MEMORANDUM

To: File

From: The Division of Economic and Risk Analysis[1]

RE: **SR-BatsBZX-2017-34**

Subject: Bats Market Close: Off-Exchange Closing Volume and Price Discovery

Date: December 1, 2017

We analyze the correlation among closing price discovery and closing price efficiency–two established metrics from the academic finance literature–with off-exchange trading activity at the close. We analyze equity securities trading and quotation data during the first quarter of 2017 to determine the amount of closing auction volume, the amount of off-exchange Market-on-Close (MOC) activity, and estimates of closing price discovery and efficiency. Our main findings are:

- Closing auction volume accounts for about 5.2 percent of daily volume for the average equity security including Exchange-Traded Products.
- On average, approximately 9.3 percent of closing volume is matched off-exchange at the primary listing exchange's closing price.
- We observe no statistically significant correlation between off-exchange MOC activity and closing price discovery or efficiency.

This analysis does not attempt to establish a causal link between off-exchange activity and closing price discovery and efficiency.

1 Introduction

On May 5th, 2017, Bats BZX Exchange, Inc. (Bats or BZX) filed with the Securities and Exchange Commission a rule proposal to introduce the Bats Market Close (BMC), a closing match process for non-BZX listed securities. Through the BMC proposal, BZX seeks to compete with primary listing exchanges and off-exchange venues to execute MOC orders. BATS represented in its filing that should the Commission approve the proposed rule change, it would file a separate proposal to offer executions of MOC orders at the official closing price, to the extent matched on BATS, at a rate less than the fee charged by the applicable primary listing market. BATS also represented that it intends for such fee to remain lower than the fee charged by the applicable primary listing market. The

[1] This is a memorandum by the Staff of the Division of Economic and Risk Analysis of the U.S. Securities and Exchange Commission. The Commission has expressed no view regarding the analysis, findings, or conclusions contained herein.

Commission received comment letters on Bats' proposed rule change from a wide range of market participants including other exchanges, market makers, issuers, retail brokers, members of Congress, and academics.[2]

On August 18, 2017, the Commission, pursuant to authority delegated to the Division of Trading and Markets, issued an order instituting proceedings to determine whether to approve or disapprove the BMC proposal.[3] The Commission's order seeks comment, including, where relevant, any specific data, statistics, or studies on a series of broad questions. Among those questions, the Commission asked what amount of trading volume at the close occurs on venues other than the primary listing exchanges and whether the matching of a significant amount of MOC orders at a venue other than the primary listing market would affect the integrity or reliability of the resulting closing price. Using established measures of price discovery and price efficiency from the academic finance literature, we analyzed the equity securities trading and quotation data to determine whether existing market fragmentation reduces MOC liquidity on primary listing exchange auctions such that the reduction harms closing price discovery.[4]

While the data we have does not allow us to predict how the proposed rule change would affect price discovery in the closing auction process, and market participants' use of limit-on-close orders in the closing auction processes, the data suggests that existing levels of fragmentation in the closing auction do not, on average, correlate with price discovery or price efficiency.

2 Institutional Background

2.1 Closing Auction Process

Although each listing exchange has unique closing processes, most share high-level similarities.[5] An exchange typically allows three types of orders: Market-on-Close, Limit-on-Close (LOC), and limit-only Imbalance Only (IO) orders.[6] MOC and LOC orders may be submitted throughout the day until some cutoff time (e.g., 3:45 (NYSE), 3:50 (NASDAQ), or 3:59 PM EST (Arca)), with a "grace period" to correct legitimate errors.[7]

The method for determining the closing prices also differs across exchanges but can be described by the following two general principles:

[2]For a complete list of comment letters see https://www.sec.gov/comments/sr-batsbzx-2017-34/batsbzx201734.htm.

[3]See https://www.sec.gov/rules/sro/batsbzx/2017/34-81437.pdf.

[4]See for example, Barclay and Hendershott (2003) and Barclay, Hendershott, and Jones (2008).

[5]For exchange-specific details see for example, https://www.nyse.com/publicdocs/nyse/markets/nyse/NYSE_Opening_and_Closing_Auctions_Fact_Sheet.pdf, https://www.nyse.com/publicdocs/nyse/markets/nyse-arca/NYSE_Arca_Auctions_Brochure.pdf, https://www.nasdaqtrader.com/content/TechnicalSupport/UserGuides/TradingProducts/crosses/openclosequickguide.pdf.

[6]NYSE refers to IO orders as "Closing Offset" Orders. See https://www.nyse.com/publicdocs/nyse/markets/nyse/NYSE_Opening_and_Closing_Auctions_Fact_Sheet.pdf.

[7]E.g., NYSE Rule 123C(3) and NASDAQ Rule 4702(b)(11).

1. Minimize any imbalance between buy and sell orders at the market close /maximize the number of shares executed through the closing process.
2. Minimize the difference between the closing price of securities in the closing process and a reference price.[8]

2.2 Alternative Venues

The primary listing exchange is not the only venue where on-close orders can be submitted and executed. For instance, NASDAQ offers Closing Crosses for NYSE-listed securities, and prints its own volume and alternative closing price. In addition in the event of a systems or technical issue on NYSE, the NASDAQ Closing Cross price may be designated as the official closing price for NYSE-listed securities.[9] MOC orders are also executed off-exchange on ATS platforms, and by broker-dealers at the official closing price.[10]

3 Data and Methodology

3.1 Sample Construction

To construct the sample, we begin with all valid trades and quotes in the NYSE TAQ (trade and quote) database in Q1 of 2017. We filter out invalid or erroneous trades and quotes following Holden and Jacobsen (2014).

