Vestigial Tails? Floor Brokers at the Close in Modern Electronic Markets*

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Abstract

The closing auction is the most important event of the trading day, now accounting for over 10% of trading volume. The NYSE closing auction design is highly advantageous to NYSE floor brokers, who have near-exclusive auction access from 3:50pm to 4:00pm. We show that closing auction quality, as measured by the accuracy of closing auction information feeds and efficiency of closing prices, is significantly worse on NYSE than Nasdaq. However, closing auction quality improved when NYSE halted floor trading during the COVID-19 pandemic. Our findings highlight the tradeoffs associated with designing a single-price call auction that accepts orders during regular trading hours.

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1 Introduction

For the past 40 years, large publicly traded firms in the United States have almost exclusively listed on the New York Stock Exchange (NYSE) or Nasdaq. One of the services provided by listing exchanges to their listed companies is the closing auction, which determines daily closing prices and affects trillions of dollars of end-of-day fund net asset values (NAVs). Listing exchanges attract nearly all closing interest and earn significant profits from the fees they charge to participate in their closing auctions. Some brokers estimate that exchanges globally now make between a third to half of all of trading revenues from closing auctions (MarketWatch, 2019). Closing auction volume has also increased by about 150% since 2012 and now represents over 10% of total trading volume. Therefore, NYSE and Nasdaq have a significant economic stake in running closing auctions and maintaining their dominant share of closing auction volume.

While it is clear that closing auctions are important to exchanges' bottom lines, it is less clear whether or how the competitive framework for closing auctions benefits investors. Closing auctions represent somewhat of an anomaly in U.S. exchange history because, despite their increasing importance, they have largely remained untouched by competition and innovation.[1] As a result, the rules for closing auctions on NYSE and Nasdaq reflect their own unique histories. While Nasdaq's auctions are fully electronic, NYSE maintains a "hybrid" auction market where, even today, 35% of orders are manually entered by floor brokers (NYSE, 2019a). Floor brokers' special access provides significant advantages over other traders. One advantage is that they are allowed to enter or cancel their orders (also called D-Orders, short for "discretionary orders") after the cutoff time of 3:50pm for regular orders. A second advantage is that publicly-disseminated auction information, such as the indicative closing price, does not incorporate floor brokers' orders until 3:55pm. Thus, unlike floor brokers, most ordinary investors remain in the dark about true auction interest until 3:55pm, five minutes after the cutoff time for submitting regular orders to the auction.

[1] Facing competition for closing auction volume, NYSE argued that "the auction is one of the few components of U.S market structure whose value most people actually agree upon. Until now, there's been no cause for debate because it's a process that's trusted because it works." (NYSE, 2020c).

We study differences in closing auction market quality on NYSE versus Nasdaq using novel exchange proprietary feed data from May 2011 to October 2018. In this setting, we define closing auction market quality as the absolute difference between the indicative closing auction price and the realized closing auction price (the "near price difference"), the absolute difference between indicative closing auction volume and realized closing auction volume, the size of indicative order imbalances, and the efficiency of the final closing price. Indicative closing auction information is critical for auction participants, as it helps the marginal participant determine whether their liquidity needs can be met at acceptable prices. Indeed, a recent survey of institutional trading firms showed that nearly three out of every four traders used auction feeds in deciding how to trade at the close (Markets Media, 2017). Underlining its importance, this information is publicly disseminated to traders at frequent intervals by both NYSE and Nasdaq in the last ten to fifteen minutes of the trading day.[2] We pay special attention to the period surrounding 3:55pm, when NYSE includes floor broker orders in its indicative statistics, and the period leading up to 4:00pm, when the closing auction clears.

We find that closing auction market quality is significantly worse on NYSE than Nasdaq throughout the closing auction process in four important ways. First, NYSE indicative auction prices are consistently off from actual closing auction prices compared to Nasdaq. Prior to 3:55pm, we find that the near price difference exceeds 105 basis points on NYSE, compared to only 10 basis points on Nasdaq. At exactly 3:55pm, the near price difference on NYSE sharply drops by 45 basis points due to the incorporation of floor broker orders. The large change at 3:55pm underscores the informational disadvantages of non-floor traders about closing auction supply and demand. However, even after these floor broker orders are incorporated, the near price difference remains over 60 basis points higher on NYSE. As 4:00pm approaches, the NYSE near price difference converges

[2] The imbalance disclosures can be viewed as a form of "sunshine trading"—pre-announcing intentions to trade in order to coordinate supply and demand (Admati and Pfleiderer, 1991). Consistent with this view, Mayhew, McCormick, and Spatt (2009) show that the market appears to anticipate the direction of imbalance information. Brokers attempt to use these statistics for "closing volume discovery"—in other words, to forecast closing auction liquidity. See https://www.tradersmagazine.com/departments/ecns_and_exchanges/closing-volume-discovery/.

toward zero, but still remains higher than the Nasdaq near price difference even seconds before the auction clears.

Second, indicative closing auction volume is far less indicative of realized auction volume on NYSE throughout the auction process. Before 3:55pm, NYSE indicative volume represents only 58% of realized volume. By contrast, Nasdaq indicative volume represents 98% of realized volume at the same point in time. At exactly 3:55pm, NYSE indicative volume sharply increases by 15 percentage points due to the incorporation of floor broker orders. The adjustment represents about $2.2 million in additional trading volume on average from floor brokers, or about $1.5 trillion in additional trading volume across our sample period. However, even with the 15 percentage point adjustment at 3:55pm, indicative volume is still 27% off from realized volume. The difference suggests that floor brokers represent up to $4.0 million in additional closing auction volume in the last five minutes of the trading day, or about $2.7 trillion in trading volume across our sample.

Third, auction imbalances on NYSE are consistently larger than on Nasdaq. Before 3:55pm, the ratio of the absolute indicative order imbalance to paired volume is 51% on NYSE, but only 1% on Nasdaq. The large order imbalances on NYSE represent major trading opportunities for floor traders because they have near-exclusive access to the auction after 3:50pm. At exactly 3:55pm, the order imbalance ratio on NYSE decreases by 21 percentage points, suggesting that floor traders are indeed opportunistically interacting with these imbalances. Just before the auction clears at 4:00pm, we find that the NYSE order imbalance ratio still remains fairly high at about 5.5%, suggesting that floor broker interest is not sufficient to eliminate imbalances. We also find that the sign of the order imbalance flips in one out of every six auctions on NYSE at 3:55pm, when D-Orders are incorporated into the auction feed, and during the last minute of the trading day, when D-Orders can still be modified or cancelled. Therefore, D-Orders can lead to significant unpredictability in NYSE auctions.

Fourth, closing auction prices themselves are less efficient on NYSE. In particular, we find that the closing price deviates more from the last continuous market price on NYSE, which is consistent with the larger imbalances that we observe during the final seconds of the auction. We find that closing auction price deviations on NYSE are reversed by about two-thirds in the opening auction on the following trading day, compared to only one-third on Nasdaq. The stronger overnight reversals on NYSE further suggest that the larger price dislocations on NYSE are driven by excess demand for liquidity that is not met by floor brokers. Taken together, our results suggest that the flexibility provided to NYSE floor brokers comes at a cost of less efficient auctions for investors. Whether this trade-off between flexibility and efficiency strikes the right balance is unclear. But what is clear is that the D-Order volume from floor brokers generates significant revenues for NYSE. Given that D-Order fees can be more than twice as high as regular closing auction fees, we estimate that such fees generated between $52 to $101 million in additional revenue in 2018 alone.

We use the novel NYSE floor closure during the COVID-19 pandemic to further identify the effect of floor trading on closing auction market quality. On March 23, 2020, NYSE closed its trading floor after two people at the exchange tested positive for COVID-19. The closure completely halted the use of D-Orders in NYSE closing auctions while electronic trading continued unaffected. This was the first such closure in NYSE history, as previous closures during Hurricane Sandy and 9/11 halted all trading at the exchange. During the floor closure, we find that closing auction market quality generally improved on NYSE. First, we find that indicative matched volume on NYSE at 3:55pm jumped significantly from 56% to 84% of final auction volume. Thus, the majority of auction orders were matched shortly after the cutoff time for regular auction orders, much like on Nasdaq. Second, we find that the absolute difference between the indicative closing auction price at 3:55pm and the final closing auction price decreased by about 106 basis points, or about 31% of the indicative price difference at the same time of day before the floor closure. Third, we find that the ratio of absolute order imbalance to matched volume decreased by 6 percentage points, suggesting that a larger percentage of auction participants were getting their orders filled. All of these changes are measured relative to Nasdaq, which did not experience any significant auction quality changes during this period. Furthermore, all of these changes completely reverted after NYSE reopened its trading floor on May 26, 2020. The improvements in closing auction market quality on NYSE during the floor closure are especially notable given the widespread market turmoil during the ongoing COVID-19 pandemic.

Finally, we examine the resiliency of closing auction market quality to demand shocks for closing auction liquidity. Intuitively, demand shocks are more likely to produce large order imbalances on both NYSE and Nasdaq. On NYSE, however, auction participants may be less willing to compete on price to execute against large imbalances because they are at a significant disadvantage to floor brokers, who have more knowledge about auction supply and demand and more flexibility to modify their orders after 3:50pm. Consistent with this intuition, we find that NYSE indicative prices are 15% less accurate for every standard deviation increase in pre-3:55pm abnormal indicative matched volume, compared to only 2% on Nasdaq. We also use "triple witching" days as instruments for abnormal indicative matched volume to further establish a causal connection between auction interest and market quality on NYSE. Triple witching days are days in which index futures, index options, and stock options are all set to expire—auction demand is higher on these days because traders need to either roll out or offset their positions, greatly increasing volume in these instruments and the underlying securities (Stoll and Whaley, 1990; Smith, 2006; Barclay, Hendershott, and Jones, 2008). In our first stage regression, we find that pre-3:55pm indicative matched volume is 2.8 standard deviations higher on NYSE on triple witching days. In our second stage regression, we find that indicative closing prices are about 41% less accurate due to the predicted increase in indicative matched volume.[3] While there is a similar increase in indicative matched volume on Nasdaq on triple witching days, we do not observe any economically significant changes in Nasdaq indicative closing prices in the second-stage regression. Therefore, our evidence suggests that the unique closing auction market structure on NYSE also makes the auction less resilient to liquidity demand shocks.

Our findings highlight the complexities and tradeoffs associated with operating a single-price

[3]We obtain similar findings if we use end-of-month portfolio rebalancing periods as our instrument for impatient liquidity trader volume.

call auction that accepts orders during regular trading hours. Many traders value the flexibility to modify their auction orders during the final minutes of the trading day in response to new information from the continuous trading session. NYSE caters to this demand by allowing traders to modify their orders through floor brokers until seconds before the close. However, we document that there are several downsides to this model including reduced closing price efficiency, higher auction participation fees, and less informative auction feeds. By contrast, Nasdaq provides less flexibility to modify auction orders during the final minutes of the trading day, thus inhibiting the ability of traders to strategically interact with each other in the closing auction. However, a major upside to the Nasdaq model is that it generates more efficient closing prices and more informative auction feeds. From a welfare perspective, traders are likely better off under the Nasdaq model because the efficiency gains benefit all investors who rely on the closing price. The reduced flexibility under the Nasdaq model, on the other hand, is mainly a cost to the subset of traders who may want to strategically modify their orders during the final seconds of the trading day and do not appear to contribute to price discovery.

The remainder of the paper proceeds as follows. Section 2 provides a review of the relevant literature on closing auctions and floor brokers. Section 3 presents institutional details of closing auctions and D-Orders. Section 4 presents our central hypotheses and the underlying market structure theory motivating those hypotheses. Section 5 describes the data and methodology. Section 6 tests the differences in closing auction market quality on NYSE versus Nasdaq. Section 7 shows how closing auction market quality on NYSE was affected by the NYSE floor closure during the COVID-19 pandemic. Section 8 tests the resiliency of closing auction market quality to demand shocks for closing auction liquidity on NYSE versus Nasdaq. Section 9 concludes.

2 Related Literature

Our study complements several related streams of recent research. Battalio, Jennings, and McDonald (2020) examine the NYSE "parity" rule, a vestige of the NYSE hybrid model which allows floor brokers to trade ahead of previously entered electronic orders.[4] The authors argue that the NYSE parity rule is not transparent and leads to higher costs for investors in modern electronic markets. Our results suggest that the D-Order may also be a vestigial market structure feature that benefits some investors (those with access to floor brokers), but their complexity and lack of transparency likely serve as a tax on less-sophisticated investors who rely on incomplete auction information. Bogousslavsky and Muravyev (2020) show that institutional price pressure makes closing prices less efficient. Our study provides complementary evidence that the mechanism design of the closing auction is highly important for both the efficiency of closing prices and the informativeness of closing auction feeds. Furthermore, our results suggest that the NYSE closing auction mechanism is less resilient to institutional price pressure because of the asymmetric advantages provided to NYSE floor brokers. Clark-Joseph, Ye, and Zi (2017) show that NYSE designated market makers (some of whom are NYSE floor brokers) play an important role in providing liquidity. Perhaps unsurprisingly, NYSE advertises its floor brokers as "help[ing] investors maximize the benefits of the NYSE closing auction" through the usage of D-Orders (NYSE, 2020a). Consistent with NYSE's claims, we find that D-Orders make up a significant portion of closing auction liquidity. However, we also find that the design of the NYSE closing auction generates negative externalities for investors trading around the close because of how D-Orders are incorporated into the auction and disclosed to investors.

