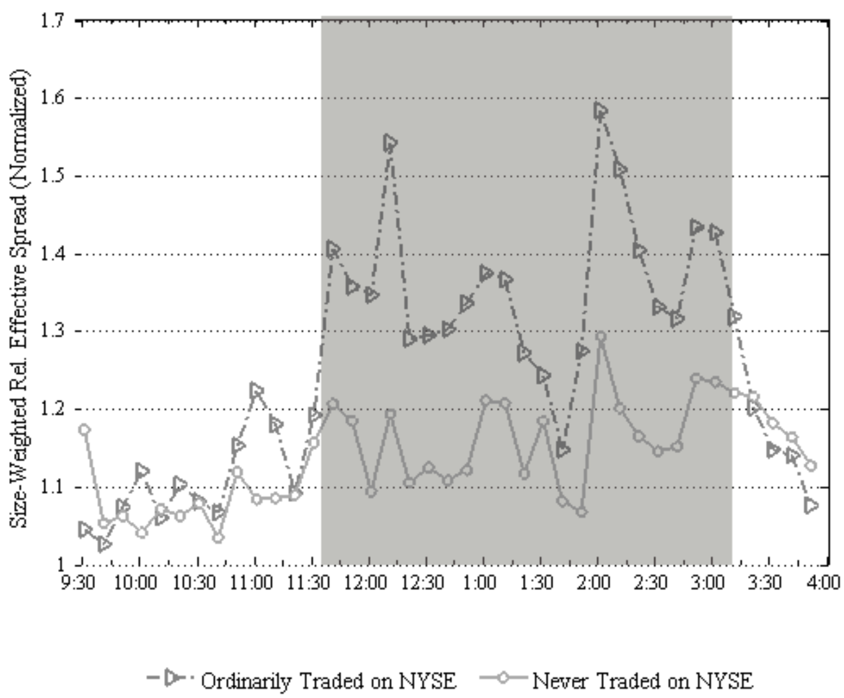


Figure 1 depicts the time-series of normalized proportional effective spreads during July 8, 2015. The gray shaded region indicates the period during which the NYSE was shut down on July 8. The dark dashed line represents the sequence of cross-sectional averages for the treatment group (stocks ordinarily traded on the NYSE), while the lighter solid line represents the sequence of cross-sectional averages for the control group (stocks never traded on the NYSE). The horizontal axis represents time, and the vertical axis represents the ratio of the spread on July 8 to the average spread at the same time of day on the other trading days in July 2015.

3 Difference-in-Differences Tests

As an initial analysis, we perform a difference-in-differences test around the NYSE trading halt. We compute the measures of liquidity for each stock on July 8, 2015 before the NYSE trading halt, during the halt, and after the halt, and then calculate the inter-period differences. For each of these inter-period differences, we compare the average among the treatment stocks to the corresponding average among the control stocks. This basic diff-in-diff procedure sets up the framework for our subsequent refinements and elaborations. Subsection 3.1 presents and discusses the primary diff-in-diff results. Subsection 3.2 considers the limitations of the control group as a fully suitable "control," and presents placebo-test results as a partial remedy. Subsection 3.3 uses the shutdown of EDGX on July 6th to directly address remaining concerns about systematic differences between the treatment-group stocks and the control-group stocks that might produce spurious diff-in-diffs results.

3.1 Diff-in-Diffs Tests Using the NYSE Halt

For each stock, we calculate the average normalized measures of liquidity in the periods before the NYSE trading halt (9:30:00 AM - 11:29:59 AM), during the halt (11:30:00 AM - 3:09:59 PM), after the halt (3:10:00 PM - 4:00:00 PM), and not during the halt (combining "before" with "after"). We then compute, on a stock-by-stock basis, the difference in liquidity across different time-periods: "during" minus "before," "during" minus "after," and "during" minus "not during." We average each inter-period difference across the 980 treatment stocks, and across the 922 control stocks, then we compare the treatment average to the control average.

To assess statistical significance, we construct bootstrap distributions using data from the entire month of July 2015, excluding July 6 and July 8. For each draw in the bootstrap distributions, a sample of 980 treatment stocks is selected randomly (with replacement), and a sample of 922 control stocks is selected randomly (with replacement); one trading

day is randomly selected (with replacement) as the source of data for the "during halt" period, and a second trading day is randomly selected as the source of data for the other period (i.e., "before," "after," or "not during"). We use four million draws to construct each bootstrap distribution. In cases where an observed value lies outside the maximum and minimum of the bootstrap distribution, we use the bootstrap distribution to extrapolate a t-statistic, then use that extrapolated t-statistic to compute the p-value. Otherwise, we obtain p-values directly from the bootstrap distribution, and back-out the corresponding t-statistics.

3.1.1 Spreads

The diff-in-diffs analysis reveals that the NYSE shutdown led to a large, significant increase in the treatment stocks' spreads, relative to the controls'. Table 2 reports the main results. For the treatment-group stocks, normalized proportional quoted spreads were approximately 29% higher during the NYSE shutdown than they were before the shutdown. By comparison, normalized proportional quoted spreads for the control-group stocks were approximately 7% higher during the NYSE shutdown than they were before the shutdown. These results indicate that the NYSE halt caused the proportional quoted spread for a typical treated stock to increase by nearly 22% relative to its baseline. Unsurprisingly, the statistical significance this massive increase is overwhelming.

Proportional effective spreads displayed a pattern very similar to that of proportional quoted spreads. The diff-in-diffs results show that the NYSE halt caused the proportional effective spread for a typical treated stock to increase by roughly 17% relative to its baseline. Although the difference-in-differences for proportional effective spreads is slightly smaller than that for proportional quoted spreads, the increase is still extremely significant, both statistically and economically.

Table 2: Normalized Spreads—Differences and Diffs-in-Diffs on July 8th (NYSE Halt)

Table 2 summarizes the results for normalized proportional quoted spreads and normalized proportional effective spreads on the day of the NYSE trading halt, July 8. For each stock, we calculate the average normalized measures of spreads in the period before the NYSE trading halt (9:30:00 AM - 11:29:59 AM), during the halt (11:30:00 AM - 3:09:59 PM), and after the halt (3:10:00 PM - 4:00:00 PM). The "not during" period combines the "before" and "after" periods. The first column of the table report the averages among the treatment stocks of the difference in liquidity across the indicated time-periods; the second column reports the analogous average among the control stocks. The third column reports the difference in these averages between the treatment group and the control group. The fourth and fifth columns report the t-statistic and p-value associated with the null hypothesis that this diff-in-diffs equals zero. The t-statistics and p-values are based on bootstrap distributions generated using data from the month of July 2015, excluding July 6 and July 8.
Quoted spreads are computed as time-weighted averages, while effective spreads are computed as trade-size-weighted averages. To adjust for intraday seasonality, we calculate the monthly average of the indicated measure for each stock during each of the 39 ten-minute time intervals, then divide the values measured on July 8th by the corresponding interval-stock monthly averages.

	Difference Across Periods		**Treatment Difference minus Control Difference**		
	Treatment	Control	Diff-in-Diffs	t-Stat	p-Value
Proportional Quoted Spread					
During minus Not	0.256	0.037	0.219	10.87	<1E-10
During minus Before	0.287	0.070	0.217	9.64	<1E-10
During minus After	0.181	-0.042	0.223	11.79	<1E-10
Proportional Effective Spread					
During minus Not	0.228	0.054	0.175	8.33	<1E-10
During minus Before	0.250	0.084	0.166	6.74	<1E-10
During minus After	0.177	-0.018	0.195	9.07	<1E-10

3.1.2 Depth

In contrast to spreads, depth does not change in any discernible way for the treatment-group stocks during the NYSE shutdown. Table 3 reports full results from our diff-in-diffs analysis of depth and dollar depth, but the concise summary is that we find no significant effects. This is not entirely surprising. Because quoted spreads widened (for the treatment-group stocks) during the NYSE shutdown, comparing depth at the NBBO during the shutdown to depth at the NBBO before or after the shutdown is not an apples-to-apples comparison. An increase in spread implies that depth at top of the book is currently at price levels that would have been considered inferior previously, when the spread was tighter.

3.2 Placebo Tests

To address the possibility that the results in Subsection 3.1 are driven by heterogeneity between treatment and control stocks, or by mechanical time-of-day effects that are not adequately corrected by our intraday-seasonality adjustments, we repeat the analysis from Subsection 3.1 using data from July 7, 2015 (the day before the NYSE shutdown), and from July 9, 2015 (the day after the NYSE shutdown). Figure 2 illustrates the placebo analysis in the case of proportional effective spreads. Both panels of Figure 2 are analogues of Figure 1. As in Figure 1, the gray shaded region indicates the period during which the NYSE was shut down on July 8th; however, the NYSE remained open and operational during those times on July 7th and 9th.

Table 4 reports the placebo-test results for normalized spreads. On the placebo days, the diffs-in-diffs are not significantly different from zero. In other words, the placebo-test results suggest that the bulk of the effects documented in Subsection 3.1 could not be driven by intraday seasonality, or stock heterogeneity—unless the treatment-group stocks differ systematically from the control-group stocks in their sensitivity to a generic "trading-venue shutdown" event. We address this remaining possibility in the next subsection.

Table 3: Normalized Depth—Differences and Diffs-in-Diffs on July 8th (NYSE Halt)

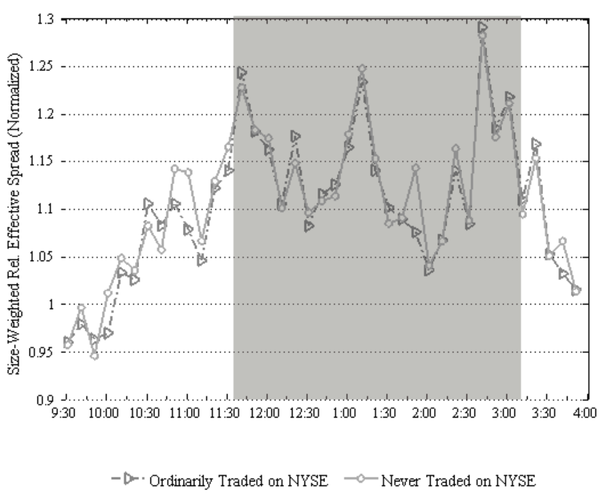
Table 3 summarizes the results for normalized depth and normalized dollar depth on the day of the NYSE trading halt, July 8. For each stock, we calculate the average normalized measures of depth in the period before the NYSE trading halt (9:30:00 AM - 11:29:59 AM), during the halt (11:30:00 AM - 3:09:59 PM), and after the halt (3:10:00 PM - 4:00:00 PM). The "not during" period combines the "before" and "after" periods. The first column of the table report the averages among the treatment stocks of the difference in liquidity across the indicated time-periods; the second column reports the analogous average among the control stocks. The third column reports the difference in these averages between the treatment group and the control group. The fourth and fifth columns report the t-statistic and p-value associated with the null hypothesis that this diff-in-diffs equals zero.

Both depth and dollar depth are computed as time-weighted averages. To adjust for intraday seasonality, we calculate the monthly average of the indicated measure for each stock during each of the 39 ten-minute time intervals, then divide the values measured on July 8th by the corresponding interval-stock monthly averages.