We use closing prices from the Center for Research in Security Prices' CRSP database, which restricts the sample to include only US-listed common stocks and exchange traded products (SHRCD = 10, 11 for stocks; SHRCD = 73 for ETPs) listed on the NYSE, NASDAQ, NYSE American (formerly MKT, AMEX), and NYSE Arca exchanges.[11] We use CRSP for closing prices instead of TAQ because CRSP records official closing prices even when there is no closing print in TAQ.[12]

For our main analyses, except where otherwise noted, we exclude days where there is no closing auction because the closing price is determined by a different process. We describe our measurement of auction activity in the next section.[13]

[8] For example, on NYSE Arca the reference price is the last sale eligible trade, and the Arca top of book (https://www.nyse.com/publicdocs/nyse/markets/nyse-arca/NYSE_Arca_Auctions_Brochure.pdf); and for NASDAQ it is the midpoint of the NASDAQ top of book (https://www.nasdaqtrader.com/content/ProductsServices/Trading/Crosses/openclose_faqs.pdf).

[9] See https://www.nasdaqtrader.com/content/ProductsServices/Trading/Crosses/fact_sheet.pdf, and https://www.sec.gov/comments/sr-batsbzx-2017-34/batsbzx201734-2228160-160802.pdf.

[10] See https://www.sec.gov/comments/sr-batsbzx-2017-34/batsbzx201734-2634580-161229.pdf.

[11] `CRSP` does not include Bats listed securities.

[12] This may occur when there is no closing auction, such as on March 20, 2017 for affected Arca securities. On that day, NYSE Arca published official closing prices on their website, which are included in CRSP (see https://www.nyse.com/publicdocs/nyse/notifications/market-status/NYSE%20Arca%20Official%20Closing%20Prices%20032017.xlsx). When there is a closing auction, CRSP and TAQ closing prices are the same.

[13] The results are qualitatively similar in the full sample which includes symbol-day observations with no closing auction volume (See Appendix A2). Hence off-exchange closing activity is uncorrelated with closing price discovery and efficiency more generally.

3.2 Measuring Off-Exchange MOC Activity

To measure the off-exchange MOC activity at the close, we use a simple heuristic approach: For each security, we use all trades from TAQ that are not cancelled or corrected that occur between 4:00–4:10 PM EST at the official closing price of the primary listing exchange according to the CRSP database. To measure primary listing auction volume, we use trade reports in TAQ with the sale condition of 6 (Closing Print).[14] We compute the fraction of closing auction share volume that occurs off-exchange by dividing the off-exchange volume by the sum of the off-exchange volume and the primary listing exchange closing auction volume.

We validate the heuristic approach using regulatory FINRA Trade Reporting Facility data, and FINRA-provided Audit Trail data. These two datasets identify off-exchange executions by venue and trace the executions back to the original order to ensure that they were entered as MOC orders. We verify that the heuristic approach produces nearly identical volume measures compared to the off-exchange executed volume of MOC orders. We do not use the regulatory data in the main analysis because the time series of Audit Trail data is limited, and because the level of detail from the regulatory data is not necessary, given the heuristic approach. We discuss the regulatory data approach in Appendix A1.

3.3 Measuring Price Discovery around the Close

The majority of commenters addressed the potential impacts of fragmenting closing auction liquidity and its impact on price discovery.[15] Specifically, commenters were concerned that fragmentation may impede price discovery.

There is no universal metric that can fully describe the price discovery process. At a high level, some types of price discovery metrics focus on the amount or quantity of price discovery, while others focus on the efficiency or quality of price discovery. Looking at only one dimension or one metric of price discovery may provide a biased or incomplete picture of the price discovery process. In this Section we discuss the quantity of price discovery at the close, and in the next section we discuss the quality of price discovery.

To quantify the amount of new information incorporated into stock prices during the closing auction period, we use the standard measure of price discovery in sequential markets from the academic finance literature–the "Weighted Price Contribution" (WPC) measure.[16] The basic intuition behind the measure is that it is possible to decompose returns, period-by-period, to determine the relative amount of new information incorporated into

[14]Exchanges may report 6 (Closing Print) and also M (Market Center Close Price) messages to the SIP. For NASDAQ-listed securities, NASDAQ reports 6 and M messages with identical price and volume information. However, for NYSE and Arca-listed securities, the exchange reports a 6 message, and NASDAQ may print an M message corresponding to the NASDAQ cross. As we are only concerned about the primary listing auction volume, we only use the volume reported in the 6 messages.

[15]See Summary of the Comments in the Order Instituting Proceedings https://www.sec.gov/rules/sro/batsbzx/2017/34-81437.pdf.

[16]Other measures of the quantity of price discovery, such as Information Shares (Hasbrouck (1995)), focus on parallel markets–e.g. one security trading on multiple venues and the relative amount of price discovery that occurs on each venue.

stock prices. Barclay and Warner (1993) originally proposed measures of price contributions to quantify the amount of price discovery associated with different trade size categories. Cao, Ghysels, and Hatheway (2000) adapted the measure for sequential time periods to quantify the amount of price discovery in the pre-opening period. Barclay and Hendershott (2003, 2008) used the measure to study the amount of price discovery occurring during overnight trading. Bacidore and Lipson (2001) and Ellul, Shin, and Tonks (2005) used the measure to study price discovery around the opening and closing auctions.