Our study also contributes to the literature on optimal market design in equities markets. Several studies have shown that market quality improves after an exchange introduces a call auction to determine the equilibrium stock price at the beginning or end of the trading day (Pagano and Schwartz, 2003; Hillion and Suominen, 2004; Smith, 2006; Comerton-Forde, Lau, and McInish, 2007; Kandel, Rindi, and Bosetti, 2012; Pagano, Peng, and Schwartz, 2013).[5] Liquidity and price

[4]See https://www.nyse.com/article/parity-priority-explainer.

[5]Theoretical studies further show that frequent call auctions during the intraday trading period can also improve market quality because traders are forced to compete on price instead of speed (Budish, Cramton, and Shim, 2015; Jagannathan, 2020). Periodic auctions can also aggregate information more efficiently and are more robust to problems arising from information asymmetries (Madhavan, 1992).

efficiency are also generally higher on exchanges which operate fully-electronic or hybrid auctions instead of purely dealer-driven auctions (Ellul, Shin, and Tonks, 2005; Storkenmaier and Riordan, 2008; Hendershott and Moulton, 2011; Onur and Reiffen, 2018). Efficiency outcomes are better again if the exchange provides a high degree of pre-trade transparency about auction supply and demand (Baruch, 2005; Boehmer, Saar, and Yu, 2005; Chakraborty, Pagano, and Schwartz, 2012; Boussetta, Daures-Lescourret, and Moinas, 2020). However, other studies have noted that automated trading systems operating in the continuous market may not be able to fully replicate the benefits of human-based intermediation such as the customized handling of large institutional orders (Venkataraman, 2001). Floor traders may be able to facilitate better price discovery in the continuous market because they can see individual orders in addition to aggregated supply and demand schedules (Madhavan and Panchapagesan, 2000). Finally, Brogaard, Ringgenberg, and Roesch (2020) show that intraday volatility and effective spreads on NYSE increased after the COVID-19 floor closure, further suggesting that there is some value to floor trading during the trading day.[6] In this study, we focus on the closing auction, an increasingly important "size discovery" mechanism for large liquidity traders (Chakraborty et al., 2012; Duffie and Zhu, 2017) that does not necessarily require special arrangements for floor brokers to operate efficiently. Indeed, we provide causal evidence that closing auction market quality is higher when all auction participants, floor brokers and non-floor brokers alike, have symmetric access to the auction and complete information about supply and demand during the order submission window—as they do on Nasdaq and most all other modern exchanges.

[6] One interpretation of their results, in combination with our results about the closing auction market quality improvements on NYSE during the COVID-19 floor closure, is that the special access provided to NYSE floor brokers in the closing auction is a partial subsidy to designated market maker firms which have floor trading operations in addition to affirmative obligations to continuously post narrow spreads in the intraday trading session.

3 Institutional Background

Closing auctions are typically the most important liquidity event of the day, both in terms of trading in and around the auction. For most stocks, an intraday volume profile reveals a distinct U-shaped pattern, sometimes called a liquidity "smile" or "smirk," with high trading activity clustered around the open and increasingly around the close (McInish and Wood, 1992; Foster and Viswanathan, 1993; Russell and Engle, 2010). In this section, we highlight some of the relevant institutional details of closing auctions on NYSE and Nasdaq.

3.1 Auction orders and timeline

During our sample period, market-on-close (MOC) orders can be submitted to the NYSE closing auction from 6:30am to 3:50pm or the Nasdaq closing auction from 4:00am to 3:55pm. Limit-on-close (LOC) orders can be submitted to the NYSE closing auction until 3:50pm and the Nasdaq closing auction until 3:58pm. Following the cutoff times of 3:50pm on NYSE and 3:55pm on Nasdaq, MOC and LOC orders cannot be modified or cancelled (although exceptions can be made for legitimate errors). An MOC order is an unpriced order to buy or sell shares in the closing auction at the to-be-determined closing price. An LOC order specifies a maximum buy price or minimum sell price at which the trader is willing to buy or sell shares in the closing auction. If the exchange reports an imbalance between the total shares supplied and the total shares demanded at the current reference price (typically the last sale price in the continuous trading session), then traders can also submit imbalance-on-close (IOC) orders at any time to reduce the order imbalance. Figure 1 summarizes the auction timelines for NYSE and Nasdaq.[7]

Traders on NYSE can submit D-Orders to the closing auction until 3:59:50pm. D-Orders are handled manually by NYSE floor brokers on behalf of their clients.[8] Up until 3:59:50pm, these

[7]For more information about the closing auctions on NYSE and Nasdaq, 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.

[8]Floor brokers are independent members of the exchange who handle agency orders. Designated market-makers (DMM)—much like the specialists of the past—also have employees on the floor. In contrast to floor brokers, the vast

orders can also be cancelled or modified. Unlike IOC orders, these orders can add to publicly-disseminated order imbalances. Although NYSE publicly disseminates closing auction statistics (such as the indicative closing price) starting at 3:45pm, it does not incorporate D-Orders into these statistics until 3:55pm, five minutes after the cutoff time for regular MOC and LOC orders. NYSE and its floor brokers advertise D-Orders as a way of maximizing trading flexibility and accessing liquidity in the close. NYSE also advertises its hybrid model as superior to a fully-electronic model during times of market volatility (NYSE, 2019b). D-Orders make up about one-third of all auction volume, suggesting that many traders value the flexibility associated with adding, modifying, or cancelling orders in the last ten minutes of the trading day.[9]

The closing auctions on NYSE and Nasdaq both run at 4:00pm. The closing price is determined by the intersection of the supply and demand curves populated by the MOC, LOC, and IOC orders, D-Orders, and unfilled orders in the limit order book. If the curves intersect at multiple prices but the same quantity, which can and does occur with discrete prices and a finite number of non-atomistic auction participants, then a closing price is chosen that minimizes the order imbalance. If there are still multiple prices, then the exchanges typically choose a closing price from this set that minimizes the price dislocation relative to the continuous market. The final print contains the closing price and matched volume, and is typically published to the public tape immediately after the close.[10]

majority of DMM activity consists of proprietary electronic trading—indeed they are required to employ algorithms for maintaining quotes throughout regular trading hours (NYSE Rule 104). Hence although both floor brokers and DMMs are "floor traders" their businesses and activities are distinct.

[9]In August 2019, NYSE migrated its trading platform to its new, fully-electronic "Pillar" platform. NYSE D-Orders are now entered electronically like all other orders but still handled by floor brokers. Previously, floor brokers could enter "d-Quotes" (the predecessor to D-Orders) either manually or via a handheld device. Apart from the electronic entry, D-Orders are functionally equivalent to d-Quotes.

[10]If there is not enough interest in the closing auction, then no closing auction process runs. In such cases, an alternative price such as the the last sale price, the midpoint of the exchange's best bid and offer, or a volume-weighted average price is used, depending on the rules of the exchange. In this study, we focus on stock-days in which the closing price is determined by the intersection of supply and demand in the closing auction, which represents almost all stock-days during our sample period.

3.2 Imbalance messages

NYSE and Nasdaq publicly disseminate closing auction imbalance messages every five seconds starting at 3:45pm and 3:50pm, respectively, during our sample period. Unlike the closing print, the auction imbalance messages disseminated by NYSE and Nasdaq are currently only available through subscriptions to the listing exchanges' proprietary feeds. The imbalance messages generally include the near price, far price, indicative matched volume, and the indicative order imbalance.[11] The near price is the clearing price for orders that are currently submitted to the auction and the continuous limit order book. Hence, the near price is essentially the indicative closing price at any given point in time, and the closing price is the final near price. The far price is the clearing price for orders that are currently submitted to the auction but not the continuous limit order book. Indicative matched volume is the volume of shares that would be traded if the auction were to clear at the current reference price, typically the last sale price in the continuous market. Indicative order imbalance is the signed difference between the total number of shares supplied and demanded at the current reference price. Traders can use these closing auction statistics to determine if there is sufficient liquidity in the closing auction for their orders, although it is important to note that D-Orders are not included in these statistics until 3:55pm.

3.3 Fees

In the continuous market, the typical fee for taking liquidity is between $0.20 to $0.30 per 100 shares traded. However, this cost is often offset by the availability of rebates for posting liquidity, which are typically slightly lower than the fees for taking liquidity, and can be anywhere from $0.10 to $0.30 cents per 100 shares traded. By contrast, exchanges charge between $0.04 to $0.11 per 100 shares to each side of a closing auction transaction. The fee increases if the customer uses a D-Order. In particular, NYSE charges a fee of $0.05 to $0.15 per 100 shares to remove liquidity at

[11] This is the terminology for Nasdaq. The analogs for the near price and far price on NYSE are the "continuous book clearing price" and the "auction interest clearing price." See https://www.nyse.com/publicdocs/nyse/data/XDP_Imbalances_Feed_Client_Specification_v2.2b.pdf and https://www.nasdaqtrader.com/content/productsservices/Trading/ClosingCrossfaq.pdf.

the close using D-Orders, and an additional fee of \$0.03 to \$0.10 per hundred shares if the D-Order is last modified in the final 25 minutes of the trading day.[12] Thus, D-Order fees can be more than twice as high as regular order fees in the closing auction. To provide context, NYSE reportedly made \$149 million from auction trading fees in 2018, representing more than half of its revenues from all trading volume on its platform (WSJ, 2019a). Given that D-Orders make up 35% of all NYSE closing volume, we estimate that D-Orders brought in \$52 million to \$101 million in fee revenues for NYSE in 2018.

4 Theoretical Motivation and Hypothesis Development

Closing auctions in modern equity markets are generally viewed by institutional investors as a "liquidity focal point" where large quantities of shares can be exchanged with minimal price impact (Norges Bank, 2020).[13] Many institutional investors participate in the closing auction because they are required to trade at the closing price for that day ("benchmark investors"). For example, investment funds frequently trade in closing auctions because their inflows and outflows are benchmarked to daily closing prices. Index funds are also required to trade in closing auctions to minimize daily tracking error. Other institutional investors, however, only participate in the closing auction if there is sufficient liquidity to trade against ("flexible investors"). D-Orders on NYSE are popular because they provide flexible investors with the option to add, modify, or cancel their closing auction orders in the last ten minutes of the trading day. For example, if the NYSE auction feed at 3:58pm indicates that the closing auction will clear at a price that is significantly higher than the efficient price in the continuous market due to a large liquidity imbalance, then D-Order users who submitted matching buy orders may want to cancel those orders to avoid transacting at an inefficient price.

[12] In this context, "last modified" refers to the later of the order's entry time, final modification, or cancellation. See https://www.nyse.com/publicdocs/nyse/markets/nyse/NYSE_Price_List.pdf at footnote 10.

[13] The concept of a liquidity focal point is largely borne out by the theoretical predictions in Admati and Pfleiderer (1988).

Foucault, Kadan, and Kandel (2005) and Roşu (2009) model the interactions of impatient and patient traders in a continuous limit order book. In their settings, impatient traders incur larger penalties than patient traders for non-executions. An equilibrium outcome from both models is that impatient traders will submit aggressively-priced limit orders to increase the chance of a fast execution, while patient traders will submit non-aggressive limit orders. In our setting, we can similarly think of our benchmark investors as impatient traders who submit aggressively-priced limit orders to the closing auction. The flexible investors, meanwhile, can be thought of as patient traders who submit non-aggressive limit orders to the closing auction and cancel or modify these orders as the efficient price in the continuous market changes, much like the adjustments of standing limit orders to permanent price changes in Roşu (2009). Also, we should note that an important difference between our setting and the settings in Foucault et al. (2005) and Roşu (2009) is that trading takes place in a single-price call auction instead of a continuous double auction. However, the qualitative predictions about investor behavior from Foucault et al. (2005) and Roşu (2009) still apply in our setting, in that impatient traders will want to maximize their execution probabilities by submitting aggressively-priced limit orders, even if trading only occurs at a single point in time instead of in continuous time, while patient traders will only want to participate in the closing auction if there is sufficient liquidity to trade against.

