# 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 U.S. 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 proprietary data set, to identify the causal impact of Designated Market Maker (DMM) participation on liquidity. When the voluntary liquidity providers on one exchange were removed, liquidity remained unchanged; when DMMs were removed, liquidity decreased market-wide. We find evidence consistent with the idea that these DMMs, despite facing only mild formal obligations, significantly improve liquidity in the modern electronic marketplace.

JEL Classification. G14, G24

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## 1. Introduction

In decades past, designated market makers (DMMs) were central fixtures of the equities trading landscape in the United States. However, since the advent of the Regulation of National Market System (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 market quality in their stocks. Nevertheless, modern electronic markets rely almost entirely on voluntary liquidity provision, and the markets generally seem to function well. Although the 2010 Flash Crash rekindled interest in market-maker obligations at times of extreme market turmoil, it is not obvious that DMMs remain relevant in ordinary times. In U.S. markets, modern DMMs' obligations seem too small to clearly differentiate them from voluntary liquidity providers. However, using a pair of natural experiments, we find strong evidence consistent with the notion that these DMMs continue to exert an economically significant influence on U.S. markets.

The New York Stock Exchange (NYSE) is the only major exchange in the U.S. that still has DMMs, and these DMMs face relatively light obligations. The NYSE DMMs' mild obligations contrast sharply with those of, for example, some European DMMs who are required to keep the spread within contractually prescribed limits that many times bind.[1] Rigid obligations such as these "maximum spread rules" can certainly induce changes in various dimensions of market quality. The scope for mild obligations to produce changes in market quality is less obvious.

The bulk of the obligations that the NYSE DMMs face are somewhat subjective. These DMMs are required, "insofar as reasonably practicable," to maintain a "fair and orderly" market in their stocks, which implies maintaining price continuity with reasonable depth, and minimizing of the effects of temporary disparity between supply and demand. They have no obligation to narrow the bid-ask spread. The DMMs' explicitly quantified obligations, even in the most restrictive cases, are quite mild: DMMs must quote at the national best bid and offer (NBBO) at least 15% of the time, and maintain quotes not more than 8% away from the NBB/NBO. For context, the average proportional quoted spread among the NYSE stocks that we study is roughly 18 basis points (bps). Although NYSE DMMs can potentially face disciplinary action and fines if they fail to maintain a

[1] See, for example, Venkataraman and Waisburd (2007), Anand et al. (2009), Menkveld and Wang (2013), and Bessembinder et al. (2015).

fair and orderly market insofar as reasonably practicable, the extent to which the loosely worded fair-and-orderly obligations have independent "bite" is unclear.

To investigate the causal impact of NYSE DMMs' presence in the market, we begin by exploiting a natural experiment that arose on July 8, 2015, when a computer glitch forced the NYSE to halt trading from 11:32 a.m. to 3:10 p.m. This unexpected, exogenous event provides a unique opportunity to examine the impact of DMMs on market quality, since the trading halt exogenously removed all DMMs from the market.[2] Moreover, non-NYSE-listed stocks do not trade on the NYSE, so they were not directly affected by the exchange's trading halt. 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 significantly relative to that of non-NYSE-listed stocks after the trading halt began. Compared to the control group, the average NBBO proportional quoted 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. Almost immediately after trading resumed on the NYSE, spreads for the NYSE-listed stocks narrowed to their pre-halt values.

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, a second exogenous exchange-shutdown helps us to alleviate this concern. 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 reduction of liquidity observed during the NYSE shutdown therefore presents a puzzle. The trading halt closed down only one exchange out of 11. Liquidity providers and demanders in

[2]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.

equities markets are not directly affected by a technology glitch at a single exchange, in that they can still 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 are readily ruled out by placebo tests using adjacent days' data. We're led to the inevitable conclusion that the NYSE is not redundant: it has some important distinguishing feature that causes improvement in liquidity.

The presence of DMMs is unambiguously one of the NYSE's distinctive features, but attributing liquidity effects to DMMs requires additional analysis. To explicitly investigate whether our results reflect effects that may be attributable to the presence/absence of DMMs, we analyze a proprietary NYSE data set that documents the participation rate of the DMM for each NYSE-listed stock. This data set enables us to isolate the trading on the NYSE where DMMs, as opposed to non-DMMs, participated. 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 we find no evidence that the non-DMM participation rate has such predictive power. In other words, the NYSE market share does not appear to explain any additional cross-sectional variation beyond what is explained by the share of DMM participation alone. These findings are consistent with the notion that DMM participation drives the liquidity results.

Our study contributes to the literature by examining an exogenous loss of DMMs, thereby avoiding the problem of self-selection bias pervasive in empirical studies on the impact of DMMs. The extant empirical literature on DMMs focuses on the introduction of the voluntary DMM contracts in France, Italy, the Netherlands, and Sweden. [3] 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

[3] See Venkataraman and Waisburd (2007), Nimalendran and Petrella (2003) and Perroti and Rindi (2010), Menkveld and Wang (2013), and Anand et al. (2009), respectively.