Specifically, Weighted Price Contribution measures the percentage of the return that occurs in period s, weighted by the absolute return:

$$WPC_s = \sum_t \left(\frac{|r_t|}{\sum_t |r_t|} \right) \times \left(\frac{r_{s,t}}{r_t} \right), \tag{1}$$

where the numerator in the first term of the sum is the weight, and the second term is the "price contribution." The denominator in the first term is the sum of all weights.

We take s to be the last fifteen minutes of the trading day from 3:45–4:00 PM EST which covers the "Closing Period" of the primary listing exchanges.[17] Therefore, $r_{s,t}$ is the midquote return from 3:45 PM to the official closing price of the primary listing exchange. r_t is the intraday return from the first trade price to the official closing price of the primary listing exchange.

3.4 Measuring Closing Price Efficiency

Another important concern is the efficiency of the closing price. While WPC measures the "quantity" of price discovery that occurs at the close relative to the rest of the day, it does not address the "quality" of the closing price–i.e., whether the closing price represents an over- or underreaction to new information.[18]

The market microstructure literature has long held that temporary price pressures should be reversed, whereas informed order flow should generate permanent price changes (e.g., Hasbrouck (1988)). Therefore, we focus on the relation between the return over the last fifteen minutes of the day r_{15}, measured from the midquote at 3:45 PM EST to the official closing price, and the subsequent overnight return r_o, measured from the official closing price to the first trade price after markets open the following day. The intuition is that if the closing price reflects all available information, then there should be no change in price overnight ($r_o = 0$).[19] In contrast, an overnight return reversal may indicate an

[17] NYSE stops accepting MOC/LOC orders at 3:45pm, NASDAQ stops at 3:50pm. Both allow imbalance only orders. Auctions are run at 4:00pm, and closing prices are published shortly after. See https://www.nyse.com/publicdocs/nyse/markets/nyse/NYSE_Opening_and_Closing_Auctions_Fact_Sheet.pdf and https://www.nasdaqtrader.com/content/TechnicalSupport/UserGuides/TradingProducts/crosses/openclosequickguide.pdf.

[18] For instance, Lo and MacKinlay (1988) focus on the variance ratios of stock returns at different horizons to evaluate whether empirically observed stock prices approach the theoretical limits of efficient market "random walks."

[19] If news arrives overnight and the price changes, there may still be over- or under-reactions. In theory, the over- or under-reactions may average out to zero, but it is well documented in the finance literature

initial price overreaction, and a return continuation may indicate a price underreaction. As a robustness test we also use the midquote at 9:45 AM as an alternative opening price (see Appendix A2).

Other measures of price efficiency may include return autocorrelations, variance ratios, and price delay metrics (e.g., see Comerton-Forde and Putniņš (2015)). However these measures are typically estimated over full trading periods to measure the average price efficiency in continuous trading, which may not be representative of the efficiency of the closing price, which is typically determined through an auction process.

3.5 Regression Approach

Barclay and Hendershott (2003, 2008) employ regressions of price discovery and price efficiency for overnight trading and opening prices, respectively. We use a similar approach to examine the effect of closing auction activity–both off-exchange MOC activity, and overall auction activity–on closing price discovery and price efficiency.

To examine the effect of auction activity on price discovery, we estimate regressions of the form for the sample of symbol-days for which there is an auction:

$$PC_{i,t} = \alpha + \beta_0 OffExchangeMOC_{i,t} + \beta_1 AuctionShare_{i,t} + \beta_2 X_{i,t} + \varepsilon_{i,t}, \qquad (2)$$

where $PC_{i,t}$ is the un-weighted price contribution; $OffExchangeMOC_{i,t}$ is the fraction of off-exchange MOC Share Volume, relative to total primary listing exchange closing auction share volume; and $X_{i,t}$ is a vector of control variables: Off-Exchange Share, Log Market Cap, Log Volume, Volatility, and the ratio of the absolute return over the last 15 minutes and the absolute return over the day to control for closing price volatility. Controlling for the level of Off-Exchange activity in continuous trading may be important as factors that drive market participants to off-exchange venues during continuous trading may also influence the decision to go off-exchange during the auction process. The Log Market Cap, Log Volume, and Volatility controls may be important in capturing differences in price discovery or price efficiency that are due to different security characteristics. The last control variable may be particularly important because Wang and Yang (2015) argues that Weighted Price Contributions are correlated with return volatilities. Hence, by directly controlling for the ratio of absolute returns, we can isolate the variation in Weighted Price Contributions that are unrelated to large price swings.

The Price Contribution regressions employ sampling or "probability" weights, such that the weighted regression estimate of Price Contribution on a constant–the expected value–is the "Weighted Price Contribution" from Equation 1.[20]

The primary coefficient of interest is β_0, which indicates the correlation between off-exchange MOC activity and the amount of new information compounded into the closing price–conditional on other characteristics.

that returns tend to reverse overnight (Stoll and Whaley, 1990; Campbell, Lo, and MacKinlay, 1997; Berkman, Koch, Tuttle, and Zhang, 2012).

[20]The probability weight is defined as $\sum_t \frac{|r_t|}{\sum_t |r_t|}$. By doing weighted regressions, rather than taking time-series averages and running pure cross-sectional regressions, we maintain consistent sample sizes across our price discovery and price efficiency regressions.