In light of the trader types described above, how would we expect the quality of closing auction feeds to differ on NYSE versus Nasdaq? First, consider NYSE, where the cutoff for submitting or cancelling regular closing auction orders is 3:50pm and the auction feed does not incorporate D-Orders until 3:55pm. In this setting, benchmark investors would prefer to submit their aggressively-priced limit orders before 3:50pm for several reasons: (1) regular auction order fees are significantly lower than D-Orders fees; (2) benchmark investors are price-insensitive and thus indifferent to new information reported in NYSE closing auction feeds or the continuous market after 3:50pm; and (3) the auction feeds will incorporate their orders earlier, providing flexible investors with a longer time window to react to potential imbalances. Because D-Orders are not incorporated into NYSE auction feeds until 3:55pm, the pre-3:55pm indicative auction price will only reflect the aggressively-priced limit orders from benchmark investors. Thus, the pre-3:55pm indicative price is likely to be significantly different from the realized closing price at 4:00pm. Furthermore, prior to 3:55pm, we would also expect low indicative matched volume (relative to realized matched volume at 4:00pm) and large order imbalances because D-Orders are excluded from auction feeds before 3:55pm and flexible investors choose to delay their limit orders by submitting through floor brokers.

Next, consider Nasdaq, which incorporates all closing auction orders into their feeds throughout their entire dissemination period of 3:50pm to 4:00pm. Nasdaq does not allow orders to be cancelled or modified after 3:50pm, although does allow MOC and LOC orders to be entered until 3:55pm and 3:58pm, respectively. Similar to NYSE, benchmark investors would still want to submit their aggressively-priced limit orders early in the auction process to provide flexible investors with a longer time window to react to imbalances. Unlike NYSE, however, flexible investors are only able to submit, but not cancel or modify, orders after 3:50pm. If there is enough competition between flexible investors to trade against imbalances, then the main options for flexible investors would be to quickly react to potential imbalances as soon as auction information is first disseminated at 3:50pm, or submit orders before 3:50pm in anticipation of these imbalances.[14] In either case, because late cancellations are not allowed, flexible investors will want to follow more conservative order submission strategies to avoid matching in the closing auction at an undesirable price which stems from an unexpected change in the efficient price between 3:50pm and 4:00pm. As a result, the closing auction will consist of a larger cross-section of limit orders at 3:50pm. Therefore, we expect that indicative closing auction prices and matched volume on Nasdaq at 3:50pm will be more reflective of their realized values at 4:00pm, and that order imbalances will be smaller.

Having laid out the economic intuition for closing auction dynamics on NYSE and Nasdaq, we now summarize our empirical predictions that can be tested using publicly-available auction data:

[14] If multiple investors submitted limit orders at the auction clearing price and there are not enough matching shares for those limit orders, then the matching shares are allocated by time priority. Thus, order submission speed can matter in the closing auction, especially on Nasdaq at exactly 3:50pm when order imbalances are first disseminated.

Prediction 1: The absolute difference between the indicative and realized closing auction prices on NYSE will be higher than Nasdaq throughout the closing auction process.

Prediction 2: Indicative matched volume will be significantly lower than realized matched volume on NYSE versus Nasdaq throughout the closing auction process.

Prediction 3: Indicative absolute order imbalances on NYSE will be significantly higher than Nasdaq throughout the closing auction process.

Another question naturally arises from the difference in closing auction market structures on NYSE and Nasdaq: how does the efficiency of the realized closing auction price at 4:00pm differ on one exchange versus the other? Empirically, we can think of a closing price as "efficient" if price changes at the close are not systematically reversed at the open of the next day (Amihud and Mendelson, 1987). If all auction participants truthfully submit their bids to the closing auction, then the closing auction market structure may not affect the final auction outcome since the auctioneer simply aggregates all orders to determine the equilibrium price and quantity. On the other hand, the higher fees on NYSE to participate in the closing auction after 3:50pm, in addition to the information asymmetries between floor brokers and other traders about closing auction supply and demand, may prevent some traders from participating in the closing auction. Furthermore, the information asymmetries between floor brokers and other traders may also induce strategic bidding behavior among auction participants, especially D-Order users who can cancel and modify orders up to ten seconds before the trading day ends. Therefore, our fourth empirical prediction is as follows:

Prediction 4: Closing auction price efficiency is significantly lower on NYSE compared to Nasdaq due to the differences in closing auction market structures.

The remainder of this paper will focus on testing the four predictions in this section and establishing causality using exogenous shocks to the closing auction mechanism on NYSE and benchmark investor volume.

5 Data and Methodology

Our data on indicative auction information from 2011 to 2018 comes from the SEC's MIDAS system, which aggregates and normalizes all U.S. exchange direct feeds. The MIDAS system was created in response to the Flash Crash in May 2010 as a market monitoring tool and came online in 2013.[15] Closing auction information reported on the MIDAS system for NYSE and Nasdaq includes the near price, far price, reference price, indicative paired volume, and indicative signed order imbalance. During our sample period, these statistics are available for each stock-day from 3:45pm to 4:00pm on NYSE and 3:50pm to 4:00pm on Nasdaq at five-second intervals.

Our sample includes all S&P 500 stocks from May 20, 2011 to October 29, 2018. Prior to May 20, 2011, indicative auction information is unavailable for NYSE stocks. Indicative auction information can also be fairly sparse for less liquid stocks, which is why we focus on the S&P 500. We exclude empty near price observations or near prices in the bottom or top 0.1 percentile of the distribution from our sample. These prices generally reflect days with low auction interest and indicative crosses at extreme limit order prices.[16] We obtain an additional sample of closing auction imbalance message data covering the period February 19, 2020 to July 7, 2020 from MayStreet, the provider of SEC's MIDAS data, to test closing auction market quality changes after the NYSE floor closure on March 23, 2020 and the subsequent reopening on May 26, 2020. We supplement our imbalance data with stock-day variables from the Wharton Research Data Services (WRDS) Intraday Indicator data set (IID). These data are derived by WRDS from the NYSE Trade and Quote (TAQ) database. In particular, we obtain the following standard stock-day variables: (1) average dollar effective spread; (2) Kyle's lambda, which measures price impact and is based on the Kyle (1985) model; (3) intraday volatility, which is based on transaction-level returns; and (4) intraday trading volume. We primarily use these variables as controls in our multivariate regressions

[15]For some of the history around MIDAS, see https://www.marketsmedia.com/sec-has-midas-touch/.

[16]We also exclude observations in which the ratio of indicative paired volume to realized closing auction volume, the ratio of indicative absolute order imbalance to indicative paired volume, or the absolute percentage difference between the near price and the final closing auction price is in the top 0.5 percentile of its distribution.

later in the paper.[17]

Panels A and B of Table 1 provide summary statistics for the NYSE- and Nasdaq-listed stocks in our sample. As expected, daily trading volume tends to be fairly high in these stocks, with median stock-day trading volumes of about $118 million on NYSE and $126 million on Nasdaq. Trading volume in the closing auction is approximately equal on both exchanges at about $16 million to $18 million. Across our sample period, closing volume on NYSE represents 9% of daily volume, which is about two percentage points higher than Nasdaq. Compared to NYSE, the percentage effective spread on Nasdaq is about 0.7 basis points higher and Kyle's lambda is about 2% higher, indicating that Nasdaq stocks are slightly less liquid. This is likely due to differences in the types of stocks that tend to be listed on Nasdaq—such as technology stocks—which have historically had higher volatility. We find that intraday volatility and absolute open-to-close returns are also higher on Nasdaq compared to NYSE. Our baseline tests in this study largely focus on differences in closing auction indicative statistics around 3:55pm, when D-Orders are incorporated into the NYSE statistics, and just before 4:00pm, when the closing auctions clear, for NYSE versus Nasdaq. The differences in the summary statistics between the two exchanges are fairly minor and unlikely to affect our tests, and we make sure to control for stock-level liquidity measures in our multivariate regressions.

6 Baseline Results

According to our first three empirical predictions in Section 4, the indicative auction statistics reported by NYSE should be significantly off from their eventual realized values at 4:00pm compared to Nasdaq. In this section, we test these three predictions by comparing indicative closing auction statistics on NYSE and Nasdaq during their dissemination windows. Toward the end of this section, we test our fourth empirical prediction that closing auction efficiency is also worse on NYSE by

[17] See https://wrds-web.wharton.upenn.edu/wrds/ds/wrdsapps/intradayind/taqms/index.cfm?navId=524 for basic descriptions of these control variables.

examining the magnitude of price changes at the close and extent to which these price changes revert overnight.

6.1 Graphical Evidence and Univariate Results

Figure 2 shows the evolution of the average near price difference, which we define as the absolute difference (in basis points) between the near price and the final closing auction price, on NYSE versus Nasdaq. When Nasdaq first reports the near price at 3:50pm, the near price difference equals about 50 basis points. Five seconds later, the near price difference shifts to just under 20 basis points. After that, it monotonically converges to zero as 4:00pm approaches. By contrast, when NYSE first reports the near price at 3:45pm, the near price difference equals 120 basis points, with no immediate change five seconds later. Ten minutes later, the difference is still fairly high at about 100 basis points. At exactly 3:55pm, when D-Orders are incorporated into the closing auction statistics, the near price difference shifts downward to about 50 basis points. After that, it monotonically converges to zero as 4:00pm approaches. Overall, this figure shows that indicative closing prices on NYSE are significantly less accurate than Nasdaq throughout the auction process. Furthermore, the large shifts in the indicative price on NYSE starting at exactly 3:55pm suggest that floor brokers are opportunistically interacting with auction imbalances after the cutoff time for regular auction orders from other investors. Prediction 1 from our model is supported by this graphical evidence.[18]

Figure 3 presents the evolution of the average paired volume ratio, which we define as the ratio of indicative paired volume to final auction volume. On NYSE, the average paired volume ratio remains stable at about 58% from 3:45pm to 3:55pm. That is, 42% of final auction volume is not reflected in the closing auction indicative statistics during this time period. At exactly 3:55pm, the ratio jumps to about 73% and then monotonically converges to 100% as 4:00pm approaches.

[18] In Internet Appendix A, we also provide a graph of the reference price difference, the absolute difference between the reference price from the continuous market and the realized closing price, on NYSE versus Nasdaq. The reference price difference is largely the same on both exchanges, suggesting that the continuous market efficiently incorporates price-relevant information on both exchanges.

This evidence suggests that floor brokers represent up to 42% of volume in the closing auction. On Nasdaq, however, the average paired volume ratio starts at about 80%, immediately increases to 96%, and then converges to 100% as 4:00pm approaches over the next ten minutes. That is, indicative closing auction volume on Nasdaq almost immediately reflects the final closing auction volume. Overall, this evidence is consistent with our Prediction 2 that indicative closing auction volume is much less reflective of final closing auction volume on NYSE than Nasdaq.

Figure 4 presents the evolution of the average order imbalance (OIB) ratio, which we define as the ratio of indicative absolute order imbalance to indicative paired volume. On NYSE, the average OIB ratio remains stable at about 51% from 3:45pm to 3:55pm. The large OIB ratio represents an opportunity for floor brokers to trade against imbalances by submitting, modifying, or even cancelling D-Orders on the buy side or sell side during the last ten minutes of the trading day. At exactly 3:55pm, the OIB ratio jumps down to about 31%. As 4:00pm approaches, the OIB ratio then monotonically converges toward about 7%, which represents the unfilled orders at the final reference price. On Nasdaq, however, the OIB ratio starts at about 31%, immediately jumps down to about 5%, and then monotonically converges to about 1% as the close approaches. Thus, we find that imbalances are more likely to be minimized throughout the auction process on Nasdaq compared to NYSE.[19] Overall, this evidence from this figure is consistent with our Prediction 3 that order imbalances are consistently larger on NYSE than Nasdaq, especially before 3:55pm.

We also provide auction-level summary statistics at 3:54:55pm and 3:55pm on NYSE versus Nasdaq to further illustrate how the late incorporation of D-Orders at 3:55pm reduces the informativeness of NYSE auction feeds. Table 2, Panel A documents significant changes in NYSE auction statistics at 3:55pm and insignificant changes at 3:54:55pm. In particular, at 3:55pm, the near price decreases by 56 basis points, paired volume increases by $2.2 million, and absolute order imbalance decreases by $1.5 million, on average. For about 15% of stock-days on NYSE, we also find that the order imbalance changes sign at 3:55:00pm, suggesting that floor brokers are not necessarily

[19] We also observe a small uptick in order imbalances on NYSE in the final seconds leading into the close which could be due to last-minute D-Order modifications or cancellations.

reducing auction imbalances as 4:00pm approaches. By contrast, Table 2, Panel B shows that there are no significant changes in auction statistics on Nasdaq at 3:54:55pm or 3:55pm, further suggesting that the changes on NYSE at 3:55pm are directly attributable to floor brokers' orders. Therefore, the evidence from this table suggests that NYSE indicative closing auction statistics are significantly affected by orders from floor brokers, who have near-exclusive access to the closing auction after 3:50pm.