	Difference Across Periods		**Treatment Difference minus Control Difference**		
	Treatment	Control	Diff-in-Diffs	t-Stat	p-Value
Depth					
During minus Not	0.036	0.023	0.013	0.528	0.598
During minus Before	0.011	-0.007	0.018	0.653	0.514
During minus After	0.096	0.093	0.003	0.092	0.926
Dollar Depth					
During minus Not	0.034	0.019	0.015	0.592	0.554
During minus Before	0.007	-0.012	0.019	0.712	0.477
During minus After	0.097	0.093	0.004	0.146	0.884

Figure 2: Normalized Proportional Effective Spreads: Placebos for the NYSE Halt

Panel A: July 7th



Panel B: July 9th

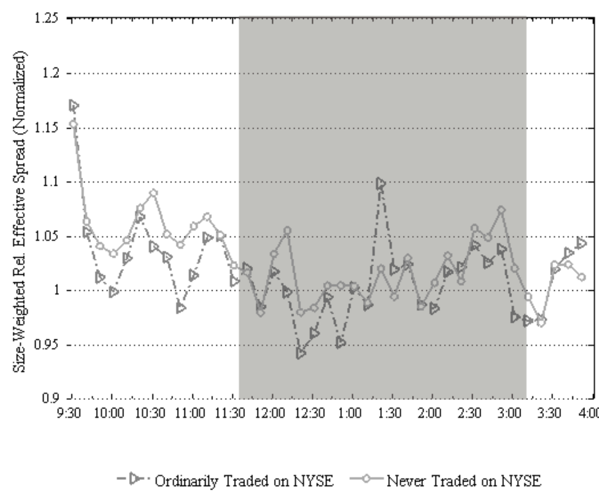


Figure 2 depicts the time-series of normalized proportional effective spreads during July 7th (Panel A) and July 9th (Panel B). The gray shaded region indicates the period during which the NYSE was shut down on July 8; the NYSE was not shut down during this period on July 7 or July 9. The dark dashed line represents the sequence of cross-sectional averages for the treatment group (stocks ordinarily traded on the NYSE), while the lighter solid line represents the sequence of cross-sectional averages for the control group (stocks never traded on the NYSE). The horizontal axis represents time, and the vertical axis represents the ratio of the spread on July 7 (July 9) to the average spread at the same time of day on the other trading days in July 2015.

Table 4: Normalized Spreads—NYSE-Halt Placebo Tests on July 7th and July 9th

Table 4 reports the placebo-test results for normalized proportional quoted spreads (Panel A) and normalized proportional effective spreads (Panel B). Using data from July 7th, and then July 9th, we repeat the analysis from Subsection 3.1: for each stock, we calculate the average normalized measures of spreads in the period before the time of NYSE trading halt on July 8th (9:30:00 AM - 11:29:59 AM), during the time of the halt on July 8th (11:30:00 AM - 3:09:59 PM), and after the time of the halt on July 8th (3:10:00 PM - 4:00:00 PM). The "not during" period combines the "before" and "after" periods. The first column of the table report the averages among the treatment stocks of the difference in liquidity across the indicated time-periods; the second column reports the analogous average among the control stocks. The third column reports the difference in these averages between the treatment group and the control group. The fourth and fifth columns report the t-statistic and p-value associated with the null hypothesis that this diff-in-diffs equals zero. The t-statistics and p-values are based on bootstrap distributions generated using data from the month of July 2015, excluding July 6 and July 8.

Panel A: Normalized Proportional Quoted Spread

	Difference Across Periods		**Treatment Diff minus Control Diff**		
	Treatment	Control	Diff-in-Diffs	t-Stat	p-Value
July 7th					
During minus Not	0.086	0.069	0.017	0.839	0.401
During minus Before	0.097	0.075	0.022	0.960	0.337
During minus After	0.059	0.054	0.005	0.258	0.796
July 9th					
During minus Not	-0.030	-0.034	0.004	0.197	0.844
During minus Before	-0.040	-0.053	0.013	0.574	0.566
During minus After	-0.005	0.013	-0.018	-0.921	0.357

Panel B: Normalized Proportional Effective Spread

	Difference Across Periods		**Treatment Diff minus Control Diff**		
	Treatment	Control	Diff-in-Diffs	t-Stat	p-Value
July 7th					
During minus Not	0.095	0.089	0.006	0.299	0.765
During minus Before	0.106	0.096	0.010	0.404	0.686
During minus After	0.069	0.072	-0.003	-0.126	0.900
July 9th					
During minus Not	-0.027	-0.031	0.004	0.187	0.852
During minus Before	-0.037	-0.049	0.012	0.468	0.640
During minus After	-0.003	0.011	-0.014	-0.656	0.512

3.3 EDGX Shutdown

The preceding subsections establish that during the NYSE trading halt on July 8th, the NYSE-listed stocks that comprise our treatment group exhibited a dramatic reduction in liquidity relative to non-NYSE-listed stocks that comprise our control group. However, the listing decision—upon which the control-group vs. treatment-group assignment is made—is not random. Although we verify that our results are robust to the application of standard matching techniques that pair up treatment-stocks with comparable control-stocks matching schemes cannot alleviate the fundamental concern that our treatment stocks might be more sensitive to a general "shutdown shock" than are our control stocks (for brevity, we do not report the matching results). We address and allay this concern by examining a separate exogenous technology-related trading halt that occurred on the EDGX platform two days prior to the NYSE glitch, and which allows us to directly observe how a trading-venue shutdown affects the stocks in our sample. In the process, we find evidence to support the conventional view that removing one trading venue from a highly fragmented market has little or no effect on the market's functioning. This finding also highlights why the severe degradation of liquidity during the NYSE halt seems at first glance to be so anomalous.

On July 6, 2015, at 9:41 a.m., EDGX suspended trading, saying in a note to customers that it was investigating "an issue related to platform modifications rolled out today." EDGX resumed trading at 10:20 a.m., according to a statement on the company's website.[4] EDGX is the fourth largest stock exchange in the United States; in the last week of September 2015, EDGX covered 8.08% of consolidated trading volume, whereas NYSE covered 13.02% trading volume in the same period. A shutdown of EDGX is a non-trivial event (although we find that the *effects* of the July 6th shutdown *were* trivial). More importantly, all of the stocks in both our treatment group and our control group trade on EDGX, so both groups were exposed to the EDGX shutdown.

[4]Source: https://www.batstrading.com/alerts/72398/status/

We apply the same general methodology used in Subsections 3.1 and 3.2 to analyze the effects of the EDGX shutdown. However, we now calculate the average normalized measures of liquidity in the time period during the EDGX shutdown (9:40:00 AM - 10:19:59 AM), and in the complementary portion of the trading day. Because the EDGX shutdown occurred so early in the day, we do not separately examine the pre-shutdown and post-shutdown periods, but instead combine them into a single "not during the EDGX shutdown" period.

As shown in Panel A of Table 5, we find no evidence that spreads for the treatment-group stocks increased more during the EDGX shutdown than did spreads for the control-group stocks, nor do we find evidence that depth for the treatment-group stocks decreased more during the EDGX shutdown than did depth for the control-group stocks. As shown in Panel B of Table 5, repeating the EDGX analysis on placebo data from July 9th delivers increases in average spreads comparable to the increases observed during the actual EDGX shutdown, for both control-group stocks and treatment-group stocks, independently. Results for depth and dollar depth (not reported) are analogous. The EDGX shutdown really seems to have had almost no effect on the market as a whole.

Since the fraction of trading on EDGX is generally higher among the control-group stocks than among the treatment-group stocks, we run a cross-sectional regression to explicitly control for the typical fraction of each stock's trading that takes place on EDGX. For each stock, we compute the average fraction of total trading volume (across all exchanges and off-exchange trading venues) that executes on EDGX in the three trading days preceding July 6th, 2015. For stock i, we denote this fraction by $EDGXshare_i$. In light of our earlier results, we focus on normalized proportional quoted spread and normalized proportional effective spread as our measures of liquidity. For each stock, we construct the "during-EDGX-halt minus not-during-EDGX-halt" difference in the liquidity measure, which we denote generically by Δ_i^{EDGX} for stock i. We then regress Δ^{EDGX} on $EDGXshare$; to allow for systematic differences between control and treatment stocks' sensitivity to a general "shutdown shock," we use separate intercepts for treatments and

Table 5: Liquidity Diffs-in-Diffs for the EDGX Halt

Table 5 summarizes the results for diff-in-diffs of various liquidity measures during the EDGX shutdown on July 6, 2015. All liquidity measures are normalized—i.e., adjusted to correct for intraday seasonality effects—in the same manner used throughout the rest of the paper. We calculate the average normalized liquidity measures for the period during the EDGX shutdown (9:40:00 AM - 10:19:59 AM), and for the complementary portion of the trading day. The first column reports the averages among the treatment stocks of the difference in the indicated liquidity measure between the "during-shutdown" and "not-during-shutdown" periods; the second column reports the analogous averages among the control stocks. The third column reports the difference in these averages between the treatment group and the control group. For spreads, we test the null hypothesis that the diff-in-diffs is *less than or equal to zero*, while for depths, we test the null hypothesis that the diff-in-diffs is *greater than or equal to zero*. The fourth and fifth columns report, respectively, the t-statistics and p-values associated with the null hypothesis. The t-statistics and p-values are based on bootstrap distributions generated using data from the month of July 2015, excluding July 6 and July 8. Panel A reports results for the actual day of the EDGX shutdown, July 6th. To provide context, Panel B compares the results from July 6 against placebo-test results from July 7 and July 9.

Panel A: EDGX Shutdown

	During minus Not During		**Treatment Diff minus Control Diff**		
	Treatment	Control	Mean	t-Stat	p-Value
Proportional Qtd Spread	-0.0045	0.0349	-0.0394	-1.68	0.952
Proportional Eff Spread	0.0006	0.0445	-0.0438	-1.72	0.955
Depth	0.0383	0.0584	-0.0201	-0.50	0.383
Dollar Depth	0.0366	0.0530	-0.0164	-0.41	0.315

Panel B: Placebos

	During minus Not During		**Treatment Diff minus Control Diff**		
	Treatment	Control	Mean	t-Stat	p-Value
Proportional Qtd Spread					
Placebo, July 7	-0.1410	-0.1242	-0.0168	-0.72	0.763
EDGX Halt, July 6	-0.0045	0.0349	-0.0394	-1.68	0.952
Placebo, July 9	0.0012	0.0223	-0.0211	-0.90	0.816
Proportional Eff Spread					
Placebo, July 7	-0.1330	-0.1200	-0.0130	-0.51	0.692
EDGX Halt, July 6	0.0006	0.0445	-0.0438	-1.72	0.955
Placebo, July 9	0.0082	0.0192	-0.0110	-0.43	0.666

controls:

$$\Delta^{EDGX} = \psi_1 \mathbb{I}_{treatment} + \psi_2 \mathbb{I}_{control} + \psi_3 EDGXshare + \epsilon \tag{1}$$

where $\mathbb{I}_{treatment}$ and $\mathbb{I}_{control}$ are indicator variables ($\mathbb{I}_{treatment,i} = 1$ if stock i is in the treatment group and $\mathbb{I}_{treatment,i} = 0$ otherwise, and we define $\mathbb{I}_{control,i} \coloneqq 1 - \mathbb{I}_{treatment,i}$).

Table 6 presents estimation results from regression (1). With the exception of the control-group intercept with quoted spreads, none of the parameter-estimates are statistically significant. For both quoted spreads and effective spreads, the treatment-group intercepts are negative and the control-group intercepts are positive. These results are consistent with the findings from the EDGX diff-in-diffs analysis.

The evidence from the EDGX shutdown indicates that the results in Subsection 3.1 are not driven by some systematic difference in how the treatment-group and control-group stocks react to a generic trading-venue shutdown, but rather are driven by some effect unique to the shutdown of the NYSE. Furthermore, the EDGX evidence offers some confirmation that observing any meaningful effects at all as a consequence of the NYSE shutdown should seem like an oddity.