To examine the effect of auction activity on the efficiency of the closing prices we estimate two regressions, dropping i, t subscripts for brevity:

$$PriceReversal = \alpha + \beta_0 OffExchangeMOC + \beta_1 AuctionShare + \beta_2 X + \varepsilon, \tag{3}$$

$$PriceReaction = \alpha + \beta_0 OffExchangeMOC + \beta_1 AuctionShare + \beta_2 X + \varepsilon, \tag{4}$$

where $PriceReversal$ is the percent midquote return from 3:45 PM EST to official close price or "last 15 minute" (r_{15}) return multiplied by the percent return from the official close price to first trade price or "overnight return" (r_o).[21] $PriceReaction$ is an indicator which takes the value one if r_o and r_{15} are of the same sign (return continuation or price underreaction), minus one if r_o and r_{15} are of the opposite sign (return reversal or price overreaction), and is zero otherwise.

As before, the primary coefficient of interest in Equation 3 and 4 is β_0, which measures the correlation between off-exchange MOC activity and price reversals.

4 Results

4.1 Summary Statistics

Table 1 presents summary statistics for the primary sample period of 2017Q1. For the average stock in the sample, the WPC is six percent, meaning that, on a weighted basis, six percent of the intraday return occurs in the last fifteen minutes of the day. The median stock WPC is nearly four percent, which indicates that the distribution of price contributions is right skewed–meaning that some symbols have significantly higher WPC than the median symbol. The average off-exchange MOC share volume as a percent of total closing volume is 9.3 percent. The percent of off-exchange share volume relative to total continuous trading volume on exchanges is on average 46 percent. These findings are consistent with the concentration of liquidity in primary listing exchange closing auctions. Primary exchange closing Auction Share accounts for 5.2 percent of total continuous trading volume on average. On average, continuous trading volume in the last fifteen minutes accounts for 13.2 percent of total continuous trading volume. The median symbol in the sample has a market capitalization of $416,850,000, and share volume traded of 158,755. The median symbol has a daily stock return volatility (standard deviation) estimated over the previous month of 1.5 percent.

Table 1 here

4.2 Off-Exchange MOC Activity and Closing Prices

Our analysis focuses on whether market fragmentation reduces MOC liquidity on primary listing exchange auctions such that the reduction harms closing price discovery. In this Section, we examine the correlation between closing prices and existing off-exchange

[21] See Barclay et al. (2008) for more details on the Price Reversal measure.

MOC activity as a proxy for the fragmentation of closing auction volume. Table 2 reports regressions of closing price discovery and efficiency on off-exchange MOC activity, as well as primary listing exchange closing auction activity.

In Column 1, the dependent variable is the Price Contribution, corresponding to Equation 2. The insignificant coefficient on off-exchange MOC Share indicates that it there is no statistically significant correlation with price discovery. However, a ten percent higher primary Auction Share corresponds to two percent higher price contribution during the last fifteen minutes.

In Column 2, the dependent variable is the Price Reversal, corresponding to Equation 3. The coefficient on Off Exchange MOC Share is statistically indistinguishable from zero, as is the coefficient on primary Auction Share. The negative coefficient on the constant indicates that returns tend to exhibit reversals overnight, on average. The tendency for overnight return reversals are well-documented in the finance literature, which indicates that there is no reason to believe that our reversal findings are different from previous studies (e.g., Stoll and Whaley (1990); Campbell et al. (1997); Berkman et al. (2012)).

In Column 3, the dependent variable is the Price Reaction, corresponding to Equation 4. Neither off-exchange MOC Share nor primary Auction Share predicts under- or over-reaction.

Table 2 here

These results suggest that increased MOC activity away from the primary listing exchange closing auctions does not correspond to lower price discovery or price efficiency.[22] Auctions appear to play an important role in price discovery as symbols with higher Auction Share volume appear to have more price discovery around the close. This is not surprising, because total Auction Share volume includes price-setting LOC orders. Taken together, the results suggest that higher off-exchange MOC activity–which may reduce primary auction MOC activity–does not seem to reduce the informativeness of closing prices.

5 Conclusion

This analysis evaluates the correlation between existing off-exchange MOC activity and closing price discovery and efficiency. Overall, the data suggests that existing levels of fragmentation in the closing auction do not, on average, correlate with price discovery or price efficiency.

[22] The results are also robust to the inclusion of stock or day fixed effects (not tabulated).

Appendix

A1 Identifying Off-Exchange MOCs using Regulatory Data

An alternative way to measure off-exchange MOC activity is to use FINRA Order Audit Trail (OATS) data to identify order executions marked specifically as Market-on-Close. For example, one ATS offers MOCs according to publically available filings, but other ATS, and other brokers submit MOC orders. The advantage of using OATS is that the same participants consistently mark their orders as MOC across the sample period. The disadvantage of using OATS is that it does not distinguish between media and non-media reported executions. Hence estimates based on OATS data alone are likely to be systematically over-estimating off-exchange closing volume relative to the off-exchange volume reported to the SIP.[23]

To filter out non-media reported executions requires FINRA TRF data.[24] The challenge with using FINRA TRF data alone is that there is no order metadata which explicitly identifies executions as MOC executions. Therefore, we identify "off-exchange MOC" activity using FINRA TRF executions with the following filters informed by matched OATS executions:

- We restrict the sample of trades to executions after 4:00 PM (Market Close) and before 4:10 PM.
  - All MOC orders in the OATS sample execute within minutes of market close, once the closing price is made available.
  - We verify that TRF execution timestamps correspond to OATS execution timestamps.
- We filter out all non-media reported trades.
- We further restrict trades to executions that occur at the official closing price from the primary listing exchange as reported by CRSP.
  - Continuous trading occurs in many ATS until 5 PM so the price filter helps to avoid picking up trades that are not pegged to the official closing price.