6.2 Multivariate Results

In this section, we formally test the differences in closing auction market quality on NYSE versus Nasdaq in a multivariate regression setting. In particular, we focus on three important times in the auction dissemination window and construct indicator variables for each of these times: (a) 3:54pm, when D-Orders have not yet been incorporated into the NYSE auction feeds ($\mathbb{1}^{3:54}$); (b) 3:55pm, when D-Orders are incorporated into NYSE auction feeds ($\mathbb{1}^{3:55}$); and (c) 3:59:55pm, the last dissemination period before the closing auctions clear ($\mathbb{1}^{3:59}$).[20] For each stock-day (i,d) and time-of-day t, we construct a sample of indicative closing auction quality statistics (y). We then test the following difference-in-differences ordinary least squares (OLS) regression model:

$$
\begin{aligned}
y_{i,t,d} \quad &= \quad \beta_1 \cdot NYSE_i \times \mathbb{1}^{3:54} + \beta_2 \cdot NYSE_i \times \mathbb{1}^{3:55} + \beta_3 \cdot NYSE_i \times \mathbb{1}^{3:59} \\
&+ \quad \beta_4 \cdot \mathbb{1}^{3:54} + \beta_5 \cdot \mathbb{1}^{3:55} + \alpha + \gamma X_{i,d-1} + \varepsilon_{i,t,d},
\end{aligned}
\tag{1}
$$

where $NYSE$ is an indicator variable that equals one if stock i is listed on NYSE, α is a constant term, and X is a vector of stock-day control variables which includes the natural log of dollar trading volume, transaction-level return volatility, average percent effective spread, and Kyle's lambda. Standard errors are double-clustered by symbol and date. In alternative specifications, we

[20] Alternatively, we can test the difference in each auction statistic y on NYSE versus Nasdaq before, after, and exactly at 3:55pm using all auction feed data instead of these three specific times. However, this approach would bias the point estimate at 3:55pm for NYSE because of the differing trends in y on NYSE versus Nasdaq, as shown in the previous three figures.

also include a vector of stock and date fixed effects, $\delta_{i,d}$. The constant in our baseline specifications with no controls or fixed effects has the interpretation of the average indicative auction statistic on Nasdaq at 3:59:55pm. We are primarily interested in the first three beta coefficients, as they represent the differences in closing auction quality on NYSE relative to Nasdaq at different points in the auction.

We first use the absolute near price difference as the dependent variable y in the above regression model. The results are reported in Table 3. Across specifications, we find that the absolute near price difference on NYSE at 3:54pm is about 108 basis points higher than Nasdaq, suggesting that the pre-3:55pm indicative closing auction price is much less indicative of the eventual closing auction price at 4:00pm on NYSE. At exactly 3:55pm, the absolute near price difference on NYSE is about 64 basis points higher than Nasdaq. The sudden shift of 44 basis points is due to the incorporation of D-Orders at 3:55pm. However, even with the incorporation of D-Orders, the near price difference is still significantly higher on NYSE. Finally, at 3:59:55pm, we find that the absolute near price difference on NYSE is about 1 to 2 basis points higher relative to Nasdaq. In absolute terms, the average near price difference on NYSE is about 3.9 basis points at 3:59:55pm. To put this estimate in perspective, the 3.9 basis point difference in the last five seconds of the trading day represents about 3.8% of the absolute open-to-close return for the average NYSE-listed stock, compared to only 2.5% for the average Nasdaq-listed stock. Overall, the evidence from this table supports our Prediction 1. This evidence is also consistent with Figure 2, which shows that inaccuracies in NYSE auction feeds persist up until the final seconds of the auction, even as the near price approximately converges to the realized closing price. The fact that much of the convergence occurs well after the cutoff time for most regular auction orders on NYSE implies that that floor brokers bear significant responsibility for minimizing imbalances on NYSE.

Next, we use the paired volume ratio as the dependent variable y in our regression model, where paired volume ratio is defined as the ratio of indicative matched volume to realized closing auction volume at 4:00pm (multiplied by 100). The results are reported in Panel A of Table 4. At 3:54pm, the NYSE paired volume ratio is about 40 percentage points lower than Nasdaq (58% vs 98%), which has already nearly converged to its eventual matched volume at 4:00pm. At 3:55pm, the NYSE paired volume ratio increases by 15 percentage points due to the incorporation of D-Orders, but still remains substantially lower than the Nasdaq paired volume ratio. Finally, at 3:59:55pm, the NYSE paired volume ratio has since increased to about 96%, which is still lower than the Nasdaq paired volume ratio by about three percentage points. Overall, the evidence from this panel supports our Prediction 2 and corroborates our evidence in Figure 3. In Panel B of Table 4, we use dollar indicative matched volume as the dependent variable instead of the paired volume ratio. In this case, we find that NYSE indicative matched volume is about $8.6 million lower than Nasdaq at 3:54pm and $6.4 million lower at 3:55pm. The change of $2.2 million at exactly 3:55pm on NYSE represents additional volume matched by floor brokers using D-Orders, or about $1.5 trillion in total additional matched volume across our sample period. The remaining auction volume matched after 3:55pm is also likely represented by floor brokers who submit D-Orders in response to new auction information.

Finally, we use the absolute order imbalance ratio as the dependent variable y in our regression model, where order imbalance ratio is defined as the ratio of indicative absolute order imbalance to matched volume (multiplied by 100). The results are reported in Panel A of Table 5. At 3:54pm, the imbalance ratio on NYSE (53%) is about 50 percentage points higher than Nasdaq (3%). At 3:55pm, the NYSE imbalance ratio sharply decreases by 20 percentage points, but still remains significantly higher than Nasdaq. Like our previous tests, the sharp decrease at 3:55pm represents incoming D-Orders that interact with excess supply or demand in the auction. At 3:59:55pm, the NYSE imbalance ratio equals about 6% compared to only 1% on Nasdaq. Overall, we find that imbalances are consistently higher on NYSE throughout the auction process, consistent with our Prediction 3. In Panel B of Table 5, we use absolute dollar order imbalance as the dependent variable y and show that imbalances are about $2.6 million higher on NYSE at 3:54pm, $2.1 million higher at 3:55pm, and $0.6 million higher at 3:59:55pm. In Panel C, we use "imbalance sign change" as the dependent variable y, where imbalance sign change is defined as an indicator variable that equals one if the order imbalance changes signs relative to the previous minute. At 3:54pm on NYSE, we find no significant evidence that imbalances change on that minute. However, at 3:55pm, we find that the imbalance sign changes about 16% of the time on NYSE relative to Nasdaq (which experiences a sign change less than 1% of the time). That is, the sign changes on NYSE at 3:55pm in about one out of every six auctions. At 3:59:55pm, the imbalance sign on NYSE changes about 18% of the time, or in just under one out of every five auctions. The imbalance sign changes at 3:55pm and 3:59:55pm are very likely attributable to floor brokers' D-Orders because these are the only orders that can add to imbalances after 3:50pm on NYSE. These last results suggest that D-Orders can also lead to significant unpredictability in the closing auction.[21]

6.3 Closing Price Efficiency

If the closing auction process is inefficient because of inaccurate closing auction information, then a natural followup question is whether the realized closing auction price at 4:00pm is also inefficient. In the case of NYSE, most auction participants have limited options for participating in the closing auction after 3:50pm. Indeed, the evidence from the previous section indicates that order imbalances are consistently higher on NYSE, even seconds before the auction clears. Most auction participants also have incomplete information about closing auction supply and demand before 3:55pm, when D-Orders are incorporated into NYSE auction statistics. Furthermore, because D-Order users can cancel their orders up until 3:59:50pm, market participants may not even have complete information until the last ten seconds of continuous trading. Therefore, the incomplete information environment may lead to inaccurate closing auction prices.

We begin by testing the absolute difference between the last closing auction reference price—

[21] In Internet Appendix B, we show that closing auction transmission latency, as measured by the number of microseconds between the timestamp provided by the stock exchange and the timestamp recorded by the data provided, increases by 140 microseconds at exactly 3:55pm, or about 16% of the typical transmission latency on NYSE. Thus, high-bandwidth subscribers may have an informational advantage over lower-bandwidth subscribers on NYSE at 3:55pm.

generally the last sale price—and the realized closing auction price at 4:00pm ($|r^{lc}|$) on NYSE versus Nasdaq.[22] This is similar to the approach used in Bogousslavsky and Muravyev (2020), who use the absolute difference between the closing quote midpoint and the closing auction price to test the effect of institutional price pressure on closing auction prices. Formally, we test the following simple regression model:

$$|r^{lc}_{i,d}| \quad = \quad \beta_1 \cdot NYSE_i + \gamma X_{i,d-1} + \delta_d + \varepsilon_{i,d}, \tag{2}$$

where X is the vector of stock-day control variables used in our previous tests and δ_d is a vector of date fixed effects. If the closing auction price on NYSE is less efficient, then we would expect a greater dislocation in the NYSE closing auction price (relative to the prevailing reference price) in the form of a positive and significant β_1 coefficient.

The results of this test are reported in Column (1) of Table 6. We find that the average dislocation in the closing auction price on NYSE is about 0.30 basis points higher than Nasdaq, consistent with the larger order imbalances on NYSE at both 3:55pm (Table 5) and just before the auction clears at 4:00pm (Figure 4). In Column (2) of Table 6, we test the same regression model but instead use the absolute difference between the prevailing NBBO midpoint and the realized closing auction price at 4:00pm ($|r^{mc}|$). In this case, we find that the closing auction price dislocation is about 0.63 basis points higher than Nasdaq. The larger effect in Column (2) suggests that some traders may be more likely to aggressively trade in the direction of the auction imbalance in the lit market just before the auction clears at 4:00pm. Overall, our evidence indicates that dislocations in closing auction prices are larger on NYSE.

The closing auction price dislocations on NYSE by themselves are not definitive evidence that closing auction prices are less efficient. The closing auction may just incorporate additional price-relevant information not reflected in the continuous market. Motivated by Amihud and Mendelson

[22] We use the reference price in this calculation because it is used to compute indicative matched volume and, more importantly, indicative order imbalances. If there are larger indicative order imbalances, then we should expect larger dislocations between the reference price and closing price.

(1987) and Bogousslavsky and Muravyev (2020), we also examine whether there are overnight reversals in the closing auction price dislocations on NYSE versus Nasdaq. If an overnight reversal occurs, this implies that the closing auction did not clear at an efficient price. We test the following regression model:

$$r_{i,d}^{co} = \beta_1 \cdot r_{i,d}^{mc} \times NYSE + \beta_2 \cdot r_{i,d}^{mc} + \gamma X_{i,d-1} + \delta_{i,d} + \varepsilon_{i,d}, \tag{3}$$

where r^{co} is the return based on the closing price of day t and the opening price of day $t+1$, r^{mc} is defined as before, X is the same vector of stock-day control variables used in our previous tests, and $\delta_{i,d}$ is a vector of stock and date fixed effects. The β_2 coefficient represents the magnitude of the overnight reversal for Nasdaq, and the β_1 coefficient represents the magnitude of the overnight reversal for NYSE relative to Nasdaq. Large dislocations combined with overnight reversals on NYSE may be due to institutional price pressures at the close (Lou, Polk, and Skouras, 2019; Bogousslavsky and Muravyev, 2020) that are not sufficiently covered by NYSE floor brokers.

The results of the regression test are reported in Column (3) of Table 6. First, we find that a one basis point dislocation in the closing auction price on Nasdaq is reversed by 0.27 basis points at the open of the following day, on average. More importantly, we find that the strength of this reversal increases by a statistically significant 0.39 basis points on NYSE, for a total reversal of 0.66 basis points.[23] That is, the average reversal in closing auction prices is more than twice as strong on NYSE compared to Nasdaq, further suggesting that the closing auction price is less efficient on NYSE than Nasdaq. Overall, these results are consistent with our Prediction 4, and supplement our evidence that the NYSE closing auction structure creates auction information inefficiencies which ultimately affect the realized closing auction price.

[23] The overnight reversals documented in this study are slightly weaker than those documented in Bogousslavsky and Muravyev (2020). This is likely due to the different stock samples. We focus on stocks in the S&P 500, where closing auctions are more likely to populate and clear on a regular basis. By contrast, Bogousslavsky and Muravyev (2020) focus on a sample of approximately 5,000 NYSE- and Nasdaq-listed stocks, where inefficiencies at the close are more likely to be greater due to a relative lack of liquidity and trading interest.

7 COVID-19 NYSE Floor Closure

The first COVID-19 novel coronavirus infection in the United States was reported on January 19, 2020. As of October 1, 2020, there have been over 35 million reported cases worldwide and over 200,000 deaths in the U.S. alone. The economic impact has also been enormous, with most businesses and entire states shutting down for weeks. As a result, financial markets have experienced drastic increases in volatility and declines in market value and liquidity. NYSE was also significantly affected by COVID-19 in a unique way. In particular, NYSE completely halted floor trading starting on March 23, 2020 after two people at the exchange tested positive for the COVID-19 coronavirus. Notably, it was the first time that NYSE had ever closed floor trading while keeping the rest of the electronic market open. Previously closures, such as those for Hurricane Sandy or the 9/11 terrorist attacks, halted all trading (WSJ, 2020). On May 26, 2020, NYSE reopened its trading floor after consulting public health experts and implementing safety protocols for NYSE floor traders. Relevant to this study, the floor closure precluded floor broker order entry on NYSE, providing a unique natural experiment to study closing auction market quality on NYSE without floor broker activity. The subsequent reopening provides a second natural experiment to study whether closing auction market quality on NYSE reverted back to its pre-closure level.