4 Distinguishing a DMM Effect from a General NYSE Effect

In the case of the EDGX trading halt, shutting down one exchange out of eleven had no significant effect—the outcome that we would typically expect. By contrast, in the case of the NYSE trading halt, shutting down one exchange out of eleven had a massively significant effect. The NYSE shutdown drastically impaired liquidity for the treatment-group stocks. However, this result could be driven by the fact that the NYSE is the listing market for the treatment stocks. Despite consistently losing market share to competing exchanges, the NYSE remains the largest market center for its listed stocks. The reduction of liquidity during the NYSE trading halt might simply have been the consequence of losing the listing market. More generally, the decrease in liquidity during the NYSE shutdown

Table 6: EDGX Market-Share and Variation in Liquidity Diffs During the EDGX Halt

Table 6 reports results from cross-sectional regressions of "during-EDGX-halt minus not-during-EDGX-halt" differences in liquidity (denoted Δ_i^{EDGX}), on the average fraction of a stock's total consolidated volume that executed at EDGX in the three trading days preceding the EDGX halt (denoted $EDGXshare_i$). To allow for systematic differences between control and treatment stocks' sensitivity to a general "shutdown shock," we include separate intercepts for the two groups:

$$\Delta^{EDGX} = \psi_1 \mathbb{I}_{treatment} + \psi_2 \mathbb{I}_{control} + \psi_3 EDGXshare + \epsilon$$

The indicator variable $\mathbb{I}_{treatment,i}$ equals 1 if stock i is in the treatment group and equals 0 otherwise; we set $\mathbb{I}_{control,i} := 1 - \mathbb{I}_{treatment,i}$ to define the indicator variable for control-group stocks. Standard errors are in parentheses. ***, **, and * indicate the statistical significance at the 1%, 5%, and 10% levels, respectively.

	Diff. in Normalized Proportional Quoted Spread	Diff. in Normalized Proportional Effective Spread
	(1)	*(2)*
$\mathbb{I}_{treatment}$	-0.0078	-0.0048
	(0.0103)	(0.0165)
$\mathbb{I}_{control}$	0.0299**	0.0362
	(0.0139)	(0.0222)
$EDGXshare$	0.0625	0.1020
	(0.1496)	(0.2393)
Adjusted R^2	0.0090	0.0044

might reflect a consequence of removing from the market some NYSE-specific feature other than DMMs. Were that true, we would expect stocks that ordinarily have a higher market share in the NYSE to exhibit larger reduction in liquidity during the halt, but holding fixed NYSE market-share, the level of DMM participation would not matter. Conversely, if DMMs are responsible (in part or in whole) for the observed liquidity effects, those effects should be stronger among stocks where DMM participation was ordinarily higher, *ceteris paribus*.

We use a proprietary dataset provided by the NYSE to determine DMM participation rates for each of the NYSE-listed stocks in our sample. The proprietary dataset reports the daily share-volume and dollar-volume of liquidity provided by the DMM for each NYSE-listed stock. We also know the stock-level total daily volumes that execute on the NYSE, so we can isolate the component of trading on the NYSE where DMMs, as opposed to non-DMMs, provided liquidity.

4.1 Explanatory Power of Cross-Sectional Variation in DMM Participation Rates

For each stock, we compute the average fraction of total trading volume, in shares, (across all exchanges and off-exchange trading venues) that executed on the NYSE in the three trading days preceding July 8th, 2015. For stock i, we denote this fraction by $NYSEshare_i$. We decompose $NYSEshare_i$ into a DMM component ($DMMshare_i$) and a non-DMM component ($NonDMMshare_i$), then examine these two components' power to explain cross-sectional variation in the reductions of liquidity that occurred during the July 8th trading halt.

As before, we focus on normalized proportional quoted spread and normalized proportional effective spread as our measures of liquidity. For each stock, we construct the "during-halt minus before-halt" difference in the liquidity measure, now denoting this dif-

ference generically by Δ_i for stock i. We estimate the following equation:

$$\Delta_i = \beta_0 + \beta_1 DMMshare_i + \beta_2 NonDMMshare_i + \epsilon_i \tag{2}$$

If the reduction in liquidity during the NYSE shutdown was caused by the removal of DMMs from the market, rather than the removal of some other NYSE-specific element, then the coefficient β_1 on $DMMshare$ should be significant and positive, and the coefficient β_2 on $NonDMMshare$ should not be significant. This is precisely what we find in the data.

Table 7 reports the regression results. Column 1 shows that stocks with higher DMM participation rates in the days preceding the NYSE halt experienced larger increases in proportional quoted spreads during the halt. However, the non-DMM participation rate on the NYSE, pre-halt, is not a significant predictor of spread increases during the halt. Column 4 shows that the results for effective spreads are analogous.

We also run the following regressions:

$$\Delta_i = \alpha_0 + \alpha_1 NYSEshare_i + \epsilon_i \tag{3}$$

$$\Delta_i = \gamma_0 + \gamma_1 DMMshare_i + \epsilon_i \tag{4}$$

That is, we regress the changes in liquidity during the NYSE shutdown on pre-halt NYSE market-share in each stock, and we regress the changes in liquidity during the NYSE shutdown on pre-halt DMM participation. Table 7 reports the results of these regressions as well. Columns 3 and 6 display the results for Equation (3). Absent further decomposition, pre-halt NYSE market-share appears to be a significant predictor for increases in quoted and effective spreads during the NYSE halt. However, the results for Equation (4), displayed in Columns 2 and 5, reveal that the DMM component of pre-halt NYSE market-share entirely subsumes this predictive power. Pre-halt NYSE market-share only matters to the extent that it proxies for pre-halt DMM participation. The adjusted R^2

Table 7: Explanatory Power of DMM vs. Non-DMM Participation Rates for Liquidity Reduction During NYSE Halt

Table 7 reports results from cross-sectional regressions of "during-NYSE-halt minus before-NYSE-halt" differences in liquidity, on stock-by-stock measures of NYSE market-share and DMM participation prior to the NYSE trading halt. The variable $NYSEshare_i$ represents average fraction of total trading volume (across all exchanges and off-exchange trading venues) in stock i that executes on the NYSE during the three trading days preceding July 8th, 2015. We decompose this NYSE market-share into a DMM component, $DMMshare_i$, and a non-DMM component, $NonDMMshare_i$, where $NYSEshare_i \equiv DMMshare_i + NonDMMshare_i$. Standard errors are in parentheses. ***, **, and * indicate the statistical significance at the 1%, 5%, and 10% levels, respectively.

	Diff. in Normalized Proportional Quoted Spread			Diff. in Normalized Proportional Effective Spread		
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
$DMMshare$	1.931***	1.877***		1.353***	1.314***	
	(0.197)	(0.190)		(0.263)	(0.253)	
$NonDMMshare$	-0.675			-0.482		
	(0.656)			(0.876)		
$NYSEshare$			1.576***			1.103***
			(0.171)			(0.227)
Constant	-0.057	-0.065*	-0.049	0.009	0.004	0.015
	(0.038)	(0.037)	(0.038)	(0.050)	(0.049)	(0.050)
Adjusted R^2	0.0919	0.0919	0.0812	0.0271	0.0278	0.0246

from estimating Equation (4), using just $DMMshare$ as the explanatory variable, is noticeably larger than that from estimating Equation (3), using $NYSEshare$ as the lone explanatory variable.

4.2 Robustness Checks

To verify the robustness of the regression results, we re-run regression (2) with additional control variables that have been indicated previously to correlate with DMM participation. Specifically, we include price, the logarithm of market capitalization, and the number of analysts that follow each stock. We include price because the DMMs that we consider would generally be classified as HFTs, and O'Hara, Saar and Zhong (2015) and Yao and Ye (2015) find that HFTs are more likely to provide liquidity to low-priced stocks. Bessembinder, Hao and Zheng (2015) find that small firms and firms with greater information asymmetry would be more likely to benefit from DMMs; we therefore include firm size (i.e. log market cap) and, following Anand, Tanggaard and Weaver (2009), include number of analysts as a proxy for information asymmetry. We include these extra variables to better distinguish the effects of cross-sectional variation in $DMMshare$ from the effects of cross-sectional variation along other dimensions. In essence, we are now using as right-hand-side variables the residuals obtained from regressions of $DMMshare$ and $NonDMMshare$ on price, log market cap, and analyst coverage.[5]

Table 8 displays the estimates from these expanded regressions. The results for quoted spreads (Column 1) are comparable to those for effective spreads (Column 2). Although price turns out to be a very significant explanatory variable, the key results from our earlier regressions are unchanged. The coefficient on $DMMshare$ remains positive and highly statistically significant, while the coefficient on $NonDMMshare$ remains statistically insignificant by a wide margin.

Collectively, the findings in this Section indicate that the liquidity effects observed during the NYSE shutdown were indeed driven by the removal of DMMs, not by the

[5]We thank Hank Bessembinder for suggesting this approach.

Table 8: Explanatory Power of DMM vs. Non-DMM Participation Rates for Liquidity Reduction During NYSE Halt (with Additional Controls)

Table 8 reports results from cross-sectional regressions of "during-NYSE-halt minus before-NYSE-halt" differences in liquidity, on stock-by-stock measures of DMM and non-DMM participation prior to the NYSE trading halt, along with a variety of additional control variables. Notation is consistent with that of Table 7. The variable $DMMshare$ measures the ratio of volume with DMMs as liquidity providers in a given stock to total consolidated volume in that stock, and the variable $NonDMMshare$ measures the analogous ratio for the remainder of liquidity provision on the NYSE. Both of these measures are calculated using data from the three trading days preceding July 8, 2015. The variable "*price*" is the stock's average closing price; "*logmktcap*" is the logarithm of the stock's market capitalization; "*Analystcover*" is the number of analysts following the stock. Standard errors are in parentheses. ***, **, and * indicate the statistical significance at the 1%, 5%, and 10% levels, respectively.

	Diff. in Normalized Proportional Quoted Spread	Diff. in Normalized Proportional Effective Spread
	(1)	*(2)*
DMMshare	2.009***	1.439***
	(0.193)	(0.261)
NonDMMshare	0.674	0.753
	(0.668)	(0.906)
price	0.002***	0.002***
	(0.0002)	(0.0003)
logmktcap	-0.005	-0.017
	(0.010)	(0.013)
Analystcover	-0.002	-0.002
	(0.002)	(0.002)
Constant	-0.117	0.048
	(0.072)	(0.097)
Adjusted R^2	0.136	0.047

removal of the NYSE *per se.*

5 Additional Cross-Sectional Results

The preceding sections establish our central result that DMMs cause a substantial improvement in liquidity. In this section, we broaden the scope of our analysis, and exploit the unique opportunities afforded to us by the combination of exogenous variation from the NYSE glitch, and the novel dataset. We document new stylized facts about cross-sectional patterns of modern DMMs' participation, and we present new empirical results concerning the types of stocks for which DMM participation matters most. These latter results corroborate the conclusions drawn in some of the most recent research on DMMs.

5.1 DMMs vs. Other Liquidity Providers

The six current DMMs, based on their firm identity, would typically be categorized as HFTs. We investigate whether DMMs' pattern of liquidity provision differs from that of "typical" HFTs, and whether the differential liquidity outcomes caused by DMMs versus other liquidity providers can be well-explained by the cross-sectional pattern of DMMs' participation.