We developed these filters by cross-referencing OATS executions with TRF executions. We started with one ATS which handles off-exchange MOC orders, and attempted to identify all off-exchange MOC orders marked with the same order information. However, other ATS and brokers enter MOC orders in OATS, but do not mark the orders the same way. We then linked MOC orders in OATS with TRF executions to see if TRF trade modifiers could be used to systematically identify off-exchange MOC executions. Unfortunately, because of reporting differences the only common feature between the TRF and

[23]This method does not account for participants who submit MOC, but do not mark their orders as MOC.

[24]TRF executions can be linked by OATS executions by order identifier, as well as symbol, date, timestamp, and participant identifiers.

OATS executions was that they occur shortly after markets close, and they occur at the official closing price.

Because we ultimately only need TRF executions at the official closing price, it is also possible to use the public (SIP) version of the TRF in TAQ. This is the "heuristic" approach used in the main analysis. To compare the approach using public data to the approach using regulatory data, we compute symbol-day market share two ways: using valid trades from TAQ that occur at the official closing price, and using only media reported trades that occur at the official closing price from the regulatory FINRA data.

Table 3 reports summary statistics of the average MOC share estimates by symbol in August 2015 for which we have TRF, OATS, and TAQ data. The average symbol has 5.2% off-exchange MOC share whether we use the FINRA or TAQ data. Notably, the standard deviations are also the same. Hence, the two approaches produce nearly identical estimates of average off-exchange MOC activity.

Table 3 here

A2 Robustness and Sample Splits

In this Section we present further sample splits and robustness checks based on the main analysis presented in Table 2. These additional tests are intended to show that our main results are robust to different empirical specifications, and across different subsamples.

The list of robustness tests is as follows:

- All symbol-day observations including days without closing auctions (Table 4).
- Main analysis where price reversal is based on the next day's prevailing midquote at 9:45 AM (Table 5).

Our sample splits include:

- ETPs only (Table 6).
- Stocks only (Table 7).
- NYSE-listed securities (Table 8).
- NASDAQ-listed securities (Table 9).
- ARCA-listed securities (Table 10).
- NYSE American- (formerly MKT, AMEX) listed securities (Table 11).
- S&P 500 and Russell 2000 only (Table 12).
- No S&P 500 (SPX) or Russell 2000 (RTY) securities (Table 13).
- S&P 500 + Russell 2000 NYSE-listed securities (Table 14).

- S&P 500 + Russell 2000 NASDAQ-listed securities (Table 15).
- S&P 500 + Russell 2000 AMEX-listed securities (Table 16).

The ETP/stock split accounts for potential differences in the closing price formation for different types of securities. The exchange-specific splits account for potential differences in closing procedures across exchanges.

The S&P 500 and Russell 2000 samples are based on index constituents at the end of December 2016. These sample splits account for potential differences for liquid names across venues, as well as for less liquid names (Table 13).

Overall, we find mixed evidence of the relationship between off-exchange MOC activity and closing price discovery and efficiency. Tables 4, 5, 8, 11, 14, and 16 show results that are qualitatively similar to our main analysis–there is no economically or statistically significant correlation between off-exchange MOC activity and closing price discovery or price efficiency. Tables 6, 7, 9, 10, 12, and 15 find evidence of correlation between off-exchange MOC activity and increased return reversals, but we do not find consistent evidence across the two proxies in any Table. Table 13 finds evidence of a correlation between off-exchange MOC activity and price discovery (WPC), and also between off-exchange MOC activity and price continuations (Price Reaction). Because the average Price Reaction (the constant) is significantly negative, the positive correlation with Price Reaction suggests that more off-exchange MOC activity is correlated with lower price reversals.

Although we find some statistical significance, these findings are largely economically insignificant. For example, in Table 9, a ten percent increase in off-exchange MOC activity corresponds a 54 basis point increase in the tendency for returns to reverse, when the average tendency for returns to reverse (the coefficient on the constant) is 55%. In Table 13, a ten percent increase in off-exchange MOC activity corresponds to a 24 basis point increase in Weighted Price Contributions when the average WPC is 17.4%. Overall, while the results are mixed in some specifications, we do not find consistent or conclusive evidence that contradicts our main analyses.

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Tables and Figures

Table 1: **Summary Statistics**. This table reports summary statistics for the Weighted Price Contribution, Off-Exchange Market on Close share, and Off-Exchange Share over 2017Q1. Average Market Cap, Volume, and daily stock return Volatility are observed in December of 2016. The sample includes all common stocks and exchange traded products (`SHRCD = 10,11` for stocks; `SHRCD = 73` for ETPs) listed on the NYSE, NASDAQ, the NYSE American (formerly MKT, AMEX), and NYSE Arca (`EXCHCD = 1,2,3,4`).

Statistic	Mean	St. Dev.	Pctl(25)	Median	Pctl(75)
WPC	0.061	0.093	0.010	0.038	0.089
Off-Exchange MOC	0.093	0.041	0.068	0.089	0.114
Off-Exchange	0.461	0.182	0.306	0.414	0.616
Auction Share	0.052	0.051	0.004	0.040	0.090
Last 15 Share	0.132	0.058	0.086	0.133	0.173
Market Cap ($MM)	4,817.597	22,283.690	71.313	416.850	2,009.603
Volume/1000	994.949	3,836.022	29.781	158.755	654.894
Volatility	0.021	0.024	0.009	0.015	0.026