To demonstrate the effect of the floor closure and subsequent reopening on the closing auction, we first plot the mean ratio of paired auction volume at 3:54:55pm to final closing auction volume from February 19, 2020 to July 7, 2020 on NYSE and Nasdaq. Figure 5 indicates that the mean paired volume ratio on NYSE hovers around 56% for most of February and March, and then suddenly jumps to above 84% starting on March 23. The ratio then remains at that level until the floor reopens on May 26. After that, the ratio jumps back to the pre-closure level of 55%. Our results are consistent with NYSE's own analysis showing that the composition of orders in their closing auctions changed dramatically during the floor closure. Specifically, they show that D-Order volume dropped from about 30% of all closing auction volume to 0%, while MOC orders entered before 3:50pm increased from 50% to 70% (NYSE, 2020b). Therefore, our evidence indicates that a significantly larger percentage of orders were being matched earlier in the auction process on NYSE during the floor closure.[24]

We also test the effect of the NYSE floor closure and subsequent reopening on the paired volume ratio, absolute near price difference, and absolute order imbalance ratio at 3:55pm in a multivariate regression framework. The key independent variables are *Closure*, an indicator variable that equals one if the closing auction occurs after March 23, 2020, *Reopen*, an indicator variable that equals one if the closing auction occurs after May 26, 2020, $NYSE \times Closure$, and $NYSE \times Reopen$. The standalone *Closure* and *Reopen* indicator variables represent the effects of the NYSE floor closure and reopening periods on our control group of Nasdaq stocks, while $NYSE \times Closure$ and $NYSE \times Reopen$ represent the relative effects on the treatment group of NYSE stocks.

The results of these regression tests are reported in Table 7. In Column (1) of Panel A, we show that the paired volume ratio at 3:55pm on NYSE increases by about 28 percentage points during the floor closure, and subsequently reverts by about 29 percentage points after the reopening, corroborating our evidence from Figure 5. By contrast, there is no economically significant change in the paired volume ratio on Nasdaq. Column (2) of Panel A examines the effect of *Closure* and *Reopen* on the absolute near price difference. Two results stand out. First, we find that the absolute near price difference decreases by about 124 basis points after the floor closes, suggesting that NYSE's closing auction is more efficient without D-Orders. The reversal of 104 basis points in the reopening period further confirms that the change in the absolute near price difference was directly related to the floor closure. Second, we find that that the pre-closure absolute near price difference on NYSE was nearly 350 basis points higher than Nasdaq, which may be attributable to the unprecedented market turmoil during the COVID-19 pandemic. Notably, NYSE claims that their "unique hybrid market model [...] offers unmatched stability relative to other global markets, especially during times of market turbulence" (NYSE, 2019b). Our evidence suggests that this

[24]Figure 5 also indicates a partial increase in pre-3:55pm matched volume immediately prior to the NYSE floor closure. The increase in matched volume is likely driven by a high-volume "triple-witching" day just before the closure and a large spike in volatility that briefly halted trading on several trading days. We further explore closing auction market quality during periods of market turbulence in Section 8.3 of the paper.

claim by NYSE does not seem to hold during this pre-closure period. Finally, in Column (3) of Panel A, we show that the order imbalance ratio decreases by about 6 percentage points after the floor closure on NYSE relative to Nasdaq. Although statistically significant, the change is smaller than the change in the paired volume ratio because most traders switched to pre-3:50pm MOC orders following the floor closure. After the reopening, the order imbalance ratio increases by about 17 percentage points, further suggesting that the floor closure reduced order imbalances around 3:55pm on NYSE.[25]

Finally, we test the effect of the NYSE floor closure and subsequent reopening on closing price efficiency. Similar to our tests in Table 6, we examine the differences in the closing price dislocation measures ($|r^{lc}|$ and $|r^{mc}|$) and overnight price reversals on NYSE versus Nasdaq. In Column (1) of Table 7, Panel B, we find that $|r^{lc}|$ increases by 4.0 basis points on NYSE relative to Nasdaq after the floor closure, and subsequently reverts by 1.9 basis points after the floor reopens. Similarly, in Column (2), we find that $|r^{mc}|$ increases and subsequently reverts by 3.7 basis and 2.2 basis points, respectively. At first glance, these results suggest that closing price efficiency deteriorated during the floor closure. However, the lack of a complete reversal during the reopening period suggests that the larger dislocations may be unrelated to the floor closure.[26] Furthermore, as discussed in Section 6.3, the larger dislocations by themselves are not definitive evidence of a reduction in efficiency. If there are no overnight reversals associated with these dislocations, then the dislocations are more likely to reflect permanent price changes during the closure period. Using the methodology in Amihud and Mendelson (1987), we test the effects of the closure and subsequent reopening on overnight price reversals. In particular, we test the regression model in equation (3) and include $Closure$, $Reopen$, and the interactions of these variables with r^{mc}, $NYSE$, and $r^{mc} \times NYSE$ as additional independent variables. If the coefficients on $r^{mc} \times NYSE \times Closure$ and $r^{mc} \times NYSE \times Reopen$ are

[25]In all three regression tests, we exclude stock and date fixed effects so that we can also report the coefficients from the standalone $NYSE$, $Closure$, and $Reopen$ indicator variables. The coefficients on $NYSE \times Closure$ and $NYSE \times Reopen$ remain approximately unchanged if we include stock and date fixed effects in these regressions.

[26]For example, fundamental uncertainty may have increased on NYSE after the floor closure because many NYSE-listed stocks continued to face supply chain disruptions compared to Nasdaq-listed technology firms (Papanikolaou and Schmidt, 2020).

insignificant, then this would suggest that the floor closure had no effect on closing price efficiency, even with the larger dislocations. In Column (3) of Table 7, Panel B, we show that these coefficients are indeed statistically insignificant. If anything, the positive coefficient on $r^{mc} \times NYSE \times Closure$ and negative coefficient on $r^{mc} \times NYSE \times Reopen$ suggest that the NYSE reversals became weaker during the floor closure. Therefore, our evidence suggests that closing price efficiency on NYSE weakly improved during the floor closure, even with the associated COVID-19 volatility.

Taken together, our evidence from this section indicates that closing auction market quality on NYSE generally improved during the NYSE floor closure. By contrast, there were no significant changes in closing auction market quality on Nasdaq during this period, suggesting that the improvements on NYSE are attributable to the floor closure and not fundamental uncertainties associated with the COVID-19 pandemic. Furthermore, our results suggest that closing auctions on Nasdaq are more resilient to times of extreme market stress such as the COVID-19 pandemic. In the next section, we explore the resiliency of closing auctions on NYSE versus Nasdaq in more detail using exogenous shocks to demand for closing auction liquidity.

8 Closing Auction Resiliency

We have shown that the quality of closing auction feeds is significantly worse on NYSE compared to Nasdaq because of differences in the design of the closing auction process. Our proposed mechanism is that pre-3:55pm NYSE auction feeds only reflect the orders of benchmark investors who are price-insensitive and submit aggressively-priced limit orders to the closing auction, thereby leading to highly inefficient indicative closing auction prices. In this last section, we further study our proposed mechanism by exploring how closing auction market quality has evolved over time and is affected by shocks to demand from benchmark investors for closing auction liquidity.

8.1 Auction Quality Over Time

The importance of closing auctions has only increased over time. According to Figure 6, aggregate closing auction volume has steadily risen from about 4% of all trading volume in 2011 to almost 11% of all trading volume in 2018. Some attribute this upward trend to the rise of passive investment funds (WSJ, 2019b), which often benchmark their purchases and redemptions to closing prices and trade in closing auctions to minimize daily tracking error. Interestingly, in the same figure, we also document a strong upward trend in the mean absolute near price difference on NYSE just before 3:55pm. In particular, we find that the difference has significantly increased from about 40 basis points in 2011 to 265 basis points in 2018. By contrast, the absolute near price difference on Nasdaq has remained below 25 basis points for almost the entire sample period. Although we make no causal claims from this evidence, the correlation between closing auction volume and NYSE (but not Nasdaq) auction quality is nonetheless interesting. In the next two subsections, we provide more direct evidence of a causal connection between closing auction interest and NYSE auction quality using exogenous shocks to demand for closing auction liquidity.

Before moving to our causal tests, we formally test the divergence in absolute near price differences on NYSE versus Nasdaq over time. In particular, we test a multivariate regression model with the absolute near price difference at 3:54:55pm as the dependent variable and $NYSE$, $NYSE \times MidPeriod$, and $NYSE \times LatePeriod$ as the key independent variables. $MidPeriod$ is an indicator variable that equals one if the closing auction took place from January 2014 to June 2016. $LatePeriod$ is an indicator variable that equals one if the closing auction took place from July 2016 to the end of 2018. We also include the same control variables from our baseline regression model and double-cluster the standard errors by symbol and date. The results of this regression are reported in Table 8, and are largely consistent with the graphical results in Figure 6. According to Column (1), the mean absolute near price difference in the early period is about 43 basis points higher on NYSE compared to Nasdaq. This difference increases to 64 basis points in the mid-period, and again to 224 basis points during the late period. Thus, the absolute near price difference has increased by about a factor of five on NYSE since 2011. By contrast, the coefficients on the standalone $MidPeriod$ and $LatePeriod$ indicator variables are very close to zero, thus indicating that Nasdaq closing auction quality has not deteriorated over time.

8.2 Abnormal Indicative Matched Volume

As a more general test, we next examine how the accuracy of indicative closing auction prices is affected by pre-3:55pm abnormal indicative matched volume on NYSE versus Nasdaq. If pre-3:55pm indicative matched volume is abnormally high, then this plausibly reflects a positive shock to liquidity demand from benchmark investors since D-Orders are not included in auction feeds until 3:55pm. We measure abnormal indicative matched volume, denoted $Z(Volume)$, as the ratio of demeaned indicative matched volume at 3:54:55pm to its standard deviation, where the mean and standard deviation are based on the last 252 trading day observations at 3:54:55pm. We test the effect of $Z(Volume)$ on the contemporaneous absolute near price difference on NYSE versus Nasdaq to determine the resiliency of indicative auction prices to benchmark investor demand shocks under different closing auction structures.

Table 9 presents the results of our regression tests of absolute near price difference on $Z(Volume)$ and $Z(Volume) \times NYSE$. First, we find that the unconditional near price difference on NYSE is about 101 basis points higher than Nasdaq, which is consistent with our earlier evidence. Second, and more importantly, we find that the near price difference is about 15 basis points higher for every unit increase in $Z(Volume)$ on NYSE. In other words, the near price is about 15% less accurate for every unit increase in $Z(Volume)$. These results suggest that NYSE closing auction feeds are less resilient to liquidity demand shocks. However, while these results are consistent with our mechanism, they should also be interpreted with caution. One possibility that we still need to address is that both $Z(Volume)$ and near prices are both being driven by a third unobserved variable. Another possibility is that the causality works in the other direction, with inaccurate near prices driving increases in abnormal matched volume before 3:55pm. In the next section, we address these issues by instrumenting $Z(Volume)$ on exogenous shocks to benchmark investor demand for closing auction liquidity.

8.3 Triple Witching Days and End-of-Month Liquidity Trading

NYSE claims that their "unique hybrid market model [...] offers unmatched stability relative to other global markets, especially during times of market turbulence." If true, then this would contradict our prediction that closing auction market quality on NYSE is worse when there is greater demand for closing auction liquidity from benchmark investors. We examine two recurring events characterized by high market turbulence brought on by high liquidity demand from benchmark investors: (1) "triple witching days", when stock options, stock index futures, and stock index option contracts expire on the same day and a large associated spike in non-informational trading occurs (Stoll and Whaley, 1990; Barclay et al., 2008), and (2) the last trading day of the month, when many funds tend to rebalance their portfolios and trade securities to meet cash obligations (Smith, 2006; Etula, Rinne, Suominen, and Vaittinen, 2020). Triple witching days are particularly relevant for our study because they generate some the largest closing auction volumes of the year, second only to Russell rebalance days (Nasdaq, 2020).[27] Moreover, S&P rebalances their indices on triple witching days, which better overlaps with our sample of S&P 500 stocks. By contrast, volume on Russell rebalance days is largely concentrated among small-cap stocks, where auctions are infrequent and generate very low trading volume at the close.