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 suggests the relevance of preserving market-making obligations in a world of fast trading. The large majority of the six DMMs in our sample meet the definition of "high-frequency trader" (HFT) set forth in the U.S. Securities and Exchange Commission's 2010 Concept Release.[4] HFTs who do not have any market-making obligations also trade on the NYSE. We find no evidence that the loss of voluntary HFT liquidity-providers in the NYSE harms liquidity, whereas we find evidence consistent with the theory that the loss of DMMs causes spreads to widen substantially. Our empirical results complement the theory work of Bessembinder et al. (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 data set 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 data set, to analyze cross-sectional patterns in the participation and impact of DMMs. Section 6 discusses the issue of why NYSE DMMs might improve liquidity to the extent that empirical results suggest. Section 7 concludes.

## 2. Data and institutional details

In this section, we provide an overview of key institutional details of the NYSE's DMM system, describe our data and measure of liquidity, and explain the technique we use to correct for intraday seasonality in our data.

[4]The six DMM firms are Barclays, Brendan E. Cryan & Co., IMC Financial Markets, J Streicher & Co. LLC, KCG, and Virtu Financial Capital Markets LLC.

### *2.1. Institutional details*

According to the NYSE, its designated market-makers are the cornerstone of the exchange's market model. Each stock has one DMM, whom the issuer selects. DMMs are the successors of the so-called "specialists" on the NYSE.

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' affirmative obligations are not identical to those of the specialists. For example, DMMs do not face the formal Price Continuity Rule that applied to the specialists.[5] Also, DMMs do not face the negative obligations that the specialists once did. The 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," that 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. Appendix B provides the direct text of selected NYSE rules that describe DMMs' precise obligations.

### *2.2. Data and sample*

Our data are drawn from the Trade and Quote (TAQ), Center for Research in Security Prices (CRSP), and Institutional Brokers' Estimate System (I/B/E/S) databases. We also use a set of proprietary data on NYSE DMM participation that we describe in detail in Section 4, where the data enter our analysis. Our preliminary sample of stocks consists of all common stocks that are present in the Daily TAQ (DTAQ) 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.

[5] Panayides (2007) discusses the specialists' affirmative obligations, and the particular importance of the Price Continuity Rule.

**Table 1**
Summary statistics for treated and control stocks

Table 1 presents summary statistics describing the stocks in our sample for July of 2015. July 6, the day of the EDGX halt, and July 8, the day of the NYSE halt, are not used in computing these summary statistics. 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 |

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 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 NBBO prices, and we calculate liquidity measures following Holden and Jacobsen (2014).[6] The *quoted spread* is 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

[6] 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 quotes whose bids are greater than or equal to asks. We also delete cases in which the quoted spread is greater than $5.00.

spread are weighted by trade-size. We measure depth as the time-weighted average of displayed depth at the NBBO.

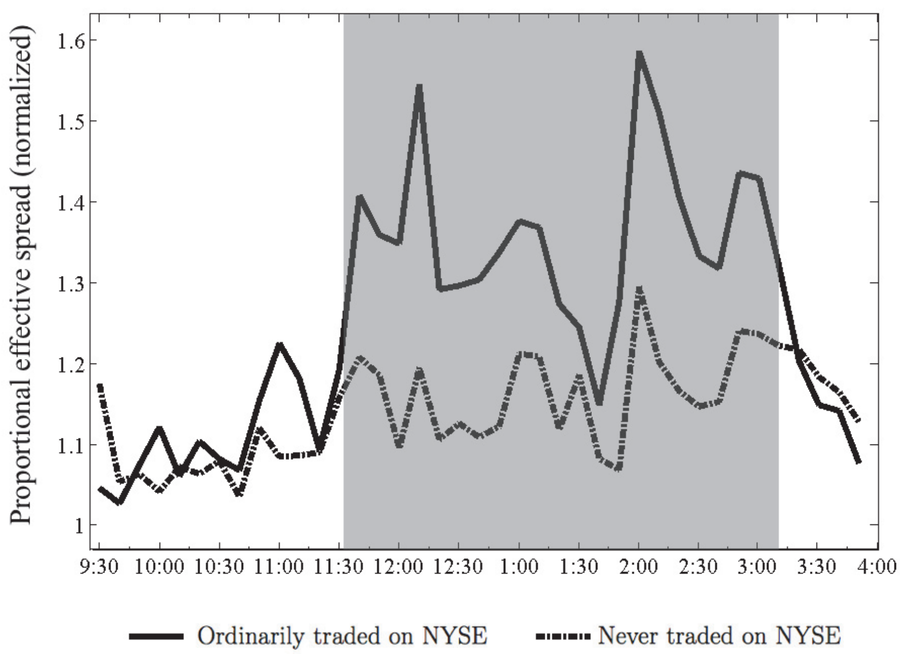
### *2.3. Intraday seasonality correction and normalizations*

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 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 correct for 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 ten-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.

Fig. 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 ten-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 the month. The solid black line reflects the cross-sectional average among the 980 treatment stocks, while the dashed line reflects the cross-sectional average among the 922 control stocks. So, for example, during the interval 12:00:00 p.m. – 12:09:59 p.m. on July 8, proportional 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. For brevity, we omit results on non-proportional spreads, but the results are nearly identical to those reported for the proportional spreads.

**Fig. 1.** Normalized proportional effective spreads on July 8th (NYSE halt). This figure 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 solid black line reflects the cross-sectional average among the 980 treatment stocks (stocks ordinarily traded on the NYSE), while the dashed line reflects the cross-sectional average among the 922 control stocks (stocks never traded on the NYSE). The horizontal axis represents time throughout the trading day, 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. For example, during the interval 12:00:00 p.m. – 12:09:59 p.m. on July 8, proportional 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.