Table 2: **Main Regressions**. This table reports regressions where the dependent variables are the Price Contributions, Price Reversals, and Auction-to-Close-to-Open Price Reactions. The primary independent variables of interest are the fraction of Off-Exchange Market-on-Close share volume relative to total Auction share volume, and the fraction of Auction share volume relative to total share volume during regular trading hours. The sample includes only the symbol-day observations where the primary listing exchange prints closing auction volume. The Price Contribution regressions employ sampling or "probability" weights, consistent with the definition of the "Weighted Price Contribution." The Price Reversal is defined as the percent last 15 minute return, multiplied by the percent overnight return. The Price Reaction variable is coded such that if the return during the last 15 minutes of trading reverses in the overnight period the Price Reaction = -1, if the return continues the Price Reaction = 1, and is zero otherwise. In all specifications, the control variables are the fraction of Off-Exchange share volume to total share volume during regular trading hours, the log average Market Cap over the previous month, log average share Volume over the previous month, return Volatility over the previous month, and the ratio of the absolute return over the last 15 minutes to the absolute return over the day. t-statistics are reported in parentheses, based on standard errors clustered by CRSP stock identifier (PERMNO). Stars indicate statistical significance.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	0.002	−0.121	−0.027
	(0.334)	(−0.577)	(−1.565)
Auction Share	0.120***	−0.011	−0.100***
	(12.284)	(−0.091)	(−3.924)
Off-Exchange Share	0.011*	−0.077	−0.034**
	(1.953)	(−1.062)	(−2.386)
Log Market Cap	−0.006***	0.014	0.015***
	(−8.950)	(0.324)	(7.402)
Log Volume	−0.007***	0.042	0.016***
	(−9.741)	(1.076)	(8.138)
Volatility	−0.056**	−5.377	−0.131
	(−1.969)	(−1.444)	(−1.242)
$\frac{\|r_{15}\|}{\|r_d\|}$	0.370***	−0.317***	0.016*
	(41.152)	(−4.247)	(1.687)
Constant	0.148***	−0.580**	−0.461***
	(17.803)	(−2.163)	(−19.602)
R^2	0.095	0.001	0.003
Observations	200,620	200,380	200,380
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 3: **Comparing TRF to TAQ MOC Share**. The sample period is August 2015 for which we have TRF, OATS, and TAQ data. "FINRA TRF (Tape Only)" is based on tape-reported TRF/OATS executions at the official closing price (from CRSP) between 4:00 and 4:10 PM EST. "TAQ" uses all valid trades in the NYSE TAQ database for the same period at the official closing price.

Statistic	Mean	St. Dev.	Pctl(25)	Median	Pctl(75)
FINRA TRF (Tape Only)	0.052	0.113	0.004	0.023	0.052
TAQ	0.052	0.113	0.004	0.022	0.051