We use triple witching days as instruments for benchmark investor trading interest to identify the resiliency of closing auctions to liquidity demand shocks on NYSE and Nasdaq. In particular,

[27] Triple witching days now also include single stock futures expirations, and thus are sometimes referred to as "quad witch" days.

we test the following instrumental variables (IV) regression model:

$$\text{First Stage (1):} \quad NYSE_i \times Z(Volume)_{i,d} =$$

$$\psi_1 \cdot NYSE_i \times Witch_d + \psi_2 \cdot Witch_d + \gamma_1 X_{i,d-1} + \delta_{i,d} + \varepsilon_{i,d}$$

$$\text{First Stage (2):} \quad Z(Volume)_{i,d} =$$

$$\lambda_1 \cdot NYSE_d \times Witch_d + \lambda_2 \cdot Witch_d + \gamma_2 X_{i,d-1} + \delta_{i,d} + e_{i,d}$$

$$\text{Second Stage:} \quad |r_{i,d}| =$$

$$\beta_1 \cdot NYSE_d \times \widehat{Z(V}olume)_{i,d} + \beta_2 \cdot Z(V\widehat{olume})_{i,d} + \gamma_3 X_{i,d-1} + \delta_{i,d} + u_{i,d}.$$

In the above set of equations, $|r_{i,d}|$ is the absolute near price difference at 3:54:55pm (in basis points), $Witch$ is an indicator variable that equals one if the trading day is on the third Friday of March, June, September, or December, and X and $\delta_{i,d}$ represent the same sets of liquidity control variables and fixed effects used in our previous regressions. The two first-stage regressions are used to separately identify the effects of $Witch$ on $Z(Volume)$ on NYSE and Nasdaq, respectively. The second-stage regression measures how the absolute near price difference is affected by abnormal indicative matched volume induced by triple witching days.

Panel A of Table 10 presents the results from the above IV regression model. The first-stage regressions in Columns (1) and (2) show that indicative matched volume is 2.8 standard deviations higher on NYSE and 2.6 standard deviations higher on Nasdaq. Thus, we have strong instruments for $Z(Volume)$ on both NYSE and Nasdaq. Importantly, in the second stage regression, we find that a unit increase in $Z(Volume)$ induced by triple-witching days increases the absolute near price difference by 13.7 basis points on NYSE and only 2.6 basis points on Nasdaq. Thus, our IV regression indicates that an increase in benchmark investor volume is associated with less accurate indicative closing auction prices on NYSE, suggesting that NYSE closing auctions are less resilient to liquidity demand shocks than Nasdaq.

Panel B of Table 4 presents additional results from the same IV regression model, except that we use end-of-month portfolio rebalancing days ($LastDay$) as our instrumental variable instead of $Witch$. These days can also be considered quasi-exogenous shocks to benchmark investor demand in the closing auction because many investment funds need to rebalance their portfolios on a monthly basis at the closing price. According to the first-stage regressions in Columns (1) and (2), during these days, indicative matched volume increases by 1.1 standard deviations on NYSE and 1.0 standard deviations on Nasdaq. In the second-stage regression, we find that a unit increase in $Z(Volume)$ induced by end-of-month portfolio rebalancing days increases the absolute near price difference by 33.0 basis points on NYSE, but only 5.6 basis points on Nasdaq. Taken together, our results indicate that closing auction market quality is worse on NYSE relative to Nasdaq when there is stronger demand for liquidity from benchmark investors.

9 Conclusion

Closing auctions have become an increasingly important event not just for liquidity, but also for accurately pricing trillions of dollars of fund NAVs. Trading in and around the auction depends critically on the availability of informative auction feeds for closing auction participants. Our paper provides some of the first evidence that the structure of the close can significantly alter the efficiency of the closing auction process as well as the final closing price. Specifically, we show that indicative closing auction statistics on NYSE are highly inaccurate compared to Nasdaq. When floor brokers' D-Orders are incorporated into the close at 3:55pm, we document large changes in the indicative auction prices, matched volume, and order imbalances, highlighting the information asymmetries between floor brokers and other traders about closing auction supply and demand. However, even after these changes at 3:55pm, the NYSE auction statistics still remain highly inaccurate compared to Nasdaq. By contrast, the indicative closing auction statistics reported by Nasdaq converge almost immediately to their eventual realized values at 4:00pm. Importantly, we also find that realized closing prices on NYSE are less efficient than on Nasdaq, with larger absolute price changes at the close and stronger overnight reversals in these price changes. Contrary to NYSE's claims about the unmatched stability of their auctions, we find that closing auction efficiency on NYSE is especially sensitive to spikes in liquidity demand on triple-witching days and end-of-month portfolio rebalancing days. Moreover, we find that when NYSE closed its floor during the COVID-19 pandemic, closing auction quality generally improved, further suggesting that the auction structure highly matters for the quality of the closing auction.

Our empirical findings highlight the importance of reducing information asymmetries in the closing auction. One possible solution is to allow non-listing exchanges to compete for trades in the close. Cboe Global Markets recently launched a competing service on its BZX stock exchange to match closing orders away from the primary listing exchanges. However, as of this writing, the product has not caught on, and it is unclear whether reducing paired volume on NYSE would increase or decrease the informativeness of its auction information. Cboe plans to match MOC orders for free, at least for an introductory period of time. Therefore, it is reasonable to assume that at least some benchmark traders seeking to maximize their execution chances will eventually utilize this service. This could lead to less-aggressively priced orders on NYSE, and hence a smaller D-Order impact at 3:55pm.

A simpler approach may be to eliminate D-Orders altogether. The Nasdaq closing auction appears to function efficiently without D-Orders, as did the NYSE closing auction during the COVID-19 floor closure, even with the associated market turbulence. If the objective of an exchange is to maximize auction efficiency, then it is unclear whether D-Orders are even necessary in a modern, fully-electronic market. However, our understanding is that some investors like the flexibility that D-Orders provide, and are happy to pay for the additional functionality. Some may even prefer the fact that their interest is hidden until 3:55pm to avoid signaling their trading intentions to high-frequency traders in the continuous market.

Therefore, a more modest approach may be to change how closing auction orders are disclosed. Our evidence suggests that closing auction market quality would improve if closing auction imbalance feeds incorporated D-Orders as soon as imbalance information was publicly disseminated. This would make closing auction information complete for all investors without sacrificing the flexibility provided by D-Orders to the subset of investors who are interested in a more active trading strategy around the close. However, an important unresolved issue remains. Floor brokers learn auction information as early as 2:00pm and therefore have a significant order flow information advantage over other investors at the close.[28] More detailed order-level data is required to study whether this order flow information asymmetry has additional implications for market efficiency, and we leave this question open for future research.

[28]Floor brokers have access to far more data leading up to the close. Specifically, floor brokers receive an update every fifteen seconds on the amount of, and imbalance between, MOC interest, marketable LOC interest, and any closing offset interest. See NYSE Rule 123C(6)b.

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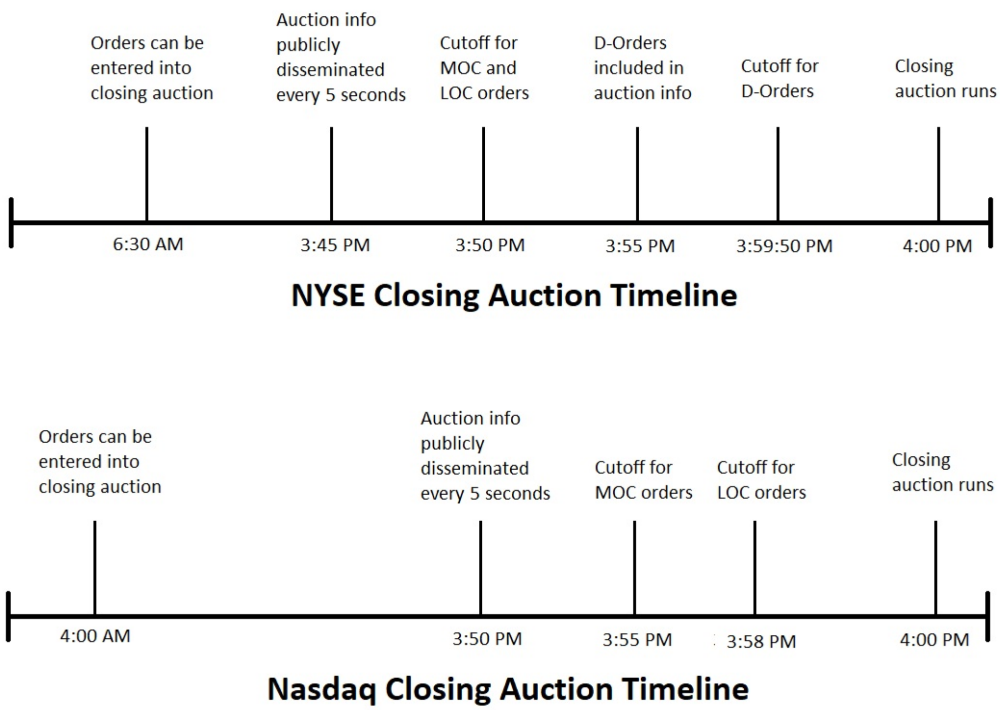

Figure 1: Closing Auction Timelines for NYSE and Nasdaq. The closing auction timelines for NYSE and Nasdaq are presented in the upper and lower halves of the figure, respectively.

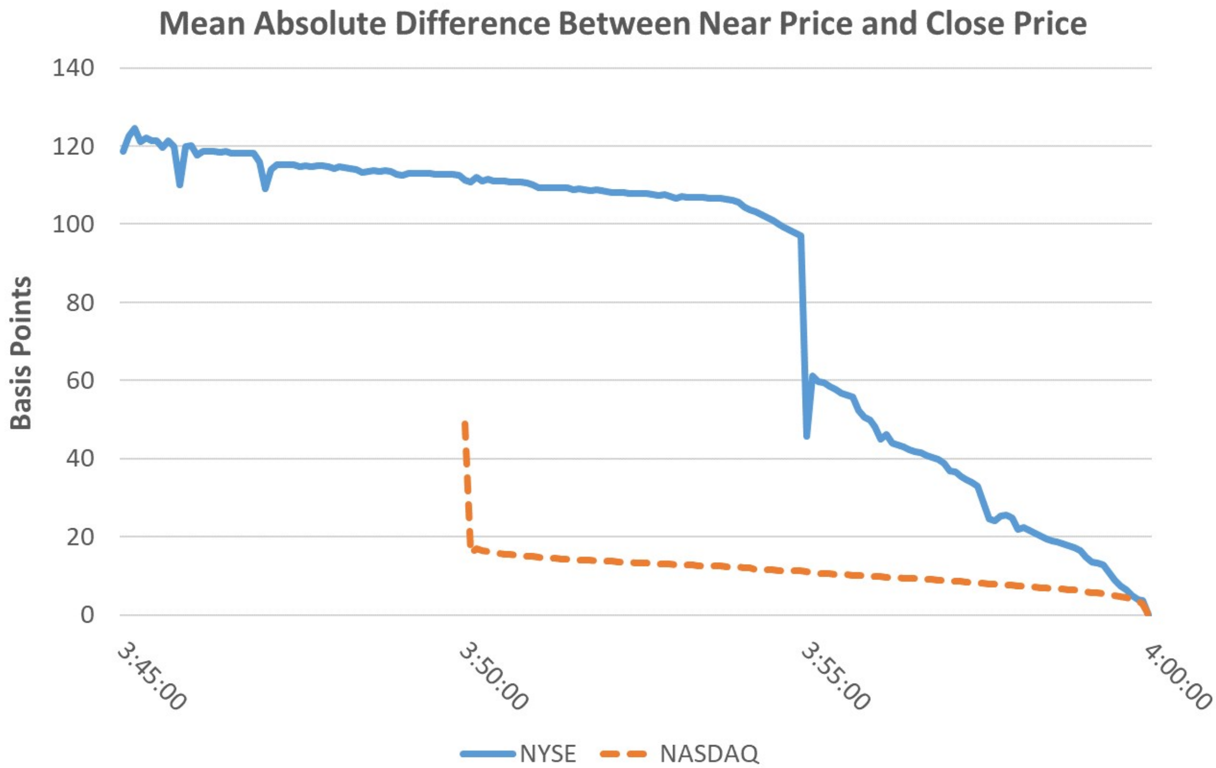

Figure 2: Near Price Evolution on NYSE and Nasdaq. This figure reports the mean absolute difference (in basis points) between the near price and the final closing auction price over time for NYSE and Nasdaq. Near price is the indicative closing auction clearing price using the orders currently submitted to the closing auction and the orders currently in the continuous limit order book. D-Orders are included in the near price calculation starting at 3:55pm.