In the NASDAQ market, no HFTs have market-making obligations for common stocks, and two stylized facts have been established for HFTs in NASDAQ. First, HFT participation rate is higher for large stocks (Brogaard, Hendershott and Riordan 2014; Yao and Ye 2015). Second, HFT liquidity provision is higher for low-priced securities. Yao and Ye (2015) show that the price competition is more constrained and the revenue of liquidity provision is higher for low-priced stocks, because the one-cent minimum tick-size imposed by SEC rule 612 leads to a higher relative tick-size (one cent divided by nominal price) for lower priced stocks. The constraints on price competition, and the higher revenue, attract traders with high speed to extract the rents available by establishing time priority.

Table 9 presents the results from regressions of DMM participation rate on price, market

cap, and analyst coverage. Analyst coverage is included to help control for variation in informational asymmetry. We use logarithms so that the regression coefficients can be interpreted as elasticities or semi-elasticities:

$$\log\left(participation_i\right) = \eta_0 + \eta_1 \log\left(price_i\right) + \eta_2 \log\left(marketcap_i\right) + \eta_3 Analystcover_i + \epsilon_i \quad (5)$$

In the first column of Table 9, the dependent variable is the logarithm of the ratio of volume with the DMM as liquidity provider in a given stock to total NYSE volume in that stock, i.e., $\log\left(\frac{DMMshare_i}{NYSEshare_i}\right)$ in our previous notation. In the second column, the dependent variable is the logarithm of the ratio of volume with DMMs as liquidity providers in a given stock to total consolidated volume in that stock, i.e., the logarithm of the variable $DMMshare_i$ considered in Section 4. Both of these measures are calculated using data from the three trading days preceding July 8, 2015.

The regression reveals two interesting facts. The first column of Table 9 shows that within the microcosm of the NYSE, DMMs' pattern of participation appears to run opposite to that of ordinary HFTs. Measured relative to other liquidity providers on the NYSE, DMMs participate more heavily in stocks with higher prices and smaller market-cap (analyst coverage has no significant effect). This indicates that DMMs' participation varies less along these two dimensions than does that of other liquidity providers on the NYSE.

However, for the purposes of understanding the changes in liquidity during the NYSE shutdown, the relevant measure is DMMs' participation relative to that of liquidity-providers in the market as a whole. As shown in the second column of Table 9, the picture flips when we consider this latter measure. In this more comprehensive context, DMMs' participation pattern actually appears analogous to that of "normal" HFTs, in that DMMs participate proportionally more in larger stocks, and in stocks with lower prices (and again, analyst coverage has no significant effect). In other words, at least by this broad-brush measure, the stocks for which DMMs provide greater fractions of total liquidity are generally the same sorts of stocks that we would expect to have high levels of voluntary HFT liquidity

provision.

5.2 Cross-Sectional Patterns in the Importance of DMMs

Stated in more concrete terms, the results in Column 2 of Table 9 indicate that DMMs tend to provide a greater fraction of market-wide liquidity for a low-priced stock than for a high-priced stock, and a greater fraction for a large-cap stock than for a small-cap stock. Nevertheless, we find empirically that DMMs' liquidity provision matters more for high-priced stocks than it does for low-priced stocks, and matters more for small stocks than it does for large stocks. Similarly, although the results in Column 2 of Table 9 indicate no significant variation in DMM participation rates as a function of analyst coverage, we find that DMMs' liquidity provision matters more for stocks with little analyst coverage than it does for stocks with a lot of analyst coverage.

Table 10 reports results from regressions of "during-NYSE-halt minus before-NYSE-halt" differences in normalized proportional quoted spreads (Δ_i), on $DMMshare$, price, log market-cap, analyst coverage, and the interaction terms $price \times DMMshare$, $logmktcap \times DMMshare$, and $Analystcover \times DMMshare$. Results for normalized proportional effective spreads are comparable to those for normalized proportional quoted spreads, so we omit the former for brevity.

Column 1 of Table 10 displays results from the regression with no interaction terms or $DMMshare$,

$$\Delta_i = \phi_0 + \phi_1 price_i + \phi_2 logmktcap_i + \phi_3 Analystcover_i + \epsilon_i \tag{6}$$

which serves as a benchmark. The coefficient ϕ_2 on log market-cap is not significant. The coefficients ϕ_1 on price and ϕ_3 on analyst coverage, respectively, *are* significant, but this significance vanishes when we include $DMMshare$ and the interaction term $price \times DMMshare$ in the regression, as shown in Column 2 of Table 10.

Given these indications that price, log market-cap, and analyst coverage (not inter-

Table 9: Patterns of Cross-Sectional Variation in DMM Liquidity Provision

Table 9 reports regression results concerning factors that explain cross-sectional variation in the DMM participation rate. Notation is consistent with that of Tables 7 and 8. The variable $\frac{DMMshare}{NYSEshare}$ measures the ratio of volume with DMMs as liquidity providers in a given stock to the NYSE volume in that stock. The variable $DMMshare$ measures the ratio of volume with DMMs as liquidity providers in a given stock to total consolidated volume in that stock. Both of these measures are calculated using data from the three trading days preceding July 8, 2015. (The logarithms of these measures are used as the dependent variables in the regressions, so that the regression coefficients can be interpreted as elasticities or semi-elasticities.) The variable "*log_ price*" is the logarithm of the stock's average closing price; "*logmktcap*" is the logarithm of the stock's market capitalization; "*Analystcover*" is the number of analysts following the stock. Standard errors are given in parentheses. ***, **, and * indicate the statistical significance at the 1%, 5%, and 10% levels, respectively.

	$\log\left(\frac{DMMshare}{NYSEshare}\right)$	$\log(DMMshare)$
	(1)	*(2)*
log_ price	0.0413***	-0.0446***
	(0.0031)	(0.0141)
logmktcap	-0.0102***	0.0338***
	(0.0022)	(0.0100)
Analystcover	0.0005	-0.0023
	(0.0003)	(0.0015)
Constant	-0.1718***	-1.8066***
	(0.0127)	(0.0578)
Adjusted R^2	0.1678	0.0128

acted with $DMMshare$) do not significantly affect the regressions when $DMMshare$ and $price \times DMMshare$ are present, for expositional clarity we focus our main analysis on specifications with just $DMMshare$ and interaction terms:

$$\Delta_i = \varphi_0 + \varphi_1 DMMshare_i + \varphi_2 \left(price \times DMMshare\right)_i + \epsilon_i \tag{7}$$

$$\Delta_i = \theta_0 + \theta_1 DMMshare_i + \theta_2 \left(price \times DMMshare\right)_i + \theta_3 \left(logmktcap \times DMMshare\right)_i + \epsilon_i$$

$$\Delta_i = \vartheta_0 + \vartheta_1 DMMshare_i + \vartheta_2 \left(price \times DMMshare\right)_i + \vartheta_3 \left(Analystcover \times DMMshare\right)_i + \epsilon_i$$

Columns 3 - 5 of Table 10 report the results for these interaction-term specifications. The coefficient φ_2 on the interaction $price \times DMMshare$ is positive and significant, while the respective coefficients θ_3 and ϑ_3 on the interactions $logmktcap \times DMMshare$ and $Analystcover \times DMMshare$ are each negative and significant. These findings suggest that after controlling for the level of pre-halt DMM participation, DMMs' effect on spreads is stronger for higher-priced stocks, smaller stocks, and stocks with more informational asymmetry (less analyst coverage).

Our results in this subsection tie closely some of the recent literature on DMMs. The finding regarding market-cap strongly directly supports the conclusions of Bessembinder, Hao and Zheng (2015), who suggest that DMM participation is more important for small firms and firms with high informational asymmetry, whereas voluntary liquidity provision may suffice for large firms and firms with low informational asymmetry. Our finding regarding price likewise supports the conclusions of Anand and Venkataraman (2015), though in a more oblique way.

Anand and Venkataraman argue that voluntary provision of liquidity provision suffices when it is more profitable, whereas DMMs provide more liquidity when there is less profit. Measuring in terms of volume, our results might superficially seem to differ from those of Anand and Venkataraman, in that we find DMM participation to be higher relative to total volume for low-priced stocks, which have larger relative tick-sizes and therefore greater potential for market-makers to earn rents. However, if we consider liquidity in

Table 10: NYSE Halt Liquidity Reduction—Effects of Market-Cap, Price, Analyst Coverage, $DMMshare$, and Interactions

Table 10 reports results from cross-sectional regressions of "during-NYSE-halt minus before-NYSE-halt" differences in normalized proportional quoted spreads, on a measure of DMM participation prior to the NYSE trading halt ("$DMMshare$"), the logarithm of stock market-cap ("*logmktcap*"), stock price ("*price*"), the number of analysts following the stock ("*Analystcover*") and the interaction terms of $DMMshare$ with each of the other three variables. The variable $DMMshare_i$ represents the average ratio of DMM volume in stock i to total consolidated volume in stock i during the three trading days preceding July 8th, 2015. Standard errors are in parentheses. ***, **, and * indicate the statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)	(5)
price	0.0011***	-0.0011			
	(0.0002)	(0.0008)			
logmktcap	0.0081	-0.0132			
	(0.0102)	(0.0099)			
Analystcover	-0.0034*	-0.0024			
	(0.0017)	(0.0016)			
DMMshare		1.2541***	1.6180***	2.2569***	1.7511***
		(0.2955)	(0.1879)	(0.3600)	(0.1959)
price× *DMMshare*		0.0174***	0.0089***	0.0104***	0.0099***
		(0.0050)	(0.0012)	(0.0014)	(0.0013)
logmktcap× *DMMshare*				-0.0820**	
				(0.0344)	
Analystcover× *DMMshare*					-0.0153**
					(0.0066)
Constant	0.2647***	0.0841	-0.0999***	-0.1061***	-0.0991***
	(0.0617)	(0.0909)	(0.0362)	(0.0363)	(0.0361)
Adjusted R^2	0.0311	0.1459	0.1389	0.1418	0.1427

more general terms—measured by outcomes, such as spreads, rather than by raw volume—the results reported in Table 10 are fully consistent with the conclusions of Anand and Venkataraman. Even though the DMMs may be less prominent liquidity providers in terms of volume-share among higher-priced stocks, DMMs' participation has stronger impact on spreads in those stocks. Since our analysis of DMM participation patterns is purely cross-sectional, a natural explanation for this effect would be time-series variation in DMMs' participation, for example, providing tighter quotes on the occasions when "Endogenous Liquidity Providers" temporarily withdraw from the market—just as Anand and Venkataraman document in the context of the Toronto Stock Exchange.

More broadly, these results again underscore the notion that, despite superficial similarities, DMMs and voluntary liquidity providers do not play interchangeable roles in modern markets.

6 Why do DMMs Matter to the Extent that They do?[6]

Although the loss of DMMs during the NYSE halt caused a substantial degradation of liquidity among NYSE-listed stocks, the loss did not obliterate the markets for those stocks, as it likely would have done a decade ago. DMMs certainly are not irrelevant, but neither are they indispensable under ordinary conditions. During the period that we examine, DMMs' quantifiable obligations with respect to maintaining market-quality would not have been remotely binding.[7] Why then would DMMs cause spreads to narrow so significantly? The answer, we propose, stems from DMMs' competition with one another to get securities assigned or "allocated" to them, and DMMs' reliance on reputation to compete for these allocations.

[6]The full texts of NYSE Rules mentioned in this section are provided for reference in Appendix B.
[7]See NYSE Rule 104(a)(1)(B)

6.1 Quoting Requirements and Rebates

We begin by ruling out the two most obvious alternative explanations, namely the formal pressure on DMMs to quote at the NBBO a specified percentage of the time, and the liquidity rebates that DMMs receive from the NYSE.