## 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-diffs procedure sets up the framework for our subsequent refinements and elaborations. Section 3.1 presents and discusses the primary diff-in-diffs results. Section 3.2 considers the limitations of the control group as a fully suitable "control," and presents placebo-test results as a partial remedy. Section 3.3 uses the shutdown of EDGX on July 6 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 a.m. – 11:29:59 a.m.), during the halt (11:30:00 a.m. – 3:09:59 p.m.), after the halt (3:10:00 p.m. – 4:00:00 p.m.), 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 twenty million draws to construct each bootstrap distribution.

**Table 2**
Normalized spread differences and diffs-in-diffs on July 8th (NYSE halt)

Table 2 summarizes difference and diff-in-diffs results for normalized proportional quoted spreads (Panel A) and normalized proportional effective spreads (Panel B) on July 8, 2015, the day of the NYSE trading halt. NYSE-listed stocks' spreads increased during the halt, and increased significantly more than did those of non-NYSE-listed stocks. Quoted spreads are computed as time-weighted averages, while effective spreads are computed as trade-size-weighted averages. To normalize for intraday seasonality, we calculate the monthly average of the indicated measure for each stock during each of the 39 ten-minute time intervals in a trading day, then divide the values measured on July 8th by the corresponding interval-stock monthly averages. For each stock, we calculate the average normalized measures of spreads in the period before the NYSE trading halt (9:30 a.m. – 11:30 a.m.), during the halt (11:30 a.m. – 3:10 p.m.), and after the halt (3:10 p.m. – 4:00 p.m.). The "not during" period combines the "before" and "after" periods. The first column in Table 2 reports the averages among the 980 NYSE-listed treatment stocks of the difference in liquidity across the indicated time-periods; the second column reports the analogous average among the 922 non-NYSE-listed control stocks. The third column reports the difference in these averages between the treatment group and the control group. The fourth column reports the $p$-value associated with the null hypothesis that this diff-in-diffs equals zero. The $p$-values are based on bootstrap distributions generated using data from the month of July 2015, excluding July 6 (the day of the EDGX halt) and July 8.

*Panel A: Proportional quoted spreads*

| | Diff across periods | | Treat diff minus Control diff | |
|---|---|---|---|---|
| | Treatment | Control | Diff-in-diffs | $p$-Value |
| During minus Not | 0.256 | 0.037 | 0.219 | $<$1E-7 |
| During minus Before | 0.287 | 0.070 | 0.217 | $<$1E-7 |
| During minus After | 0.181 | -0.042 | 0.223 | $<$1E-7 |

*Panel B: Proportional effective spreads*

| | Diff across periods | | Treat diff minus Control diff | |
|---|---|---|---|---|
| | Treatment | Control | Diff-in-diffs | $p$-Value |
| During minus Not | 0.228 | 0.054 | 0.175 | $<$1E-7 |
| During minus Before | 0.250 | 0.084 | 0.166 | $<$1E-7 |
| During minus After | 0.177 | -0.018 | 0.195 | $<$1E-7 |

#### 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 of this large 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 highly significant, both statistically and economically.

#### 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 Section 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 Section 3.1 using data from July 7 (the day before the NYSE shutdown), and from July 9 (the day after the NYSE shutdown). Fig. 2 illustrates the placebo analysis in the case of proportional effective spreads. Both panels of

**Table 3**
Normalized depth differences and diffs-in-diffs on July 8th (NYSE halt)

Table 3 summarizes results from difference-in-differences tests around the NYSE trading halt on July 8, 2015, for depth (Panel A) and dollar depth (Panel B). We find no significant difference between changes in NYSE-listed stocks' and non-NYSE-listed stocks' depth or dollar depth. Both depth and dollar depth are computed as time-weighted averages. To normalize for intraday seasonality, we calculate the monthly average of the indicated measure for each stock during each of the 39 ten-minute time intervals in a trading day, then divide the values measured on July 8th by the corresponding interval-stock monthly averages. For each stock, we calculate the average normalized measures of depth in the period before the NYSE trading halt (9:30 a.m. – 11:30 a.m.), during the halt (11:30a.m. – 3:10 p.m.), and after the halt (3:10 p.m. – 4:00 p.m.). The "not during" period combines the "before" and "after" periods. The first column of the table reports the averages among the 980 NYSE-listed treatment stocks of the difference in liquidity across the indicated time-periods, and the second column reports the analogous averages among the 922 non-NYSE-listed control stocks. The third column reports the difference in these averages between the treatment group and the control group. The fourth column reports the $p$-value associated with the null hypothesis that this diff-in-diffs equals zero. The $p$-values are based on bootstrap distributions generated using data from the month of July 2015, excluding July 6 (the day of the EDGX halt) and July 8.