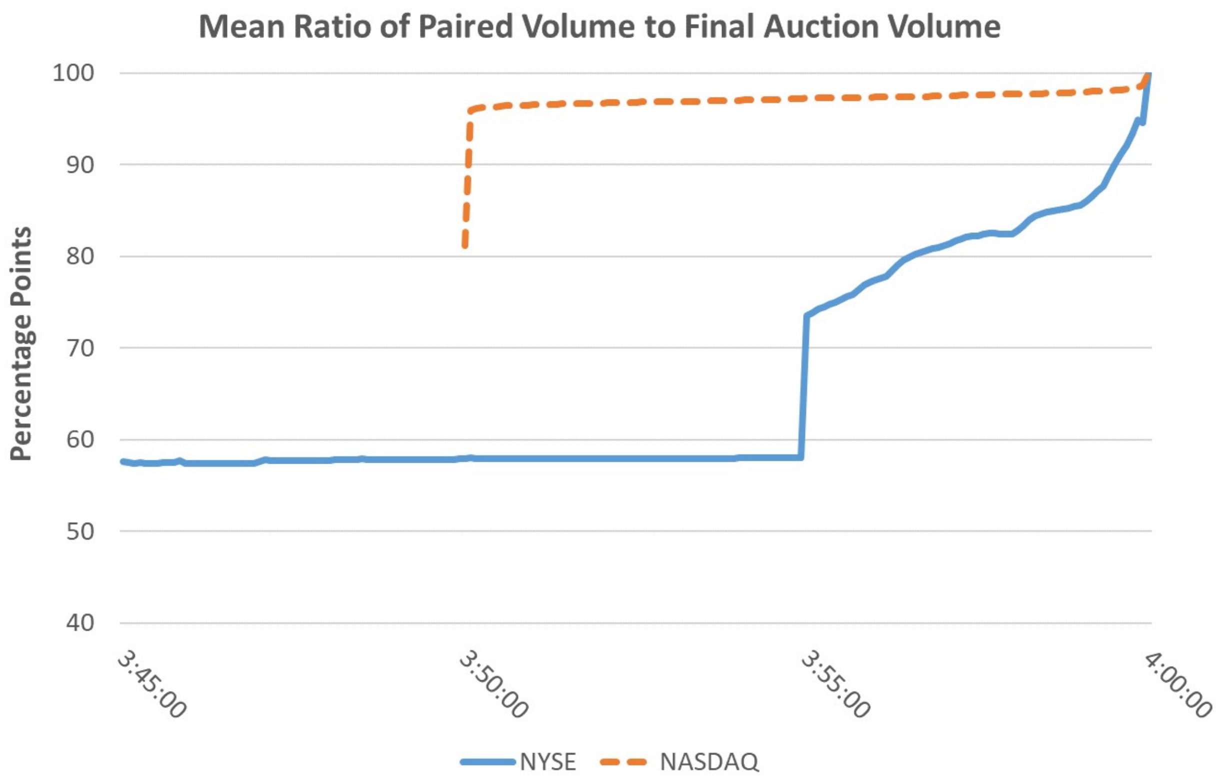

Figure 3: Ratio of Paired Volume to Final Auction Volume on NYSE and Nasdaq. This figure reports the mean ratio of paired volume to final closing auction volume (measured in percentage points) over time for NYSE and Nasdaq. Paired volume is the number of shares that would match at the current reference price using the orders currently submitted to the closing auction and the orders currently in the continuous limit order book. D-Orders are included in the paired volume calculation starting at 3:55pm. Reference price is the last transaction price in the continuous market.

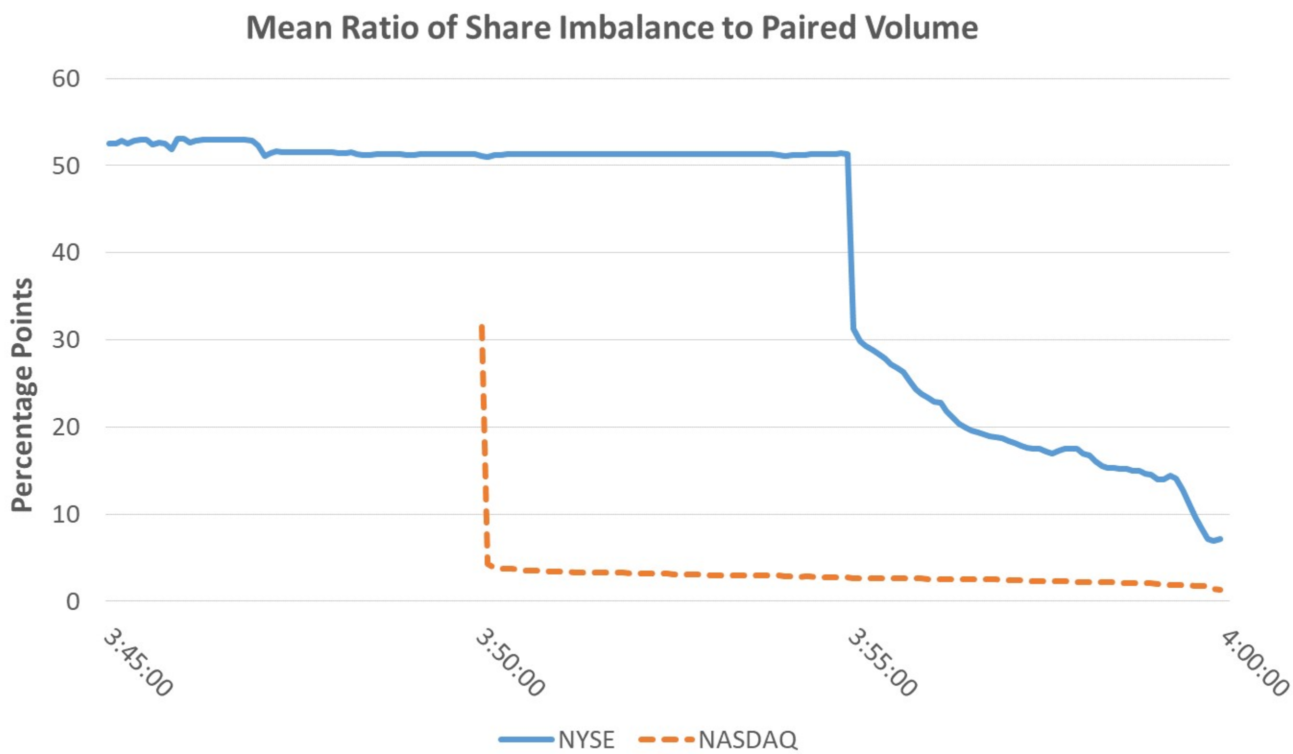

Figure 4: Ratio of Order Imbalance to Paired Volume on NYSE and Nasdaq. This figure reports the mean ratio of absolute order imbalance to paired volume (measured in percentage points) over time for NYSE and Nasdaq. Order imbalance is the signed order imbalance if the auction were to clear at the current reference price using the orders currently submitted to the closing auction and the orders currently in the continuous limit order book. Paired volume is the number of shares that would match at the current reference price using the orders currently submitted to the closing auction and the orders currently in the continuous limit order book. D-Orders are included in the order imbalance and paired volume calculations starting at 3:55pm. Reference price is the last transaction price in the continuous market.

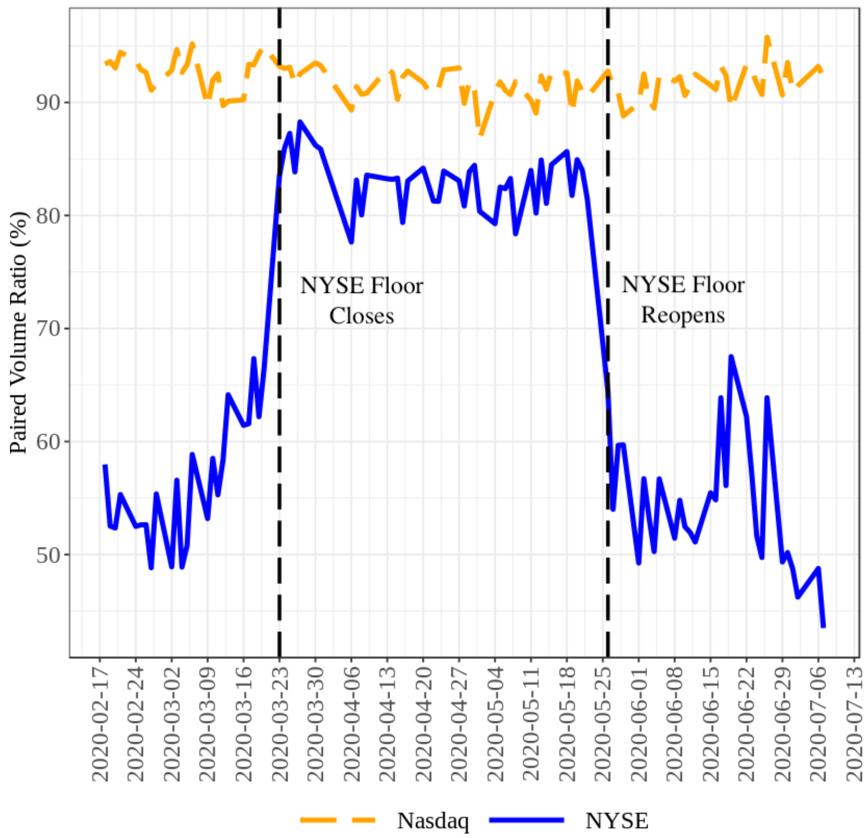

Figure 5: Paired Volume Ratio around COVID-19 NYSE Floor Closure. This figure reports estimates of the average Paired Volume Ratio around the NYSE floor closure caused by the COVID-19 pandemic. During our 2020 sample period, NYSE closed their trading floor and went fully electronic starting on March 23, 2020 because of social isolation measures associated with the COVID-19 pandemic. NYSE reopened their trading floor on May 26, 2020. Paired Volume Ratio is the ratio of indicative paired volume at 3:54:55pm to final closing auction volume (multiplied by 100). Statistics are reported separately for NYSE and Nasdaq.

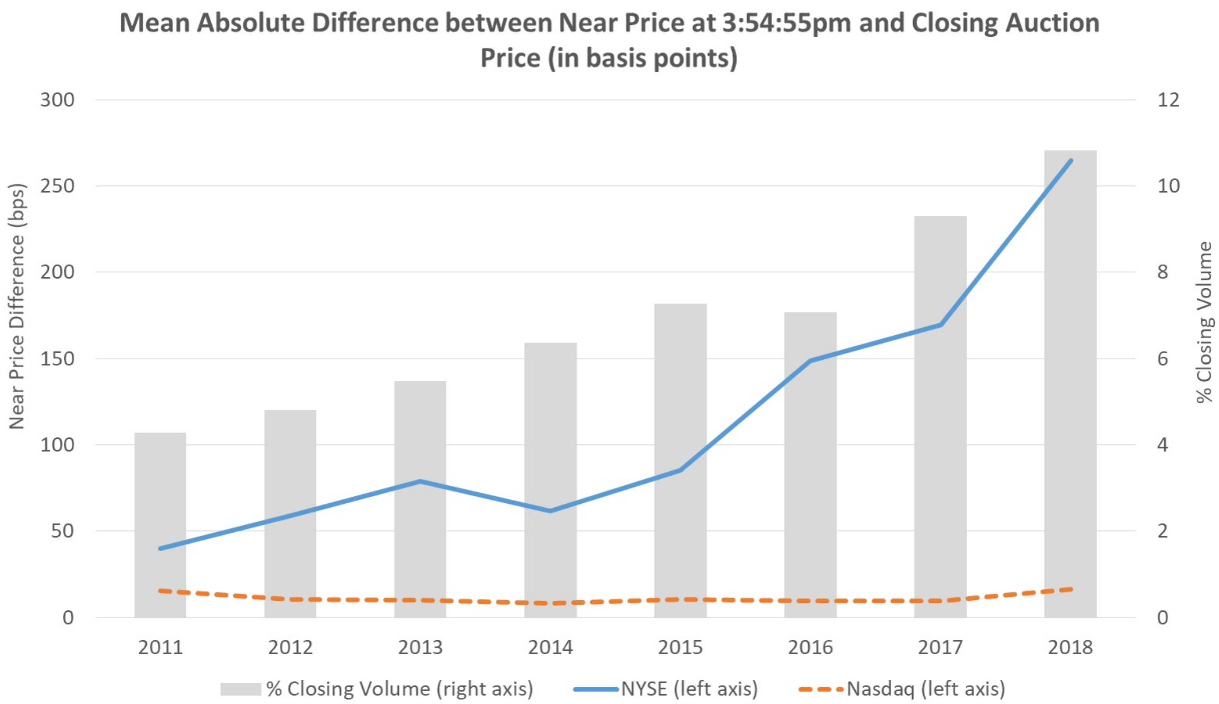

Figure 6: Average Absolute Near Price Difference on NYSE and Nasdaq by Year. This figure reports the mean absolute difference (in basis points) between the near price at 3:54:55pm and the final closing auction price for NYSE and Nasdaq during each year of our sample period. Near price is the indicative closing auction clearing price using the orders currently submitted to the closing auction and the orders currently in the continuous limit order book. D-Orders are included in the near price calculation starting at 3:55pm. The left y-axis represents the near price difference for NYSE and Nasdaq. The right y-axis represents total closing auction volume as a percentage of all trading volume on NYSE and Nasdaq.