The NYSE uses the following measures to monitor a DMM's performance: the fraction of time that the DMM quotes at the NBBO, the DMM's average size at the NBBO relative to combined NYSE size, and the DMM's executed liquidity-providing volume. However, DMMs' obligations and inducements to quote at the NBBO a specified percentage of the time fail to provide a satisfactory explanation for the dramatic reduction of liquidity during the NYSE trading halt. The same holds true for obligations to quote some particular minimum size at the NBBO. Quoting *at* the NBBO does not, in itself, narrow the spread, but rather increases depth at the NBBO prices. Had we observed negligible increases in spreads but a reduction in depth during the NYSE shutdown, those effects could have been explained in terms of DMMs' obligations to post quotes at the NBBO. However, during the shutdown, the reduction of liquidity took a very different form, namely a widening of spreads.

Next, although the NYSE offers higher liquidity rebates to DMMs than to non-DMMs, the magnitudes involved are far too small to directly explain the spread results. At the time of the NYSE shutdown, DMMs could earn liquidity rebates as high as 34 cents per 100 shares, while the highest rebate that non-DMMs could earn was 29 cents per 100 shares.[8] The mean quoted spread among treatment-group stocks between 11:30 AM and 3:10 PM on days other than July 8th was roughly 3.8 cents, so the $\approx 22\%$ increase in spreads during the NYSE halt translates to an average increase of approximately 0.85 cents. Even in the extreme hypothetical scenario where DMMs earned the maximum liquidity rebate on every trade, and liquidity suppliers on other exchanges earned the standard 0.305-cent-per-share liquidity rebate offered on NASDAQ,[9] the observed spread-increase exceeds

[8] Source: New York Stock Exchange Price List, July 1, 2015.

[9] Source: SR-NASDAQ-2014-124

by a factor of nearly ten the $(0.34 - 0.305) \times (2 \text{ sides}) = 0.07$ cents per share that could be mechanically explained through rebates. Still less can be explained if we relax the implausible assumption that DMMs earn the maximum rebate on every trade.

The inadequacy out these two obvious potential explanations indicates the legitimate significance of DMMs' more nebulous obligations—maintaining a fair and orderly market in their stocks, and facilitating price discovery throughout the day as well as at the open, close, and in periods of significant imbalances and high volatility. Since these obligations are rather subjective, their strong apparent influence on DMMs' behavior is somewhat surprising. Maintaining high market-quality entails some cost, and the broad wording of these obligations seems to leave considerable scope for shirking, as does the narrowly circumscribed set of criteria on which the NYSE evaluates DMMs' performance.

6.2 Allocation and Reputation

The NYSE actively promotes competition among DMM firms. NYSE Rule 123E(f)(1)(B), concerning conditions for the Exchange to approve a proposed merger of DMMs, stipulates that among other things, the Exchange must determine that the proposed combination would "foster competition among DMM units [i.e., DMM firms]." There is only ever one DMM per stock, so DMMs cannot compete directly in any single stock. Rather, DMMs must compete for a different type of prize.

Under NYSE Rule 103B, securities are allocated to a DMM when a security is to be initially listed on the Exchange, and when a security previously assigned to a DMM must be re-assigned. DMMs compete fiercely with one another to obtain these allocations, and with good reason: the economic magnitudes involved are large. As a stark illustration, On December 4, 2015, J.P. Morgan announced that it was firing its then-current DMM, KCG. On January 5, 2016, J.P. Morgan announced that it had selected Virtu as its new DMM. Following the December 4th announcement, KCG's stock-price fell nearly 6% intraday, and closed essentially flat, while the broader markets were up approximately 2% that day. Following the January 5th announcement, Virtu's stock-price rose about 1%, while the

broader markets were down approximately 1.5% that day. At the time of these respective announcements, KCG's market-cap was around $1.1 billion dollars, and Virtu's market-cap was approximately $3.1 billion. J.P. Morgan's allocation appears to be worth about $20 million - $60 million to a DMM.

Because DMMs can't explicitly compete on price,[10] they must instead compete on their record and reputation for maintaining high market-quality in the stocks assigned to them. There are tight restrictions on the communication permitted between DMMs and the firm selecting a DMM (see NYSE Rule 103B(III)). Historical market-quality of the stocks assigned to a given DMM, however, provide an easily interpretable and observable signal for the selecting firm. Consequently, a DMM obtains value from improving market-quality for its stocks, above and beyond any immediate benefits such as rebates; this value comes in the form of a higher expected number of newly-listing firms that will select the DMM in the future. This "reputational value" can give DMMs an incentive to improve market-quality in their stocks, even if doing so reduces the DMMs' respective profits in those stocks. Voluntary liquidity providers, by contrast, have no such incentive, since they do not compete for business on the basis of reputation (and if you have no obligations, reputation for meeting your obligations is vacuous). The reputation mechanism can explain why DMMs would tighten spreads in the manner we observe, and the economic magnitudes seem roughly appropriate. Although we propose this explanation only tentatively, it suggests new avenues for further future investigation.

7 Conclusion

The NYSE trading-halt on July 8, 2015 caused substantial reductions in liquidity among stocks that would ordinarily trade on the NYSE relative to stocks that never trade on the NYSE. This result is unusual because ten other exchanges remained open during the

[10] FINRA Rule 5250 states, "No member or person associated with a member shall accept any payment or other consideration, directly or indirectly, from an issuer of a security, or any affiliate or promoter thereof, for publishing a quotation, acting as market maker in a security, or submitting an application in connection therewith."

NYSE halt. Indeed, an unrelated technological glitch forced the temporary shutdown of EDGX just two days before the NYSE halt, and there was no analogous loss of liquidity then. Despite being just one exchange among eleven, the NYSE is not redundant. It has a distinctive element that significantly improves liquidity.

To distinguish the effect of DMMs from that of other features unique to the NYSE, we examine determinants of the cross-sectional variation in liquidity reduction among NYSE-listed stocks during the NYSE shutdown. For each stock, we compute the NYSE's market-share of trading volume during the days leading up to July 8th, then use proprietary data to separate the NYSE market-share into a DMM component and a non-DMM component. We find that stocks with higher DMM participation experience larger increases in quoted and effective spreads during the NYSE trading halt; after controlling for the DMM component, NYSE market-share does not help to explain cross-sectional variation. Our liquidity results can therefore be attributed to DMM participation, rather than some other distinguishing feature of the NYSE.

Our results demonstrate the continued significance of DMMs in the modern market. Despite the proliferation of voluntary liquidity-providers, the presence of traders with formal market-making obligations—even seemingly small and mild obligations—causes stunning improvements in liquidity.

References

[1] Amber Anand, Carsten Tanggaard, and Daniel G. Weaver, *Paying for market quality*, Journal of Financial and Quantitative Analysis **44** (2009), 1427–1457.

[2] Amber Anand and Kumar Venkataraman, *Market conditions, fragility and the economics of market making*, Journal of Financial Economics **121** (2016), 327–349.

[3] Hendrik Bessembinder, Jia Hao, and Michael L. Lemmon, *Why designate market makers? affirmative obligations and market quality*, Working paper, June 2011.

[4] Hendrik Bessembinder, Jia Hao, and Kuncheng Zheng., *Market making contracts, firm value, and the ipo decision*, Journal of Finance **70** (2015), 1997–2028.

[5] Jonathan Brogaard, Terrence Hendershott, and Ryan Riordan, *High-frequency trading and price discovery*, Review of Financial Studies **27** (2014), 2267–2306.

[6] Andrew C. Harvey, *Time series models*, 2nd ed., MIT Press, Cambridge, Mass., 1993.

[7] Craig W. Holden and Stacey Jacobsen, *Liquidity measurement problems in fast, competitive markets: expensive and cheap solutions*, Journal of Finance **69** (2014), 1747–1785.

[8] Thomas H. McInish and Robert A. Wood, *An analysis of intraday patterns in bid/ask spreads for nyse stocks*, Journal of Finance **47** (1992), 753–764.

[9] Albert J. Menkveld and Ting Wang, *How do designated market makers create value for small-caps?*, Journal of Financial Markets **16** (2013), 571–603.

[10] M. Nimalendran and Giovanni Petrella, *Do 'thinly-traded' stocks benefit from specialist intervention?*, Journal of Banking and Finance **27** (2003), 1823–1854.

[11] Maureen O'Hara, Gideon Saar, and Zhuo Zhong, *Relative tick size and the trading environment*, Working paper, Cornell University and University of Melbourne, 2015.

[12] Pietro Perptti and Barbara. Rindi, *Market makers as information providers: The natural experiment of star*, Journal of Empirical Finance **17** (2010), 895–917.

[13] Delphine Sabourin, *Are designated market makers necessary in centralized limit order markets?*, Working paper, CEREMADE and CREST., 2006.

[14] J. A. Skjeltorp and B. A. Odeggard, *When do listed firms pay for market making in their own stock?*, Financial Management **44** (2015), 241–266.

[15] Kumar Venkataraman and Andrew C. Waisburd, *The value of the designated market maker*, Journal of Financial and Quantitative Analysis **42** (2007), 735–758.

[16] Chen Yao and Mao Ye, *Why trading speed matters: A tale of queue rationing under price controls*, Working paper, University of Warwick and University of Illinois at Urbana-Champaign, 2015.

A Designated Market Makers' Privileges

Historically, specialists could observe an order first, before the market could do so. Therefore, the specialists had the ability to handle some portion of the order prior to the market. In 2008, NYSE removed the first-look advantage. DMMs now have three privileges. First, the NYSE provides more generous rebates to DMMs for providing liquidity. At the time of the NYSE shutdown on July 8, 2015, DMMs could earn rebates as high as 34 cents per 100 shares, while the highest rebate that non-DMMs could earn was 29 cents per 100 shares. Second, DMMs also receive market data quote revenue and flat monthly fees per symbol in less-active securities, based on market-quality performance. Third, instead of yielding to public limit orders at the same price, as specialists were obligated to do prior to 2008, DMMs currently have slightly more priority than each individual limit-order submitter on the book. The privilege comes from the NYSE priority-parity allocation rule for orders at the same price. This rule first divided traders into three types: the DMM for the stock, floor brokers and electronic book. Each single floor broker and the DMM constitute individual participants, whereas all orders represented in the limit order book in aggregate constitute a single participant. The orders submitted to the limit order book are executed by means of time priority with respect to entry. If a participant is the unique provider of the best bid and offer (BBO), the participant is awarded the priority and obtains 15% of incoming market orders or a minimum of one round lot, whichever is greater. After that, the remainder size of the market order shall be allocated to each participant on parity. Therefore, DMMs do not need to yield to public limit orders that were entered earlier, unless the public limit order was the first one to set BBO, whereas a public limit order needs to yield to other limit orders with time priority.

B Selected NYSE Rules[11]

NYSE Rule 103B. Security Allocation and Reallocation

I. ASSIGNMENT OF SECURITIES
Securities are allocated to a qualified DMM unit when: (1) a security is to be initially listed on the Exchange; and (2) a security previously assigned to a DMM member organization must be re-assigned pursuant to this Rule or the NYSE Listing Company Manual.

II. ELIGIBILITY FOR ALLOCATION
(A) A DMM unit is eligible to participate in the allocation process of a listed security when the DMM unit meets the quoting requirements for "Less Active" and "More Active" securities.

(B) For purposes of Section II of NYSE Rule 103B, "Less Active Security" shall mean any listed security that has a consolidated average daily volume of less than one million shares per calendar month.