*Panel A: Depth*

| | Diff across periods | | Treat diff minus Control diff | |
|---|---|---|---|---|
| | Treatment | Control | Diff-in-diffs | $p$-Value |
| During minus Not | 0.036 | 0.023 | 0.013 | 0.598 |
| During minus Before | 0.011 | -0.007 | 0.018 | 0.514 |
| During minus After | 0.096 | 0.093 | 0.003 | 0.926 |

*Panel B: Dollar depth*

| | Diff across periods | | Treat diff minus Control diff | |
|---|---|---|---|---|
| | Treatment | Control | Diff-in-diffs | $p$-Value |
| During minus Not | 0.034 | 0.019 | 0.015 | 0.554 |
| During minus Before | 0.007 | -0.012 | 0.019 | 0.477 |
| During minus After | 0.097 | 0.093 | 0.004 | 0.884 |

**Fig. 2.** Normalized proportional effective spread placebos for the NYSE halt. This figure 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, 2015; the NYSE was not shut down during this period on July 7 or July 9. The solid black line reflects the cross-sectional average among the 980 treatment stocks (stocks ordinarily traded on the NYSE), while the dashed line reflects the cross-sectional average among the 922 control stocks (stocks never traded on the NYSE). The horizontal axis represents time throughout the trading day, 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.

*Panel A: July 7th* *Panel B: July 9th*

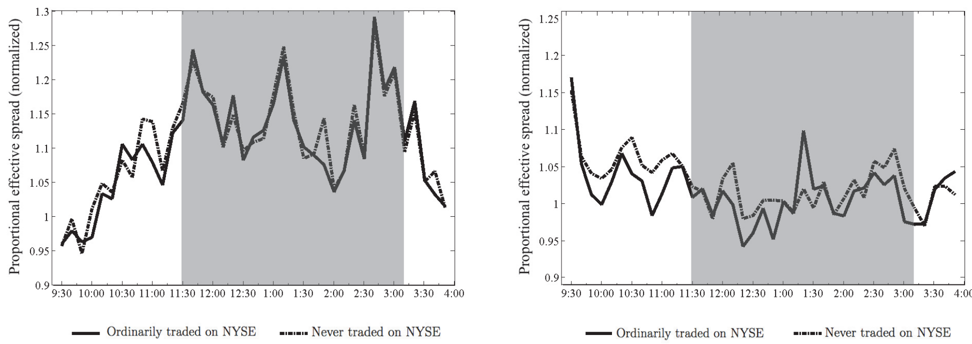



Fig. 2 are analogues of Fig. 1. As in Fig. 1, the gray shaded region indicates the period during which the NYSE was shut down on July 8; however, the NYSE remained open and operational during those times on July 7 and July 9.

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 Section 3.1 could not be driven by intraday seasonality, nor could they be driven by 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.

### *3.3. EDGX shutdown*

The preceding sections establish that during the NYSE trading halt on July 8, the NYSE-listed stocks that comprise our treatment group exhibited a significant reduction in liquidity relative to non-NYSE-listed stocks that comprise our control group. However, stocks were assigned to the control-group or treatment-group on the basis of their listing exchange, and firms' choice of listing exchange is not random. The fundamental concern, therefore, is that our treatment stocks might be more sensitive to a general "shutdown shock" than are our control stocks. We address this concern

**Table 4**
Placebo diff-in-diff results for normalized spreads on July 7th and July 9th

Table 4 reports the placebo-test diff-in-diff results for normalized proportional quoted and effective spreads. The significant diff-in-diffs spread results from the NYSE halt are not mechanical artifacts; applying identical diff-in-diffs analysis to data from days adjacent to the NYSE halt does not produce significant results. Using data from July 7th, and then July 9th, we repeat the analysis from Section 3.1: For each stock, we calculate the average normalized measures of depth in the period before the NYSE trading halt (9:30 a.m. – 11:30 a.m.), during the halt (11:30 a.m. – 3:10 p.m.), and after the halt (3:10 p.m. – 4:00 p.m.). The "not during" period combines the "before" and "after" periods. The first column of the table reports the averages among the 980 NYSE-listed treatment stocks of the difference in liquidity across the indicated time-periods, and the second column reports the analogous averages among the 922 non-NYSE-listed control stocks. The third column reports the difference in these averages between the treatment group and the control group. The fourth column reports the $p$-value associated with the null hypothesis that this diff-in-diffs equals zero. The $p$-values are based on bootstrap distributions generated using data from the month of July 2015, excluding July 6 (the day of the EDGX halt) and July 8 (the day of the NYSE halt).

*Panel A: Normalized proportional quoted spread*

| | Difference across periods | | Treatment diff minus Control diff | |
|---|---|---|---|---|
| | Treatment | Control | Diff-in-diffs | $p$-Value |
| July 7th | | | | |
| During minus Not | 0.086 | 0.069 | 0.017 | 0.401 |
| During minus Before | 0.097 | 0.075 | 0.022 | 0.337 |
| During minus After | 0.059 | 0.054 | 0.005 | 0.796 |
| July 9th | | | | |
| During minus Not | -0.030 | -0.034 | 0.004 | 0.844 |
| During minus Before | -0.040 | -0.053 | 0.013 | 0.566 |
| During minus After | -0.005 | 0.013 | -0.018 | 0.357 |

*Panel B: Normalized proportional effective spread*

| | Difference across periods | | Treatment diff minus Control diff | |
|---|---|---|---|---|
| | Treatment | Control | Diff-in-diffs | $p$-Value |
| July 7th | | | | |
| During minus Not | 0.095 | 0.089 | 0.006 | 0.765 |
| During minus Before | 0.106 | 0.096 | 0.010 | 0.686 |
| During minus After | 0.069 | 0.072 | -0.003 | 0.900 |
| July 9th | | | | |
| During minus Not | -0.027 | -0.031 | 0.004 | 0.852 |
| During minus Before | -0.037 | -0.049 | 0.012 | 0.640 |
| During minus After | -0.003 | 0.011 | -0.014 | 0.512 |

by examining a separate exogenous technology-related trading halt that occurred on the EDGX platform two days prior to the NYSE glitch. The EDGX halt allows us to directly observe how a trading-venue shutdown affects the stocks in our sample. 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.