Table 4: **All Days Including Observations Without Auctions**.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	−0.002	−0.063	−0.005
	(−0.344)	(−0.426)	(−0.322)
Auction Share	0.121***	−0.019	−0.105***
	(12.409)	(−0.163)	(−4.157)
Off-Exchange Share	0.012**	−0.063	−0.031**
	(2.003)	(−0.880)	(−2.188)
Log Market Cap	−0.006***	0.014	0.015***
	(−8.777)	(0.324)	(7.486)
Log Volume	−0.007***	0.042	0.015***
	(−9.591)	(1.065)	(7.828)
Volatility	−0.058**	−5.345	−0.125
	(−2.091)	(−1.444)	(−1.161)
$\frac{\lvert r_{15} \rvert}{\lvert r_d \rvert}$	0.370***	−0.317***	0.016*
	(41.124)	(−4.279)	(1.662)
Constant	0.147***	−0.583**	−0.458***
	(17.660)	(−2.209)	(−19.503)
R^2	0.095	0.001	0.003
Observations	201,899	201,657	201,657
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 5: **Full Sample (9:45 Open)**. This table repeats the main analysis except that the third specification uses the overnight return ending with the prevailing midquote at 9:45 AM.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reversal (9:45)
	(1)	(2)	(3)
Off-Exchange MOC Share	0.002	−0.121	−0.277
	(0.334)	(−0.577)	(−1.143)
Auction Share	0.120***	−0.011	−0.127
	(12.284)	(−0.091)	(−0.667)
Off-Exchange Share	0.011*	−0.077	−0.067
	(1.953)	(−1.062)	(−0.608)
Log Market Cap	−0.006***	0.014	0.068
	(−8.950)	(0.324)	(1.169)
Log Volume	−0.007***	0.042	0.018
	(−9.741)	(1.076)	(0.293)
Volatility	−0.056**	−5.377	−5.090
	(−1.969)	(−1.444)	(−1.027)
$\frac{\lvert r_{15}\rvert}{\lvert r_d\rvert}$	0.370***	−0.317***	−0.491***
	(41.152)	(−4.247)	(−5.382)
Constant	0.148***	−0.580**	−1.002***
	(17.803)	(−2.163)	(−3.266)
R^2	0.095	0.001	0.001
Observations	200,620	200,380	190,190
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 6: **ETP Only**.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	0.026	-0.047^{*}	0.030
	(1.458)	(-1.930)	(0.560)
Auction Share	0.180^{***}	-0.050^{**}	-0.235^{**}
	(3.501)	(-2.113)	(-2.055)
Off-Exchange Share	-0.002	-0.036	-0.137^{***}
	(-0.178)	(-1.029)	(-4.396)
Log Market Cap	-0.008^{***}	0.0003	0.015^{***}
	(-5.057)	(0.052)	(2.696)
Log Volume	-0.002	-0.002	-0.010^{*}
	(-1.320)	(-0.264)	(-1.713)
Volatility	-0.206	-2.261^{*}	-0.043
	(-1.478)	(-1.672)	(-0.066)
$\frac{\lvert r_{15}\rvert}{\lvert r_d\rvert}$	0.202^{***}	-0.026	0.031
	(7.079)	(-1.461)	(1.218)
Constant	0.118^{***}	0.063	-0.078
	(6.040)	(0.825)	(-1.204)
R^2	0.032	0.001	0.001
Observations	29,374	29,367	29,367
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 7: **Stock Only**.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	−0.001	−0.149	−0.032*
	(−0.130)	(−0.616)	(−1.711)
Auction Share	0.114***	−0.015	−0.074***
	(11.244)	(−0.117)	(−2.831)
Off-Exchange Share	0.022***	−0.186	−0.059***
	(3.184)	(−1.249)	(−3.176)
Log Market Cap	−0.006***	0.011	0.014***
	(−7.272)	(0.217)	(6.311)
Log Volume	−0.007***	0.052	0.019***
	(−9.170)	(1.057)	(9.262)
Volatility	−0.069**	−5.251	−0.023
	(−2.434)	(−1.274)	(−0.218)
$\frac{\lvert r_{15} \rvert}{\lvert r_d \rvert}$	0.378***	−0.360***	0.016
	(40.900)	(−4.093)	(1.581)
Constant	0.138***	−0.626**	−0.497***
	(15.604)	(−2.158)	(−19.205)
R^2	0.099	0.001	0.004
Observations	171,246	171,013	171,013
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 8: **NYSE Only**.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	0.007	0.016	0.009
	(0.978)	(0.342)	(0.309)
Auction Share	0.052***	−0.291	−0.139***
	(3.246)	(−1.365)	(−3.298)
Off-Exchange Share	0.004	−0.197***	−0.120***
	(0.362)	(−2.833)	(−3.185)
Log Market Cap	−0.009***	−0.042	0.017***
	(−7.396)	(−1.569)	(4.037)
Log Volume	−0.001	0.030*	0.004
	(−0.756)	(1.764)	(0.848)
Volatility	−0.361**	−7.998*	0.202
	(−2.277)	(−1.887)	(0.591)
$\frac{\lvert r_{15} \rvert}{\lvert r_d \rvert}$	0.231***	−0.076	0.012
	(13.781)	(−1.516)	(0.675)
Constant	0.134***	0.474*	−0.312***
	(10.001)	(1.787)	(−6.817)
R^2	0.037	0.001	0.001
Observations	68,616	68,607	68,607
Note:			$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 9: **NASDAQ Only**.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	−0.002	−0.115	−0.054**
	(−0.220)	(−0.294)	(−2.218)
Auction Share	0.145***	0.159	−0.050
	(10.909)	(0.948)	(−1.434)
Off-Exchange Share	0.010	0.027	−0.001
	(1.211)	(0.162)	(−0.030)
Log Market Cap	−0.006***	0.016	0.014***
	(−6.248)	(0.206)	(4.931)
Log Volume	−0.008***	0.078	0.022***
	(−7.679)	(1.068)	(8.447)
Volatility	−0.040	−5.350	−0.106
	(−1.293)	(−1.186)	(−0.916)
$\frac{\lvert r_{15}\rvert}{\lvert r_d\rvert}$	0.406***	−0.370***	0.022*
	(36.706)	(−2.793)	(1.754)
Constant	0.153***	−1.065**	−0.558***
	(12.653)	(−2.482)	(−15.622)
R^2	0.11	0.001	0.003
Observations	102,585	102,390	102,390