(C) For purposes of Section II of NYSE Rule 103B, a "More Active Security" shall mean any listed security that has a consolidated average daily volume equal to or greater than one million shares per calendar month.

(D) For Less Active Securities a DMM unit must maintain a bid and an offer at the National Best Bid ("NBB") and National Best Offer ("NBO") (collectively herein "NBBO") for an aggregate average monthly NBBO of 15% or more during a calendar month.

(E) For More Active Securities a DMM unit must maintain a bid and an offer at the NBBO for an aggregate average monthly NBBO of 10% or more during a calendar month.

(F) A DMM unit will be deemed to have met its quoting requirements for Less Active and More Active securities for the "Trading Days" in a calendar month pursuant the provisions of subsection (H) below.

(G) For purposes of Section II of NYSE Rule 103B, "Trading Day" shall mean any day on which the Exchange is scheduled to be open for business. Days on which the Exchange closes prior to 4:00 p.m. (Eastern Time) for any reason, which may include any regulatory halt or trading halt, shall be considered a Trading Day.

(H) The Exchange will determine for each security:

(1) the "Daily NBB Quoting Percentage" by determining the percentage of time a DMM unit has at least one round lot of displayed interest in an Exchange bid at the National Best Bid during each Trading Day for a calendar month;

(2) the "Daily NBO Quoting Percentage" by determining the percentage of time a DMM unit has at least one round lot of displayed interest in an Exchange offer at the National Best Offer during each Trading Day for a calendar month;

(3) the "Average Daily NBBO Quoting Percentage" for each Trading Day by summing the "Daily NBB Quoting Percentage" and the "Daily NBO Quoting Percentage" then dividing such

[11] The text in this Appendix, including labeling of rule subsections, is quoted directly from the NYSE Rules, available at the time of this writing at http://nyserules.nyse.com/NYSE/Rules/. All rights belong to the copyright holder.

sum by two;

(4) the "Monthly Average NBBO Quoting Percentage" for each security by summing the security's "Average Daily NBBO Quoting Percentages" for each Trading Day in a calendar month then dividing the resulting sum by the total number of Trading Days in such calendar month; and

(5) for the total Less Active Securities (More Active Securities) assigned to a DMM unit, the Exchange will determine the "Aggregate Monthly Average NBBO Quoting Percentage" by summing the Monthly Average NBBO Quoting Percentages for each Less Active Security (More Active Security) assigned to a DMM unit, then dividing such sum by the total number of Less Active Securities (More Active Securities) assigned to such DMM unit.

(I) A DMM unit's eligibility to participate in the allocation process is determined at the time the interview is scheduled by the Exchange.

(J) Failure to Meet Performance Standards

(1) If a DMM unit fails to meet the requirements of NYSE Rule 103B, Section II(D) and (E) for a one-month period, the Exchange will issue an initial warning letter to the unit, advising it of its poor performance. The DMM unit shall provide in writing an explanation and articulation of corrective action.

(2) If the DMM unit fails to meet the requirement of NYSE Rule 103B, Section II(D) and (E) for a second consecutive month, the DMM unit will be ineligible to participate in the allocation process for a minimum of two months following the second consecutive month of its failure to meet its quoting requirement ("Penalty Period"). The DMM unit must satisfy the quoting requirement for the two consecutive months of the Penalty Period.

(3) In the event a DMM unit fails to meet its quoting requirements for the two consecutive months of the Penalty Period, the DMM unit will remain ineligible to participate in the allocation process until it has met the quoting requirement for a consecutive two calendar month period.

(4) The Exchange will review each DMM unit's trading on a monthly basis to determine whether the DMM unit has satisfied its quoting requirement.

(K) Affiliated entity considerations

The Exchange shall not permit a DMM unit to interview to be the assigned DMM unit or be allocated a security that is directly related to the performance or credit of any of its affiliated entities.

III. ALLOCATION

The issuer may select its DMM unit directly or delegate the authority to the Exchange to select its DMM unit. After the Exchange provides written notice to DMM units that the issuer is listing on the Exchange, no individual associated with a DMM unit may contact such issuer, or the Exchange Selection Panel if applicable, until the allocation is made, except as otherwise provided below.

(A) DMM Unit Selected by the Issuer

(1) The issuer shall select a minimum of four DMM units to interview from the pool of DMM units eligible to participate in the allocation process.

(2) Interview Between the Issuer and DMM Units

(a) DMM units selected for an interview may provide material to the Exchange which will be given to the issuer prior to the scheduled interview. Such material may include a corporate overview of the DMM unit and the trading experience of the designated DMM. DMM units are prohibited from giving issuers information about other DMM units or any additional market performance data.

...

(d) Following its interview, a DMM unit may not have any contact with an issuer. If an issuer has a follow-up question regarding any DMM unit(s) it interviewed, it must be conveyed to

the Exchange. The Exchange will contact the DMM unit(s) to which the question pertains and will provide any available information received from the DMM unit(s) to the listing company.
...
(B) DMM Unit Selected by the Exchange

(1) If the issuer delegates authority to the Exchange to select its DMM unit, an Exchange Selection Panel ("ESP") shall be convened to select a DMM unit based on a review of all information available to the issuer. ... Such issuer may choose to submit a letter to the ESP indicating its preference and supporting justification for a particular DMM unit. The ESP may consider such letter in performing its duty to select a DMM unit for the issuer.
...

IV. REALLOCATION

(A) Change of DMM Unit upon Request of Issuer

(1) When an issuer has requested and confirmed a change of DMM unit pursuant to Section 806.01 of the Exchange Listed Company Manual, the security will be put up for reallocation as soon as practicable, in accordance with the allocation process set forth in NYSE Rule 103B, Section III.

(2) No negative inference for allocation or regulatory purposes is to be made against a subject DMM unit in the event that a DMM unit is changed pursuant to Section 806.01 of the Exchange Listed Company Manual. Similarly, the DMM unit shall not be afforded preferential treatment in subsequent allocations as a result of a change pursuant to such provision.

V. EGREGIOUS SITUATIONS

(A) In any instance where a DMM unit's performance in a particular market situation was, in the judgment of the Exchange, so egregiously deficient as to call into question the Exchange's integrity or impair the Exchange's reputation for maintaining an efficient, fair, and orderly market, the CEO or his or her designee may immediately initiate a reallocation proceeding upon written notice to the DMM unit and the issuer specifying the reasons for the initiation of the proceeding.

(B) Following this decision, if the CEO or his or her designee makes a final determination that a security should be referred for reallocation, the CEO or his or her designee will, in his or her expert business judgment, be responsible for reallocating the security to the one of the remaining DMM units eligible for allocation.

(C) The CEO or his or her designee shall then make a final determination as to which one or more of the DMM unit's security shall be referred for reallocation. All determinations made by the CEO or his or her designee shall be communicated in writing to the DMM unit, with a statement of the reasons for such determinations.

(D) A decision by the Exchange that one or more securities should be reallocated shall be final, subject to the DMM unit's right to have such decision reviewed by the Exchange's Board of Directors.

(E) In the event that a DMM unit asserts its right to review, no reallocation may occur until the Board of Directors completes its review.
...

NYSE Rule 104. Dealings and Responsibilities of DMMs

104(a) DMMs registered in one or more securities traded on the Exchange must engage in a course of dealings for their own account to assist in the maintenance of a fair and orderly market insofar as reasonably practicable. The responsibilities and duties of a DMM specifically include, but are not limited to, the following:

(1) Assist the Exchange by providing liquidity as needed to provide a reasonable quotation and by maintaining a continuous two-sided quote with a displayed size of at least one round lot.

(A) With respect to maintaining a continuous two-sided quote with reasonable size, DMM units must maintain a bid or an offer at the National Best Bid and National Best Offer ("inside") at least 15% of the trading day for securities in which the DMM unit is registered with a consolidated average daily volume of less than one million shares, and at least 10% for securities in which the DMM unit is registered with a consolidated average daily volume equal to or greater than one million shares. Time at the inside is calculated as the average of the percentage of time the DMM unit has a bid or offer at the inside. In calculating whether a DMM is meeting the 15% and 10% measure, credit will be given for executions for the liquidity provided by the DMM. Reserve or other hidden orders entered by the DMM will not be included in the inside quote calculations.

(B) Pricing Obligations. For NMS stocks (as defined in Rule 600 under Regulation NMS) a DMM shall adhere to the pricing obligations established by this Rule during the trading day; provided, however, that such pricing obligations (i) shall not commence during any trading day until after the first regular way transaction on the primary listing market in the security, as reported by the responsible single plan processor, and (ii) shall be suspended during a trading halt, suspension, or pause, and shall not re-commence until after the first regular way transaction on the primary listing market in the security following such halt, suspension, or pause, as reported by the responsible single plan processor.

(i) Bid and Offer Quotations. At the time of entry of the DMM's bid (offer) interest, the price of the bid (offer) interest shall be not more than the Designated Percentage away from the then current National Best Bid (Offer), or if no National Best Bid (Offer), not more than the Designated Percentage away from the last reported sale from the responsible single plan processor. In the event that the National Best Bid (Offer) (or if no National Best Bid (Offer), the last reported sale) increases (decreases) to a level that would cause the bid (offer) interest to be more than the Defined Limit away from the National Best Bid (Offer) (or if no National Best Bid (Offer), the last reported sale), or if the bid (offer) is executed or cancelled, the DMM shall enter new bid (offer) interest at a price not more than the Designated Percentage away from the then current National Best Bid (Offer) (or if no National Best Bid (Offer), the last reported sale), or identify to the Exchange current resting interest that satisfies the DMM's obligation according paragraph (1)(A), above.

(ii) The National Best Bid and Offer shall be determined by the Exchange in accordance with its procedures for determining protected quotations under Rule 600 under Regulation NMS.

(iii) For purposes of this Rule, the "Designated Percentage" shall be 8% for securities subject to Rule 80C(a)(i), 28% for securities subject to Rule 80C(a)(ii), and 30% for securities subject to Rule 80C(a)(iii), except that between 9:30 a.m. and 9:45 a.m. and between 3:35 p.m. and the close of trading, when Rule 80C is not in effect, the Designated Percentage shall be 20% for securities subject to Rule 80C(a)(i), 28% for securities subject to Rule 80C(a)(ii), and 30% for securities subject to Rule 80C(a)(iii).

(iv) For purposes of this Rule, the "Defined Limit" shall be 9.5% for securities subject to Rule 80C(a)(i), 29.5% for securities subject to Rule 80C(a)(ii), and 31.5% for securities subject to Rule 80C(a)(iii), except that between 9:30 a.m. and 9:45 a.m. and between 3:35 p.m. and the close of trading, when Rule 80C is not in effect, the Defined Limit shall be 21.5% for securities

subject to Rule 80C(a)(i), 29.5% for securities subject to Rule 80C(a)(ii), and 31.5% for securities subject to Rule 80C(a)(iii).

Nothing in this Rule shall preclude a DMM from quoting at price levels that are closer to the National Best Bid and Offer than the levels required by this Rule.

(2) Facilitate openings and reopenings, including the Midday Auction, for each of the securities in which the DMM is registered as required under Exchange rules. This may include supplying liquidity as needed. (See Rule 123D for additional responsibilities of DMMs with respect to openings and Rule 13 with respect to Reserve Order interest procedures at the opening.) DMM and DMM unit algorithms will have access to aggregate order information in order to comply with this requirement. (See Supplementary Material .05 of this 104 with respect to odd-lot order information to the DMM unit algorithm.)