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.[7] 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 nontrivial event (although we find that the effects of the July 6th shutdown were trivial).

We apply the same general methodology used in Sections 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 a.m. – 10:19:59 a.m.), 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 neither find 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.[8] 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 seems to have had almost no effect on the market as a whole.

The evidence from the EDGX shutdown indicates that the results in Section 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

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

[8]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. We find no evidence that our results in this section are driven by differences in the fraction of trading on EDGX.

**Table 5**
Liquidity differences and diffs-in-diffs from the EDGX halt

Table 5 summarizes the results for diffs-in-diffs of various liquidity measures on July 6, 2015, the day of the EDGX halt. Unlike the NYSE halt on July 8, the EDGX halt did not produce significant differences in liquidity. To normalize for intraday seasonality, we calculate the monthly average of the indicated measure for each stock during each of the 39 ten-minute time intervals of the trading day, then divide the values measured on July 6th by the corresponding interval-stock monthly averages. We calculate the average normalized liquidity measures for the period during the EDGX shutdown (9:40 a.m. – 10:20 a.m.), 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 the $p$-values associated with the indicated null hypothesis. The $p$-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 halt, 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 halt*

| | During minus Not during | | Treatment diff minus Control diff | | |
|---|---|---|---|---|---|
| | Treatment | Control | Mean | $p$-Value | $p$-Value |
| | | | | $H_0 : DiD \leq 0$ | $H_0 : DiD \geq 0$ |
| *Proport. qtd spread* | -0.0045 | 0.0349 | -0.0394 | 0.951 | - |
| *Proport. eff spread* | 0.0006 | 0.0445 | -0.0438 | 0.956 | - |
| *Depth* | 0.0383 | 0.0584 | -0.0201 | - | 0.384 |
| *Dollar depth* | 0.0366 | 0.0530 | -0.0164 | - | 0.315 |

*Panel B: EDGX halt vs. placebos*

| | During minus Not during | | Treatment diff minus Control diff | |
|---|---|---|---|---|
| | Treatment | Control | Mean | $p$-Value |
| | | | | ($H_0 : DiD \leq 0$) |
| *Proport. qtd spread* | | | | |
| Placebo, July 7 | -0.1410 | -0.1242 | -0.0168 | 0.763 |
| EDGX halt, July 6 | -0.0045 | 0.0349 | -0.0394 | 0.951 |
| Placebo, July 9 | 0.0012 | 0.0223 | -0.0211 | 0.817 |
| *Proport. eff spread* | | | | |
| Placebo, July 7 | -0.1330 | -0.1200 | -0.0130 | 0.691 |
| EDGX halt, July 6 | 0.0006 | 0.0445 | -0.0438 | 0.956 |
| Placebo, July 9 | 0.0082 | 0.0192 | -0.0110 | 0.666 |

the NYSE.

## 4. Distinguishing a DMM effect from a general NYSE effect

In the case of the EDGX trading halt, shutting down one exchange out of 11 had no significant effect. By contrast, in the case of the NYSE trading halt, shutting down one exchange out of 11 had a significant effect: the NYSE shutdown 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 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 data set obtained from the NYSE to determine DMM participation rates for each of the NYSE-listed stocks in our sample. The proprietary data set reports the daily share-volume and dollar-volume traded 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, participated.

### *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 8. 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 8 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 difference generically by $\Delta_i$ for stock $i$. We estimate the following equation:

$$\Delta_i \quad = \quad \beta_0 + \beta_1 DMMshare_i + \beta_2 NonDMMshare_i + \epsilon_i. \tag{1}$$

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 $\beta_1$ on $DMMshare$ should be significant and positive, and the coefficient $\beta_2$ on $NonDMMshare$ should not be significant. This is precisely what we find in the data.

Table 6 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.

*4.2. Robustness checks*

To verify the robustness of the preceding regression results, we re-run regression (1) with additional control variables that have been indicated previously to correlate with DMM participation. Specifically, we include the following for each stock: its price, the logarithm of its market capitalization, the number of analysts who follow it, and its information-share on the NYSE relative to all other exchanges combined. 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. We estimate:

$$\Delta_i = \beta_0 + \beta_1 DMMshare_i + \beta_2 NonDMMshare_i + \boldsymbol{x}_i' \boldsymbol{\beta}_3 + \epsilon_i, \tag{2}$$

where $\boldsymbol{x}_i$ denotes the vector of stock-specific controls, and $\boldsymbol{\beta}_3$ denotes the associated vector of coefficients.[9]

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

**Table 6**
Explanatory power of DMM vs. non-DMM participation rates for liquidity reduction during NYSE halt

Table 6 reports results from cross-sectional regressions of "during-NYSE-halt minus before-NYSE-halt" differences in spread, on stock-by-stock measures of DMM and non-DMM participation prior to the NYSE trading halt on July 8, 2015, along with a variety of additional control variables. The sample consists of the 980 treatment-group stocks. The variable $DMMshare$ measures the ratio of DMM volume in a given stock to total consolidated volume in that stock, and the variable $NonDMMshare$ measures the analogous ratio for the remainder of volume 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; *InfoShrNYSE* is the NYSE's information share for the stock (the average of the estimated minimum and maximum bounds). Standard errors are in parentheses. ***, **, and * indicate the statistical significance at the 1%, 5%, and 10% levels, respectively.