Note: *p<0.1; **p<0.05; ***p<0.01

Table 10: **ARCA Only**.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	0.030	−0.059**	0.045
	(1.441)	(−1.972)	(0.757)
Auction Share	0.146***	−0.043*	−0.169
	(3.103)	(−1.826)	(−1.510)
Off-Exchange Share	−0.002	−0.039	−0.152***
	(−0.159)	(−0.912)	(−4.347)
Log Market Cap	−0.007***	−0.001	0.016***
	(−4.573)	(−0.165)	(2.595)
Log Volume	−0.002	−0.0004	−0.012*
	(−0.851)	(−0.050)	(−1.827)
Volatility	−0.219	−2.329*	−0.178
	(−1.513)	(−1.671)	(−0.275)
$\frac{\lvert r_{15}\rvert}{\lvert r_d\rvert}$	0.172***	−0.027	0.031
	(5.552)	(−1.194)	(1.076)
Constant	0.105***	0.066	−0.044
	(4.678)	(0.735)	(−0.618)
R^2	0.023	0.001	0.001
Observations	23,308	23,305	23,305
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 11: **AMEX Only**.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	0.013	−3.988	0.023
	(0.200)	(−1.560)	(0.231)
Auction Share	0.264^{***}	−0.531	−0.180
	(4.314)	(−0.784)	(−1.377)
Off-Exchange Share	0.063^{**}	0.464	−0.037
	(2.152)	(0.889)	(−0.491)
Log Market Cap	−0.005	0.415^{***}	0.012
	(−1.133)	(3.402)	(1.244)
Log Volume	-0.007^{*}	−0.042	0.025^{***}
	(−1.959)	(−0.755)	(3.367)
Volatility	−0.406	−4.368	0.759
	(−1.000)	(−1.041)	(1.166)
$\frac{\|r_{15}\|}{\|r_d\|}$	0.484^{***}	-1.866^{***}	−0.001
	(13.564)	(−5.323)	(−0.012)
Constant	0.095^{*}	-4.149^{***}	-0.585^{***}
	(1.937)	(−2.887)	(−4.400)
R^2	0.139	0.018	0.005
Observations	6,111	6,078	6,078
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 12: **SPX+RTY Only**.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	−0.009	−0.034	−0.081***
	(−1.499)	(−1.128)	(−3.688)
Auction Share	0.103***	−0.041	−0.087***
	(9.529)	(−0.894)	(−2.887)
Off-Exchange Share	0.003	−0.163**	−0.035
	(0.358)	(−2.331)	(−1.338)
Log Market Cap	−0.005***	0.008	0.009***
	(−4.635)	(0.996)	(2.692)
Log Volume	−0.004***	0.006	0.018***
	(−4.752)	(0.838)	(6.385)
Volatility	0.058	−1.916**	−0.269
	(0.824)	(−2.313)	(−1.101)
$\frac{\lvert r_{15}\rvert}{\lvert r_d\rvert}$	0.267***	−0.069***	0.040***
	(27.897)	(−2.843)	(3.188)
Constant	0.107***	−0.102*	−0.404***
	(11.963)	(−1.699)	(−12.275)
R^2	0.049	0.001	0.002
Observations	116,181	116,150	116,150
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 13: **No SPX or RTY**.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	0.024*	−0.372	0.050*
	(1.685)	(−0.647)	(1.739)
Auction Share	0.245***	−0.521	−0.181***
	(11.537)	(−1.575)	(−3.674)
Off-Exchange Share	−0.005	0.224*	−0.009
	(−0.579)	(1.772)	(−0.480)
Log Market Cap	−0.007***	0.027	0.018***
	(−6.943)	(0.384)	(7.028)
Log Volume	−0.009***	0.082	0.015***
	(−8.491)	(1.197)	(5.646)
Volatility	−0.051	−6.060	−0.086
	(−1.600)	(−1.337)	(−0.733)
$\frac{\lvert r_{15}\rvert}{\lvert r_d\rvert}$	0.440***	−0.546***	−0.007
	(32.291)	(−3.501)	(−0.495)
Constant	0.174***	−1.333***	−0.514***
	(12.671)	(−2.819)	(−14.672)
R^2	0.132	0.001	0.005
Observations	84,439	84,230	84,230
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 14: **SPX or RTY NYSE Only**.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	0.001	−0.006	−0.019
	(0.164)	(−0.266)	(−0.531)
Auction Share	0.043^{***}	-0.064^{*}	-0.104^{**}
	(2.754)	(−1.816)	(−2.112)
Off-Exchange Share	0.001	-0.159^{***}	-0.159^{***}
	(0.081)	(−2.601)	(−3.393)
Log Market Cap	-0.008^{***}	0.001	0.013^{***}
	(−6.317)	(0.099)	(2.610)
Log Volume	−0.0004	0.0001	0.009^{*}
	(−0.290)	(0.019)	(1.803)
Volatility	-0.226^{*}	-1.632^{**}	0.161
	(−1.824)	(−2.140)	(0.309)
$\frac{\lvert r_{15}\rvert}{\lvert r_d\rvert}$	0.225^{***}	−0.024	0.019
	(13.879)	(−0.630)	(0.933)
Constant	0.120^{***}	0.072	-0.309^{***}
	(9.536)	(1.505)	(−5.918)
R^2	0.033	0.001	0.002
Observations	49,998	49,995	49,995
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 15: **SPX or RTY NASDAQ Only**.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	-0.012	-0.054	-0.112^{***}
	(-1.556)	(-1.070)	(-3.838)
Auction Share	0.127^{***}	-0.011	-0.087^{**}
	(9.090)	(-0.148)	(-2.217)
Off-Exchange Share	-0.001	-0.142	0.035
	(-0.136)	(-1.518)	(1.079)
Log Market Cap	-0.004^{**}	0.018	0.003
	(-2.557)	(1.253)	(0.630)
Log Volume	-0.005^{***}	0.008	0.022^{***}
	(-4.085)	(0.698)	(5.745)
Volatility	0.111	-1.924^{*}	-0.448
	(1.377)	(-1.770)	(-1.592)
$\frac{\lvert r_{15}\rvert}{\lvert r_d\rvert}$	0.277^{***}	-0.087^{***}	0.061^{***}
	(22.789)	(-2.715)	(3.719)
Constant	0.100^{***}	-0.276^{**}	-0.398^{***}
	(7.735)	(-2.394)	(-8.165)
R^2	0.053	0.001	0.002
Observations	64,095	64,068	64,068
Note:			$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 16: **SPX or RTY AMEX Only**.

	Dependent variable:		
	Price Contribution	Price Reversal	Price Reaction
	(1)	(2)	(3)
Off-Exchange MOC Share	−0.023	−0.009	−0.122
	(−0.555)	(−0.028)	(−0.887)
Auction Share	0.189**	−0.021	−0.081
	(2.605)	(−0.063)	(−0.461)
Off-Exchange Share	0.026	0.027	−0.076
	(0.571)	(0.095)	(−0.539)
Log Market Cap	0.006	0.057*	0.015
	(1.449)	(1.737)	(0.829)
Log Volume	−0.007*	−0.009	0.016
	(−2.009)	(−0.416)	(1.566)
Volatility	−0.051	−1.444	1.120
	(−0.118)	(−0.570)	(0.965)
$\frac{\|r_{15}\|}{\|r_d\|}$	0.451***	−0.422**	−0.041
	(10.127)	(−2.206)	(−0.521)
Constant	−0.019	−0.579	−0.478
	(−0.292)	(−1.523)	(−1.618)
R^2	0.13	0.005	0.002
Observations	2,088	2,087	2,087
Note:			*p<0.1; **p<0.05; ***p<0.01