(3) Facilitate the close of trading for each of the securities in which the DMM is registered as required by Exchange rules. This may include supplying liquidity as needed. (See Rule 123C for additional responsibilities of DMMs with respect to closes and Rule 13 with respect to Reserve Order interest procedures at the close.) DMM and DMM unit algorithms will have access to aggregate order information in order to comply with this requirement.

...

104(f) Functions of DMMs

(i) Any member who expects to act as a DMM in any listed stock must be registered as a DMM. See Rule 103 for registration requirements for DMMs.

(ii) The function of a member acting as a DMM on the Floor of the Exchange includes the maintenance, in so far as reasonably practicable, of a fair and orderly market on the Exchange in the stocks in which he or she is so acting. The maintenance of a fair and orderly market implies the maintenance of price continuity with reasonable depth, to the extent possible consistent with the ability of participants to use reserve orders, and the minimizing of the effects of temporary disparity between supply and demand. In connection with the maintenance of a fair and orderly market, it is commonly desirable that a member acting as DMM engage to a reasonable degree under existing circumstances in dealings for the DMM's own account when lack of price continuity, lack of depth, or disparity between supply and demand exists or is reasonably to be anticipated.

(iii) The Exchange will supply DMMs with suggested Depth Guidelines for each security in which a DMM is registered. The administration of the Depth Guidelines will be contained in notices periodically issued to all DMMs. In connection with a DMM's responsibility to maintain a fair and orderly market, DMMs will be expected to quote and trade with reference to the Depth Guidelines where necessary.

(iv) DMMs are designated as market maker on the Exchange for all purposes under the Securities Exchange Act of 1934 and the rules and regulations thereunder.

NYSE Rule 123E. DMM Combination Review Policy

(a) No DMM unit shall complete a "proposed combination" (as defined below in paragraph (b) of this rule) with one or more other DMM units unless the combination has been approved by the Exchange.

(b) For purposes of this rule, a "proposed combination" means:

(1) a transaction in which two or more DMM units agree to merge or otherwise combine their businesses, with the result that the total number of existing independent DMM units will be reduced;

(2) two or more DMM units agree to combine their businesses with the result that the existing number of DMM units will not be reduced, but one or more of the surviving units is substantially reduced in size; or

(3) a DMM unit merges or otherwise combines with a non-DMM business resulting in a change of control of the existing DMM unit.

(c) Proponents of a DMM unit combination must make a written submission to the Office of the Corporate Secretary of the Exchange, discussing all the factors for review pursuant to subparagraph (d) below. The written submission should also address and discuss:

(1) performance in any securities received through previous combinations or transfers of registrations during the preceding two years;

(2) whether the resulting DMM unit will maintain staffing adequate to the needs of the market place;

(3) whether the proposed combined unit will have a real-time surveillance system that monitors DMM trading and uses exception alerts to detect unusual trades or trading patterns; and

(4) whether the proposed combined unit will have disaster recovery facilities for its computer network and software;

(5) whether it has designated specific individuals to handle unusual situations on the Floor (if so, the names of the individuals);

(6) whether the combined unit will employ a "zone" or other management system on the Floor (with identification of the names of the individuals and their specific responsibilities, as applicable); and

(7) whether the combined unit will designate a senior staff member to be responsible for reviewing DMM performance data, with specific procedures for correcting any deficiencies identified.

(d) The Exchange will consider the following criteria in its review of a proposed combination:

(1) the ability of the DMM unit or units resulting from the transaction to comply with NYSE rules, including, without limitation, the provision of Rule 98; Rule 103; Rule 103B, Section II; and Rule 104;

(2) whether the proposed combination minimizes both the potential for financial failure and the negative consequences of any such failure on the DMM system as a whole;

(3) whether the proposed combination maintains or increases operational efficiencies;

(4) the surviving DMM unit's commitment to the Exchange market, including but not limited to whether the constituent DMM units:

(A) work to support, strengthen and advance the Exchange, its market and its competitiveness in relation to other markets;

(B) participate upon request in the Exchange's marketing seminars, sales calls and other marketing initiatives seeking to attract order flow and new listings;

(C) accept innovations in order-routing and other trade-support systems and willingness to make optimal use of the systems once they become fully operational;

(D) assist other units by providing capital and personnel in unusual market situations, such as "breakouts" and difficult openings;

(E) engage in efforts to streamline the efficiency of its own operations and its competitive posture; and

(5) The effect of the proposed combination on overall concentration of DMM units.

(e) Where a proposed combination involves an organization that is not a DMM unit, consideration shall entail an assessment of whether the organization will work to support, strengthen and advance the Exchange, and its competitiveness in relation to other markets.

(f) The Exchange shall approve or disapprove a proposed combination within ten (10) business days based on its assessment of the criteria pursuant to subparagraph (d) above and, in the case of a proposed combination involving a non-DMM unit, its assessment of the additional criteria pursuant to subparagraph (e) above. The Exchange reserves the right to extend its review process if the information submitted by the proponents of the DMM combination is inadequate or requires additional time to review in order for the Exchange to reach a decision.

(1) The Exchange shall approve a proposed combination if the proposed combination satisfies the criteria set forth in Rule 123E(d)(1)-(5) and if the Exchange determines that the proposed combination would:

(A) not create or foster concentration in the DMM business detrimental to the Exchange and its markets;

(B) foster competition among DMM units; and

(C) enhance the performance of the constituent DMM unit and the quality of the markets in the securities involved.

(g) The Exchange may condition its approval upon compliance by the resulting DMM unit with any steps the Exchange may specify to address any concerns it may have in regard to considerations of the above criteria.

(h) In any instance where the Exchange does not approve a proposed DMM combination, the proponents of such proposed combination have a right to have such decision reviewed by the Exchange's Board of Directors.

C Consolidated Tables and Figures

For readers' convenience, we consolidate in this Appendix all of the tables that appear in the body of the paper. These tables are identical to their counterparts in the body of the paper.

Table 1: Summary Statistics for Treated and Control Stocks

Table 1 presents summary statistics for the stocks in our sample. The "treated" group consists of 980 stocks that are traded on the NYSE. The "control" group consists of 922 stocks that do not trade on the NYSE.

	Treated		**Control**	
	Mean	*Std. Dev.*	*Mean*	*Std. Dev.*
Quoted Spread (cent)	5.24	7.46	7.87	11.83
Proportional Quoted Spread (bps)	17.80	19.67	20.97	20.64
Effective Spread (cent)	3.62	5.13	5.84	13.53
Proportional Effective Spread (bps)	12.76	13.96	18.41	59.70
Dollar Depth (thousand)	22.80	42.61	23.86	39.31
Daily Dollar Volume (million)	23.31	51.55	26.68	91.43
Price (dollars)	32.51	22.61	34.67	26.11
Market Capitalization (billion)	2.77	8.47	2.87	9.88

Table 2: Normalized Spreads—Differences and Diffs-in-Diffs on July 8th (NYSE Halt)

Table 2 summarizes the results for normalized proportional quoted spreads and normalized proportional effective spreads on the day of the NYSE trading halt, July 8. For each stock, we calculate the average normalized measures of spreads in the period before the NYSE trading halt (9:30:00 AM - 11:29:59 AM), during the halt (11:30:00 AM - 3:09:59 PM), and after the halt (3:10:00 PM - 4:00:00 PM). The "not during" period combines the "before" and "after" periods. The first column of the table report the averages among the treatment stocks of the difference in liquidity across the indicated time-periods; the second column reports the analogous average among the control stocks. The third column reports the difference in these averages between the treatment group and the control group. The fourth and fifth columns report the t-statistic and p-value associated with the null hypothesis that this diff-in-diffs equals zero. The t-statistics and p-values are based on bootstrap distributions generated using data from the month of July 2015, excluding July 6 and July 8.
Quoted spreads are computed as time-weighted averages, while effective spreads are computed as trade-size-weighted averages. To adjust for intraday seasonality, we calculate the monthly average of the indicated measure for each stock during each of the 39 ten-minute time intervals, then divide the values measured on July 8th by the corresponding interval-stock monthly averages.

	Difference Across Periods		**Treatment Difference minus Control Difference**		
	Treatment	Control	Diff-in-Diffs	t-Stat	p-Value
Proportional Quoted Spread					
During minus Not	0.256	0.037	0.219	10.87	$<$1E-10
During minus Before	0.287	0.070	0.217	9.64	$<$1E-10
During minus After	0.181	-0.042	0.223	11.79	$<$1E-10
Proportional Effective Spread					
During minus Not	0.228	0.054	0.175	8.33	$<$1E-10
During minus Before	0.250	0.084	0.166	6.74	$<$1E-10
During minus After	0.177	-0.018	0.195	9.07	$<$1E-10

Table 3: Normalized Depth—Differences and Diffs-in-Diffs on July 8th (NYSE Halt)

Table 3 summarizes the results for normalized depth and normalized dollar depth on the day of the NYSE trading halt, July 8. For each stock, we calculate the average normalized measures of depth in the period before the NYSE trading halt (9:30:00 AM - 11:29:59 AM), during the halt (11:30:00 AM - 3:09:59 PM), and after the halt (3:10:00 PM - 4:00:00 PM). The "not during" period combines the "before" and "after" periods. The first column of the table report the averages among the treatment stocks of the difference in liquidity across the indicated time-periods; the second column reports the analogous average among the control stocks. The third column reports the difference in these averages between the treatment group and the control group. The fourth and fifth columns report the t-statistic and p-value associated with the null hypothesis that this diff-in-diffs equals zero. Both depth and dollar depth are computed as time-weighted averages. To adjust for intraday seasonality, we calculate the monthly average of the indicated measure for each stock during each of the 39 ten-minute time intervals, then divide the values measured on July 8th by the corresponding interval-stock monthly averages.

	Difference Across Periods		**Treatment Difference minus Control Difference**		
	Treatment	Control	Diff-in-Diffs	t-Stat	p-Value
Depth					
During minus Not	0.036	0.023	0.013	0.528	0.598
During minus Before	0.011	-0.007	0.018	0.653	0.514
During minus After	0.096	0.093	0.003	0.092	0.926
Dollar Depth					
During minus Not	0.034	0.019	0.015	0.592	0.554
During minus Before	0.007	-0.012	0.019	0.712	0.477
During minus After	0.097	0.093	0.004	0.146	0.884

Table 4: Normalized Spreads—NYSE-Halt Placebo Tests on July 7th and July 9th

Table 4 reports the placebo-test results for normalized proportional quoted spreads (Panel A) and normalized proportional effective spreads (Panel B). Using data from July 7th, and then July 9th, we repeat the analysis from Subsection 3.1: for each stock, we calculate the average normalized measures of spreads in the period before the time of NYSE trading halt on July 8th (9:30:00 AM - 11:29:59 AM), during the time of the halt on July 8th (11:30:00 AM - 3:09:59 PM), and after the time of the halt on July 8th (3:10:00 PM - 4:00:00 PM). The "not during" period combines the "before" and "after" periods. The first column of the table report the averages among the treatment stocks of the difference in liquidity across the indicated time-periods; the second column reports the analogous average among the control stocks. The third column reports the difference in these averages between the treatment group and the control group. The fourth and fifth columns report the t-statistic and p-value associated with the null hypothesis that this diff-in-diffs equals zero. The t-statistics and p-values are based on bootstrap distributions generated using data from the month of July 2015, excluding July 6 and July 8.