| | Diff in normalized qtd spread | | | Diff in normalized eff spread | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| *DMMshare* | 1.931*** | 2.032*** | | 1.353*** | 1.458*** | |
| | (0.197) | (0.192) | | (0.263) | (0.261) | |
| *NonDMMshare* | -0.675 | 0.589 | | -0.482 | 0.679 | |
| | (0.656) | (0.668) | | (0.876) | (0.907) | |
| *NYSEshare* | | | 1.853*** | | | 1.362*** |
| | | | (0.170) | | | (0.230) |
| *Price* | | 0.002*** | 0.002*** | | 0.001*** | 0.002*** |
| | | (0.0002) | (0.0002) | | (0.0003) | (0.0003) |
| *Logmktcap* | | -0.006 | -0.008 | | -0.018 | -0.019 |
| | | (0.010) | (0.010) | | (0.013) | (0.013) |
| *Analystcover* | | -0.002 | -0.002 | | -0.001 | -0.001 |
| | | (0.002) | (0.002) | | (0.002) | (0.002) |
| *InfoShrNYSE* | | -0.188** | -0.176* | | -0.162 | -0.155 |
| | | (0.091) | (0.091) | | (0.124) | (0.124) |
| *Constant* | -0.057 | -0.016 | -0.015 | 0.009 | 0.135 | 0.135 |
| | (0.038) | (0.087) | (0.087) | (0.050) | (0.118) | (0.118) |
| *Adjusted* $R^2$ | 0.092 | 0.139 | 0.137 | 0.027 | 0.048 | 0.048 |

We include price because the DMMs that we consider would generally be classified as HFTs, and both O'Hara et al. (2015) and Yao and Ye (2015) find that HFTs are more likely to provide liquidity to low-priced stocks. Bessembinder et al. (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 et al. (2009), include number of analysts as a proxy for information asymmetry.

Hasbrouck (1995) finds that the majority of price discovery among NYSE-listed stocks occurred on the NYSE, and a valid concern is that liquidity providers might have held back during the NYSE halt if they thought that price discovery were compromised. To address this possibility, we include the NYSE information share for each stock as a stock-specific measure of the NYSE's importance to price discovery. Appendix C presents full implementation details. The Hasbrouck (1995) methodology for computing information share produces estimates of the upper and lower bounds on the NYSE information share for each stock. Following Baillie et al. (2002) and Chakravarty et al. (2004), we use the average of the upper and lower bounds. In unreported results, we verify that the coefficients on $DMMshare$ and $NonDMMshare$ are not sensitive to the choice of upper bound vs. lower bound vs. average.

Table 6 displays the estimates from these expanded regressions. The results for quoted spreads (Column 2) are comparable to those for effective spreads (Column 5). Although the additional control variables add significant explanatory power, 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.

We also run the following regressions:

$$\Delta_i \quad = \quad \alpha_0 + \alpha_1 NYSEshare_i + \boldsymbol{x}_i' \boldsymbol{\alpha}_2 + \epsilon_i, \tag{3}$$

where $\boldsymbol{x}_i$ again denotes the vector of stock-specific controls, and $\boldsymbol{\alpha}_2$ denotes the associated vector of coefficients. That is, we regress the changes in liquidity during the NYSE shutdown on pre-halt NYSE market share in each stock. Columns 3 and 6 of Table 6 report the results for Eq. (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 Eq. (2), displayed in Columns 2 and 5, reveal that the DMM component of pre-halt NYSE market share subsumes this predictive power. Pre-halt NYSE market share appears to matter only to the extent that it proxies for pre-halt DMM participation.

Collectively, the findings in this section are consistent with the idea that the liquidity effects observed during the NYSE shutdown were driven by the removal of DMMs, rather than by the removal of the NYSE per se.

## 5. Additional cross-sectional results

Sections 3 and 4 present our central findings, namely, evidence consistent with the notion that DMMs cause a substantial improvement in liquidity. In this section we broaden the scope of our analysis, using the exogenous variation from the NYSE glitch in combination with the proprietary data set to document new stylized facts about cross-sectional patterns of modern DMMs' participation, and to obtain new empirical evidence concerning the types of stocks for which DMM participation appears to matter most.

### *5.1. Cross-sectional patterns in DMM participation*

The six current NYSE DMMs, based on their firm identity, would typically be categorized as HFTs. In the context of the Nasdaq market for common stocks (where no traders, HFTs included, face market-making obligations), Yao and Ye (2015) and Brogaard et al. (2014) find that the HFT participation rate is higher for large stocks; Yao and Ye (2015) also find that HFT liquidity provision is higher for low-priced securities. We investigate whether DMMs' pattern of participation differs from that of "normal" 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.

Table 7 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:

$$\log(participation_i) = \eta_0 + \eta_1 \log(price_i) + \eta_2 \log(marketcap_i) + \eta_3 Analystcover_i + \epsilon_i. \qquad (4)$$

In the first column of Table 7, the dependent variable is the logarithm of the ratio of DMM volume 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 DMM volume 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 7 shows that within the microcosm of the NYSE, DMMs' pattern of participation appears to run opposite to that of typical HFTs. Relative to other traders on the NYSE, DMMs participate more heavily in stocks with higher prices and smaller market caps. However, for the purposes of understanding the changes in liquidity during the NYSE shutdown, the relevant measure is DMMs' participation relative to that of traders in the market as a whole. As shown in the second column of Table 7, 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. At least by this broad-brush measure, the stocks for which DMMs participate in greater fractions of total trading are generally the same sorts of stocks that one would expect to have high levels of voluntary HFT liquidity provision.