Panel A: Normalized Proportional Quoted Spread

	Difference Across Periods		**Treatment Diff minus Control Diff**		
	Treatment	Control	Diff-in-Diffs	t-Stat	p-Value
July 7th					
During minus Not	0.086	0.069	0.017	0.839	0.401
During minus Before	0.097	0.075	0.022	0.960	0.337
During minus After	0.059	0.054	0.005	0.258	0.796
July 9th					
During minus Not	-0.030	-0.034	0.004	0.197	0.844
During minus Before	-0.040	-0.053	0.013	0.574	0.566
During minus After	-0.005	0.013	-0.018	-0.921	0.357

Panel B: Normalized Proportional Effective Spread

	Difference Across Periods		**Treatment Diff minus Control Diff**		
	Treatment	Control	Diff-in-Diffs	t-Stat	p-Value
July 7th					
During minus Not	0.095	0.089	0.006	0.299	0.765
During minus Before	0.106	0.096	0.010	0.404	0.686
During minus After	0.069	0.072	-0.003	-0.126	0.900
July 9th					
During minus Not	-0.027	-0.031	0.004	0.187	0.852
During minus Before	-0.037	-0.049	0.012	0.468	0.640
During minus After	-0.003	0.011	-0.014	-0.656	0.512

Table 5: Liquidity Diffs-in-Diffs for the EDGX Halt

Table 5 summarizes the results for diff-in-diffs of various liquidity measures during the EDGX shutdown on July 6, 2015. All liquidity measures are normalized—i.e., adjusted to correct for intraday seasonality effects—in the same manner used throughout the rest of the paper. We calculate the average normalized liquidity measures for the period during the EDGX shutdown (9:40:00 AM - 10:19:59 AM), and for the complementary portion of the trading day. The first column reports the averages among the treatment stocks of the difference in the indicated liquidity measure between the "during-shutdown" and "not-during-shutdown" periods; the second column reports the analogous averages among the control stocks. The third column reports the difference in these averages between the treatment group and the control group. For spreads, we test the null hypothesis that the diff-in-diffs is *less than or equal to zero*, while for depths, we test the null hypothesis that the diff-in-diffs is *greater than or equal to zero*. The fourth and fifth columns report, respectively, the t-statistics and p-values associated with the null hypothesis. The t-statistics and p-values are based on bootstrap distributions generated using data from the month of July 2015, excluding July 6 and July 8. Panel A reports results for the actual day of the EDGX shutdown, July 6th. To provide context, Panel B compares the results from July 6 against placebo-test results from July 7 and July 9.

Panel A: EDGX Shutdown

	During minus Not During		**Treatment Diff minus Control Diff**		
	Treatment	Control	Mean	t-Stat	p-Value
Proportional Qtd Spread	-0.0045	0.0349	-0.0394	-1.68	0.952
Proportional Eff Spread	0.0006	0.0445	-0.0438	-1.72	0.955
Depth	0.0383	0.0584	-0.0201	-0.50	0.383
Dollar Depth	0.0366	0.0530	-0.0164	-0.41	0.315

Panel B: Placebos

	During minus Not During		**Treatment Diff minus Control Diff**		
	Treatment	Control	Mean	t-Stat	p-Value
Proportional Qtd Spread					
Placebo, July 7	-0.1410	-0.1242	-0.0168	-0.72	0.763
EDGX Halt, July 6	-0.0045	0.0349	-0.0394	-1.68	0.952
Placebo, July 9	0.0012	0.0223	-0.0211	-0.90	0.816
Proportional Eff Spread					
Placebo, July 7	-0.1330	-0.1200	-0.0130	-0.51	0.692
EDGX Halt, July 6	0.0006	0.0445	-0.0438	-1.72	0.955
Placebo, July 9	0.0082	0.0192	-0.0110	-0.43	0.666

Table 6: EDGX Market-Share and Variation in Liquidity Diffs During the EDGX Halt

Table 6 reports results from cross-sectional regressions of "during-EDGX-halt minus not-during-EDGX-halt" differences in liquidity (denoted Δ_i^{EDGX}), on the average fraction of a stock's total consolidated volume that executed at EDGX in the three trading days preceding the EDGX halt (denoted $EDGXshare_i$). To allow for systematic differences between control and treatment stocks' sensitivity to a general "shutdown shock," we include separate intercepts for the two groups:

$$\Delta^{EDGX} = \psi_1 \mathbb{I}_{treatment} + \psi_2 \mathbb{I}_{control} + \psi_3 EDGXshare + \epsilon$$

The indicator variable $\mathbb{I}_{treatment,i}$ equals 1 if stock i is in the treatment group and equals 0 otherwise; we set $\mathbb{I}_{control,i} := 1 - \mathbb{I}_{treatment,i}$ to define the indicator variable for control-group stocks. Standard errors are in parentheses. ***, **, and * indicate the statistical significance at the 1%, 5%, and 10% levels, respectively.

	Diff. in Normalized Proportional Quoted Spread	Diff. in Normalized Proportional Effective Spread
	(1)	*(2)*
$\mathbb{I}_{treatment}$	-0.0078	-0.0048
	(0.0103)	(0.0165)
$\mathbb{I}_{control}$	0.0299**	0.0362
	(0.0139)	(0.0222)
$EDGXshare$	0.0625	0.1020
	(0.1496)	(0.2393)
Adjusted R^2	0.0090	0.0044

Table 7: Explanatory Power of DMM vs. Non-DMM Participation Rates for Liquidity Reduction During NYSE Halt

Table 7 reports results from cross-sectional regressions of "during-NYSE-halt minus before-NYSE-halt" differences in liquidity, on stock-by-stock measures of NYSE market-share and DMM participation prior to the NYSE trading halt. The variable $NYSEshare_i$ represents average fraction of total trading volume (across all exchanges and off-exchange trading venues) in stock i that executes on the NYSE during the three trading days preceding July 8th, 2015. We decompose this NYSE market-share into a DMM component, $DMMshare_i$, and a non-DMM component, $NonDMMshare_i$, where $NYSEshare_i \equiv DMMshare_i + NonDMMshare_i$. Standard errors are in parentheses. ***, **, and * indicate the statistical significance at the 1%, 5%, and 10% levels, respectively.

	Diff. in Normalized Proportional Quoted Spread			Diff. in Normalized Proportional Effective Spread		
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
$DMMshare$	1.931***	1.877***		1.353***	1.314***	
	(0.197)	(0.190)		(0.263)	(0.253)	
$NonDMMshare$	-0.675			-0.482		
	(0.656)			(0.876)		
$NYSEshare$			1.576***			1.103***
			(0.171)			(0.227)
Constant	-0.057	-0.065*	-0.049	0.009	0.004	0.015
	(0.038)	(0.037)	(0.038)	(0.050)	(0.049)	(0.050)
Adjusted R^2	0.0919	0.0919	0.0812	0.0271	0.0278	0.0246

Table 8: Explanatory Power of DMM vs. Non-DMM Participation Rates for Liquidity Reduction During NYSE Halt (with Additional Controls)

Table 8 reports results from cross-sectional regressions of "during-NYSE-halt minus before-NYSE-halt" differences in liquidity, on stock-by-stock measures of DMM and non-DMM participation prior to the NYSE trading halt, along with a variety of additional control variables. Notation is consistent with that of Table 7. The variable $DMMshare$ measures the ratio of volume with DMMs as liquidity providers in a given stock to total consolidated volume in that stock, and the variable $NonDMMshare$ measures the analogous ratio for the remainder of liquidity provision on the NYSE. Both of these measures are calculated using data from the three trading days preceding July 8, 2015. The variable "*price*" is the stock's average closing price; "*logmktcap*" is the logarithm of the stock's market capitalization; "*AnalystCoverage*" is the number of analysts following the stock. Standard errors are in parentheses. ***, **, and * indicate the statistical significance at the 1%, 5%, and 10% levels, respectively.

	Diff. in Normalized Proportional Quoted Spread	Diff. in Normalized Proportional Effective Spread
	(1)	*(2)*
$DMMshare$	2.009***	1.439***
	(0.193)	(0.261)
$NonDMMshare$	0.674	0.753
	(0.668)	(0.906)
price	0.002***	0.002***
	(0.0002)	(0.0003)
logmktcap	-0.005	-0.017
	(0.010)	(0.013)
AnalystCoverage	-0.002	-0.002
	(0.002)	(0.002)
Constant	-0.117	0.048
	(0.072)	(0.097)
Adjusted R^2	0.136	0.047

Table 9: Patterns of Cross-Sectional Variation in DMM Liquidity Provision

Table 9 reports regression results concerning factors that explain cross-sectional variation in the DMM participation rate. Notation is consistent with that of Tables 7 and 8. The variable $\frac{DMMshare}{NYSEshare}$ measures the ratio of volume with DMMs as liquidity providers in a given stock to the NYSE volume in that stock. The variable $DMMshare$ measures the ratio of volume with DMMs as liquidity providers in a given stock to total consolidated volume in that stock. Both of these measures are calculated using data from the three trading days preceding July 8, 2015. (The logarithms of these measures are used as the dependent variables in the regressions, so that the regression coefficients can be interpreted as elasticities or semi-elasticities.) The variable "*log_ price*" is the logarithm of the stock's average closing price; "*logmktcap*" is the logarithm of the stock's market capitalization; "*AnalystCoverage*" is the number of analysts following the stock. Standard errors are given in parentheses. ***, **, and * indicate the statistical significance at the 1%, 5%, and 10% levels, respectively.

	$\log\left(\frac{DMMshare}{NYSEshare}\right)$	$\log\left(DMMshare\right)$
	(1)	*(2)*
log_ price	0.0413***	-0.0446***
	(0.0031)	(0.0141)
logmktcap	-0.0102***	0.0338***
	(0.0022)	(0.0100)
AnalystCoverage	0.0005	-0.0023
	(0.0003)	(0.0015)
Constant	-0.1718***	-1.8066***
	(0.0127)	(0.0578)
Adjusted R^2	0.1678	0.0128

Table 10: NYSE Halt Liquidity Reduction—Effects of Market-Cap, Price, Analyst Coverage, $DMMshare$, and Interactions

Table 10 reports results from cross-sectional regressions of "during-NYSE-halt minus before-NYSE-halt" differences in normalized proportional quoted spreads, on a measure of DMM participation prior to the NYSE trading halt ("$DMMshare$"), the logarithm of stock market-cap ("*logmktcap"),* stock price ("*price*"), the number of analysts following the stock (*"Analystcover"*) and the interaction terms of $DMMshare$ with each of the other three variables. The variable $DMMshare_i$ represents the average ratio of DMM volume in stock i to total consolidated volume in stock i during the three trading days preceding July 8th, 2015. Standard errors are in parentheses. ***, **, and * indicate the statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)	(5)
price	0.0011***	-0.0011			
	(0.0002)	(0.0008)			
logmktcap	0.0081	-0.0132			
	(0.0102)	(0.0099)			
Analystcover	-0.0034*	-0.0024			
	(0.0017)	(0.0016)			
DMMshare		1.2541***	1.6180***	2.2569***	1.7511***
		(0.2955)	(0.1879)	(0.3600)	(0.1959)
price× *DMMshare*		0.0174***	0.0089***	0.0104***	0.0099***
		(0.0050)	(0.0012)	(0.0014)	(0.0013)
logmktcap× *DMMshare*				-0.0820**	
				(0.0344)	
Analystcover× *DMMshare*					-0.0153**
					(0.0066)
Constant	0.2647***	0.0841	-0.0999***	-0.1061***	-0.0991***
	(0.0617)	(0.0909)	(0.0362)	(0.0363)	(0.0361)
Adjusted R^2	0.0311	0.1459	0.1389	0.1418	0.1427