### *5.2. Cross-sectional patterns in DMM importance*

In a recent theoretical analysis, Bessembinder et al. (2015) demonstrate that competitive market liquidity provision can be suboptimal when fundamental uncertainty and information asymmetry are large. They suggest that DMMs are more important for small firms and firms with high informational asymmetry. Anand and Venkataraman (2016) argue that voluntary liquidity provision suffices when it is adequately profitable, and that DMMs provide comparatively more liquidity when profitability is lower. These results on liquidity do not align cleanly with our findings concerning cross-sectional patterns of DMM participation. We find that DMMs tend to participate in a greater fraction of market-wide trading for large-cap stocks than for small-cap stocks, we find no significant variation in DMM participation rates as a function of analyst coverage, and we find DMM participation to be higher relative to total volume for lower-priced stocks (which have larger relative tick-sizes and therefore offer greater potential for liquidity providers to earn rents). In this subsection, we directly examine cross-sectional patterns in the importance of DMMs for liquidity,

**Table 7**
Patterns of cross-sectional variation in DMM liquidity provision

Table 7 reports regression results concerning factors that explain cross-sectional variation in the DMM participation rate. The variable $\frac{DMMshare}{NYSEshare}$ measures the ratio of DMM volume in a given stock to the NYSE volume in that stock. The sample consists of the 980 treatment-group stocks. The variable $DMMshare$ measures the ratio of DMM volume 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 the July 8, 2015 NYSE halt. (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 |

more specifically for spreads, and compare the results to those in the literature.

To analyze the cross-sectional patterns in the effect of DMM participation on spreads, controlling for the amount of DMM participation, we run regressions of "during-NYSE-halt minus before-NYSE-halt" differences in normalized proportional quoted spreads ($\Delta_i$), 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.

Table 8 reports results from these regressions. Column 1 of Table 8 displays results from the regression with no interaction terms or $DMMshare$,

$$\Delta_i = \phi_0 + \phi_1 price_i + \phi_2 logmktcap_i + \phi_3 Analystcover_i + \epsilon_i, \tag{5}$$

which serves as a benchmark. The coefficient $\phi_2$ on log market-cap is not significant. The coefficients $\phi_1$ on price and $\phi_3$ 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 8.

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

$$\Delta_i = \varphi_0 + \varphi_1 DMMshare_i + \varphi_2 \left(price \times DMMshare\right)_i + \epsilon_i \tag{6}$$

$$\begin{aligned} \Delta_i = {} & \theta_0 + \theta_1 DMMshare_i + \theta_2 \left(price \times DMMshare\right)_i \\ & + \theta_3 \left(logmktcap \times DMMshare\right)_i + \epsilon_i \end{aligned} \tag{7}$$

$$\begin{aligned} \Delta_i = {} & \vartheta_0 + \vartheta_1 DMMshare_i + \vartheta_2 \left(price \times DMMshare\right)_i \\ & + \vartheta_3 \left(Analystcover \times DMMshare\right)_i + \epsilon_i. \end{aligned} \tag{8}$$

Columns 3, 4, and 5 of Table 8 report the results for these interaction-term specifications. The coefficient $\varphi_2$ on the interaction $price \times DMMshare$ is positive and significant, while the respective coefficients $\theta_3$ and $\vartheta_3$ 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).

The findings regarding market cap and analyst coverage support the conclusions of Bessembinder et al. (2015). Our finding regarding price likewise supports the conclusions of Anand and Venkataraman (2016). Even though the DMMs tend to be less prominent liquidity providers in terms of volume-share among higher-priced stocks and smaller stocks, DMMs' participation has stronger impact on spreads in those stocks. A natural explanation for this effect would be time-series variation in DMMs' participation, for example, providing tighter quotes on the occasions when voluntary liquidity providers temporarily withdraw from the market. Anand and Venkataraman (2016) find precisely this sort of behavior in the context of the Toronto Stock Exchange.

More broadly, the results in this subsection 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?

Although the loss of DMMs during the NYSE halt may have caused a 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 may not be irrelevant, but neither are they indispensable under ordinary conditions. During the period that we examine, DMMs' quantifiable obligations with respect to maintaining "reasonable quotes" would not have been remotely binding.[10] Why then could DMMs cause spreads to narrow significantly?

We begin by ruling out the two most obvious potential 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

[10] See NYSE Rule 104(a)(1)(B) in Appendix B.

**Table 8**
NYSE-halt liquidity reduction: effects of market cap, price, analyst coverage, DMM participation, and interactions

Table 8 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),* average closing 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 sample consists of the 980 treatment-group stocks. 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 the halt on 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* | $0.001^{***}$ | $-0.001$ | | | |
| | (0.0002) | (0.001) | | | |
| *Logmktcap* | 0.008 | $-0.013$ | | | |
| | (0.010) | (0.010) | | | |
| *Analystcover* | $-0.003^{*}$ | $-0.002$ | | | |
| | (0.002) | (0.002) | | | |
| *DMMshare* | | $1.254^{***}$ | $1.618^{***}$ | $2.257^{***}$ | $1.751^{***}$ |
| | | (0.296) | (0.188) | (0.360) | (0.196) |
| *Price*× *DMMshare* | | $0.017^{***}$ | $0.009^{***}$ | $0.010^{***}$ | $0.010^{***}$ |
| | | (0.005) | (0.001) | (0.001) | (0.001) |
| *Logmktcap*× *DMMshare* | | | | $-0.082^{**}$ | |
| | | | | (0.034) | |
| *Analystcover*× *DMMshare* | | | | | $-0.015^{**}$ |
| | | | | | (0.007) |
| *Constant* | $0.265^{***}$ | 0.084 | $-0.100^{***}$ | $-0.106^{***}$ | $-0.099^{***}$ |
| | (0.062) | (0.091) | (0.036) | (0.036) | (0.036) |
| *Adjusted* $R^2$ | 0.031 | 0.146 | 0.139 | 0.142 | 0.143 |

explanation for the significant 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.[11] The mean quoted spread among treatment-group stocks between 11:30 a.m. and 3:10 p.m. 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, the observed spread-increase exceeds 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.[12] Still less can be explained if we relax the implausible assumption that DMMs earn the maximum rebate on every trade.

The inadequacy of these two obvious potential explanations suggests the legitimate significance of DMMs' more nebulous obligations, such as maintaining a fair and orderly market in their stocks. 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 DMM obligations seems to leave considerable scope for shirking, as does the narrowly circumscribed set of quantitative criteria on which the NYSE evaluates DMMs' performance.

The manner in which NYSE DMMs compete with one another might contribute to giving the DMMs' broadly worded obligations some independent bite. There is only ever one DMM per NYSE stock, so DMMs do not compete directly with each other in any single stock. Nevertheless, DMMs

[11]Source: New York Stock Exchange Price List, July 1, 2015.
[12]Source: SR-NASDAQ-2014-124

do compete. Securities are allocated to a DMM when a security is to be initially listed on the NYSE, and DMMs compete to obtain these allocations. Because DMMs can't explicitly compete on price, they must instead compete on their record and reputation for maintaining high market quality in the stocks assigned to them.[13] Consequently, to the extent that winning additional allocations is valuable, a DMM could obtain "reputational" benefits from improving market quality for its stocks, above and beyond any immediate benefits such as rebates. This could give DMMs an incentive to improve market quality in their stocks, even if doing so reduces the DMMs' respective profits in those stocks. The reduction in a DMM's profits per stock could be offset by an increase in the expected number of allocations that the DMM will receive in the future.

While the reputation/competition channel sketched above is just one of many possibilities, it illustrates that unexpectedly significant effects arising from DMMs' broadly worded obligations might be explicable through familiar economic mechanisms. Analyses of how and why apparently mild and difficult-to-monitor DMM obligations could improve market quality may offer fruitful avenues for 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 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 11, 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 8, then use proprietary data to separate the NYSE

[13]Financial Industry Regulatory Authority (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."

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, the remainder of NYSE market share does not help to explain cross-sectional variation. The result is robust to the inclusion of a variety of stock-specific controls. These findings are consistent with the idea that the liquidity effects can be attributed to DMM participation.

Our results provide evidence consistent with the continued significance of DMMs in modern U.S. markets, despite the proliferation of voluntary liquidity-providers. The presence of traders with formal market-making obligations, even seemingly small and mild obligations, may cause meaningful improvements in liquidity.

## Appendix 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.

## Appendix B. Selected NYSE Rules[14]

### 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 recommence 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 to 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),

[14] 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.

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.

## Appendix C. Calculating the NYSE information share

For each stock-day, we build two price series with one-second time resolution, one from NYSE and the other from all other exchanges as a whole (non-NYSE).[15] Based on these two price series (NYSE and non-NYSE), we estimate the Vector Error Correction Model (VECM) set forth by Hasbrouck (1995):

$$\begin{aligned}
\Delta p_{1,t} &= \sum_{i=1}^{K} \alpha_{1,i}\Delta p_{1,t-i} + \sum_{i=1}^{K} \beta_{1,i}\Delta p_{2,t-i} + \gamma_1 \left(p_{1,t-1} - p_{2,t-1} - \mu\right) + \epsilon_{1,t} \\
\Delta p_{2,t} &= \sum_{i=1}^{K} \alpha_{2,i}\Delta p_{1,t-i} + \sum_{i=1}^{K} \beta_{2,i}\Delta p_{2,t-i} + \gamma_2 \left(p_{1,t-1} - p_{2,t-1} - \mu\right) + \epsilon_{2,t}
\end{aligned}$$

where $p_{1,t}$ and $p_{2,t}$ correspond to the two price series. $\mu$ is the sample average of $(p_{1,t} - p_{2,t})$. Building on the model estimation, we calculate the cumulative impulse response functions by forecasting the evolution of these two price series 600 seconds ahead after a unit shock. Then with cumulative impulse response functions and the covariance matrix of perturbations, the lower and upper bounds of information share can be calculated by considering the Cholesky factorizations of all the permutations of the disturbances.

[15] To confirm robustness, we use two different types of price series: the first consists of the last available trade prices at each one-second time interval, and the second consists of the midpoints from best prevailing quotes at the end of each second. The information regarding trades and quotes comes from Daily TAQ data.

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