Table 1:
Stock-Level Summary Statistics for NYSE and Nasdaq Stocks.
Panels A and B report summary statistics for NYSE and Nasdaq stocks, respectively. We use observations at the stock-day level across our sample period to construct the statistics. "% Close Volume" is the ratio of volume in the closing auction to intraday volume, multiplied by 100. "Close Price" is the closing price determined in the closing auction at 4:00pm. "Eff. Spread ($)" is the average dollar effective spread within a stock-day, where the effective spread for a trade is twice the absolute difference between the transaction price and the midpoint of the national best bid and offer (NBBO). "Eff. Spread (bps)" is the average ratio of the effective spread to the prevailing midpoint of the national best bid and offer (NBBO) within a stock-day, measured in basis points. "Lambda" is the daily coefficient resulting from a regression of transaction-level price change on signed order imbalance. "Intraday Volatility" is a daily measure of volatility on a trade-by-trade basis.

Panel A: NYSE Stocks

	Mean	Median	P5	P25	P75	P95	SD
Daily Volume ($M)	188.6	118.0	29.3	66.7	217.7	587.4	234.9
Daily Close Volume ($M)	15.9	7.4	1.3	3.6	16.6	57.6	33.0
% Close Volume	8.9	6.3	1.8	3.8	10.6	24.3	9.6
Close Price	75.62	58.62	16.88	36.43	91.21	186.22	69.21
Eff. Spread ($)	0.025	0.013	0.009	0.010	0.022	0.072	0.057
Eff. Spread (bps)	3.24	2.74	1.40	2.07	3.75	6.49	2.14
Lambda ($\times 10^6$)	0.418	0.309	-0.125	0.120	0.589	1.320	0.518
Intraday Volatility ($\times 10^6$)	0.177	0.031	0.008	0.018	0.056	0.166	37.0
Abs. Open-Close Return (bps)	101.5	71.5	6.2	32.1	134.7	298.0	115.3

Panel B: Nasdaq Stocks

	Mean	Median	P5	P25	P75	P95	SD
Daily Volume ($M)	322.6	126.2	28.2	68.2	264.5	1109.3	821.0
Daily Close Volume ($M)	17.6	6.2	1.1	3.0	15.2	66.5	50.1
% Close Volume	7.1	4.8	1.3	2.8	8.4	19.7	8.2
Close Price	92.34	53.31	12.09	31.45	85.02	305.93	163.42
Eff. Spread ($)	0.037	0.012	0.009	0.010	0.022	0.148	0.192
Eff. Spread (bps)	3.91	3.04	1.60	2.32	4.32	8.36	7.27
Lambda ($\times 10^6$)	0.427	0.325	-0.131	0.127	0.618	1.325	0.499
Intraday Volatility ($\times 10^6$)	0.571	0.036	0.010	0.021	0.069	0.214	110.1
Abs. Open-Close Return (bps)	107.9	78.0	6.5	35.0	145.6	309.8	108.3

Table 2:
Summary Statistics for NYSE and Nasdaq Stocks around 3:55:00pm.
Panels A and B present indicative closing auction statistics at 3:54:55pm and 3:55:00pm for NYSE and Nasdaq, respectively. Near price is the indicative closing auction clearing price using the orders currently submitted to the closing auction and the orders currently in the continuous limit order book. Paired volume is the number of shares that would match at the current reference price using the orders currently submitted to the closing auction and the orders currently in the continuous limit order book. Paired volume ratio is the ratio of paired volume to closing auction volume. Order imbalance is the signed share imbalance if the auction were to clear at the current reference price using the orders currently submitted to the closing auction and the orders currently in the continuous limit order book. Order imbalance ratio is the ratio of order imbalance to paired volume. Order imbalance sign change is the percentage of stock-days in which the indicative order imbalance switches from positive to negative or negative to positive during that time of day. D-Orders are included in the near price, paired volume, and order imbalance calculations starting at 3:55pm. All changes are calculated relative to the previous five-second period. For the difference calculations, ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: NYSE Stocks

	Mean at 3:54:55pm (1)	Mean at 3:55:00pm (2)	Difference (3)
$\|\Delta$Near Price$\|$ (bps)	4.99	56.29	51.31***
Paired Volume ($M)	8.49	10.43	1.93***
ΔPaired Volume ($M)	0.00	2.19	2.18***
Paired Volume Ratio (%)	57.58	73.22	15.64***
ΔPaired Volume Ratio	0.04	14.85	14.82***
$\|$Order Imbalance$\|$ ($M)	3.04	2.33	-0.71***
$\|\Delta$Order Imbalance$\|$ ($M)	0.01	1.52	1.51***
$\|$Order Imbalance Ratio$\|$ (%)	51.86	31.10	-20.76***
$\|\Delta$Order Imbalance Ratio$\|$	0.22	28.33	28.10***
Order Imbalance Sign Change (%)	0.01	14.73	14.72***

Panel B: Nasdaq Stocks

	Mean 3:54:55pm (4)	Mean at 3:55:00pm (5)	Difference (6)	Diff-in-Diffs (3) - (6)
$\|\Delta$Near Price$\|$ (bps)	0.78	1.07	0.29***	51.02***
Paired Volume ($M)	16.66	16.68	0.02	1.91***
ΔPaired Volume ($M)	0.01	0.05	0.04***	2.15***
Paired Volume Ratio (%)	97.52	97.61	0.09***	15.55***
ΔPaired Volume Ratio	0.06	0.15	0.09***	14.73***
$\|$Order Imbalance$\|$ ($M)	0.40	0.36	-0.04***	-0.66***
$\|\Delta$Order Imbalance$\|$ ($M)	0.02	0.05	0.04***	1.47***
$\|$Order Imbalance Ratio$\|$ (%)	2.48	2.39	-0.10***	-20.67***
$\|\Delta$Order Imbalance Ratio$\|$	0.10	0.20	0.10***	28.00***
Order Imbalance Sign Change (%)	0.00	0.01	0.01	14.71***

Table 3:
Indicative Closing Auction Prices on NYSE versus Nasdaq.
This table reports the absolute near price difference on NYSE versus Nasdaq at different times in the closing auction. Near price is the indicative closing auction clearing price using the orders currently submitted to the closing auction and the continuous limit order book. D-Orders are included in the near price starting at 3:55pm. The near price difference is the difference between the near price and the final closing auction point and is measured in basis points. Standard errors are double-clustered by symbol and date. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Dep. Variable: Abs. Near Price Difference (bps)

	(1)	(2)	(3)
$NYSE \times \mathbb{1}^{3:54}$	107.9***	108.9***	108.0***
	(40.34)	(40.15)	(40.37)
$NYSE \times \mathbb{1}^{3:55}$	62.74***	63.71***	63.01***
	(40.91)	(40.96)	(41.39)
$NYSE \times \mathbb{1}^{3:59}$	1.131***	2.043***	
	(11.98)	(3.40)	
$\mathbb{1}^{3:54}$	9.362***	9.405***	10.40***
	(40.84)	(40.92)	(34.96)
$\mathbb{1}^{3:55}$	9.091***	9.088***	9.080***
	(35.03)	(35.02)	(35.04)
log(Volume)		6.271***	3.894***
		(9.27)	(4.60)
Volatility		0.000476	-0.00155
		(0.86)	(-1.42)
Eff. Spread		0.0135	0.288
		(0.23)	(1.23)
Lambda		-0.508	1.022***
		(-0.99)	(2.62)
Constant	2.769***		
	(57.18)		
$NYSE \times (\mathbb{1}^{3:55} - \mathbb{1}^{3:54})$	-45.21***	-45.15***	-44.99***
	(-25.53)	(-25.55)	(-25.61)
SE Clustering	Symbol-Date	Symbol-Date	Symbol-Date
Fixed Effects	None	None	Symbol, Date
N	1,931,645	1,931,455	1,931,455
Adj. R^2	0.118	0.120	0.172

Table 4:
Indicative Matched Auction Volume on NYSE versus Nasdaq.
Panel A reports the paired volume ratio on NYSE versus Nasdaq at different times in the closing auction. Paired volume ratio is the ratio of indicative matched volume to realized closing auction volume. D-Orders are included in the near price starting at 3:55pm. Panel B reports the indicative dollar matched volume (in millions) on NYSE versus Nasdaq at different times in the closing auction. Standard errors are double-clustered by symbol and date. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Paired Volume Ratio (%)

	(1)	(2)	(3)
$NYSE \times \mathbb{1}^{3:54}$	-39.98***	-39.92***	-37.42***
	(-152.53)	(-156.08)	(-138.46)
$NYSE \times \mathbb{1}^{3:55}$	-24.54***	-24.48***	-21.96***
	(-113.52)	(-116.75)	(-99.21)
$NYSE \times \mathbb{1}^{3:59}$	-2.602***	-2.542***	
	(-18.35)	(-17.86)	
$\mathbb{1}^{3:54}$	-1.389***	-1.384***	-1.398***
	(-33.23)	(-33.29)	(-33.49)
$\mathbb{1}^{3:55}$	-1.249***	-1.248***	-1.248***
	(-31.96)	(-31.97)	(-31.96)
log(Volume)		0.662***	0.0325
		(9.45)	(0.48)
Volatility		0.000350	0.000186
		(1.21)	(0.79)
Eff. Spread		-0.0524	-0.0273
		(-1.24)	(-1.16)
Lambda		0.0614*	0.0228
		(1.91)	(0.57)
Constant	98.91***		
	(1038.5)		
$NYSE \times (\mathbb{1}^{3:55} - \mathbb{1}^{3:54})$	15.44***	15.45***	15.46***
	(81.85)	(81.82)	(81.95)
SE Clustering	Symbol-Date	Symbol-Date	Symbol-Date
Fixed Effects	None	None	Symbol, Date
N	1,931,645	1,931,455	1,931,455
Adj. R^2	0.669	0.670	0.692

Panel B: Indicative Dollar Matched Volume ($M)

	(1)	(2)	(3)
$NYSE \times \mathbb{1}^{3:54}$	-8.617***	-6.552***	-6.246***
	(-3.10)	(-4.06)	(-15.06)
$NYSE \times \mathbb{1}^{3:55}$	-6.428**	-4.213**	-3.722***
	(-2.21)	(-2.50)	(-17.17)
$NYSE \times \mathbb{1}^{3:59}$	-2.376	-0.308	
	(-0.79)	(-0.17)	
$\mathbb{1}^{3:54}$	-0.915***	-0.806***	-0.542***
	(-4.50)	(-4.38)	(-3.84)
$\mathbb{1}^{3:55}$	-0.264***	-0.267***	-0.279***
	(-6.30)	(-6.17)	(-6.05)
log(Volume)		15.13***	5.852***
		(7.01)	(6.24)
Volatility		0.00119	0.000236
		(1.17)	(0.93)
Eff. Spread		-0.178	-0.0553
		(-1.43)	(-0.91)
Lambda		0.202	0.827***
		(1.33)	(3.70)
Constant	18.11***		
	(6.29)		
$NYSE \times (\mathbb{1}^{3:55} - \mathbb{1}^{3:54})$	2.19***	2.34***	2.52***
	(9.77)	(10.76)	(12.20)
SE Clustering	Symbol-Date	Symbol-Date	Symbol-Date
Fixed Effects	None	None	Symbol, Date
N	1,931,645	1,931,455	1,931,455
Adj. R^2	0.00982	0.180	0.404

Table 5:
Indicative Order Imbalances on NYSE versus Nasdaq.
Panel A, B, and C report the absolute imbalance ratio, absolute dollar order imbalance, and imbalance sign change, respectively, on NYSE versus Nasdaq at different times in the closing auction. Absolute imbalance ratio is the ratio of absolute indicative order imbalance to indicative paired volume (multiplied by 100). Imbalance sign change is an indicative variable that equals one if the sign of the order imbalance changed relative to the previous minute. D-Orders are included in the order imbalance calculation starting at 3:55pm. Standard errors are double-clustered by symbol and date. *t*-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Abs. Imbalance Ratio (%)

	(1)	(2)	(3)
$NYSE \times \mathbb{1}^{3:54}$	49.92***	49.67***	44.64***
	(83.88)	(88.13)	(82.84)
$NYSE \times \mathbb{1}^{3:55}$	29.00***	28.73***	23.63***
	(69.35)	(66.53)	(65.86)
$NYSE \times \mathbb{1}^{3:59}$	5.238***	4.985***	
	(35.81)	(20.74)	
$\mathbb{1}^{3:54}$	1.413***	1.396***	1.282***
	(27.46)	(27.42)	(23.20)
$\mathbb{1}^{3:55}$	1.260***	1.260***	1.261***
	(26.66)	(26.66)	(26.63)
log(Volume)		-2.297***	-0.211*
		(-10.91)	(-1.67)
Volatility		-0.000952	-0.000403
		(-1.44)	(-0.88)
Eff. Spread		0.117	0.0279
		(1.30)	(1.08)
Lambda		-0.00562	0.243***
		(-0.07)	(2.69)
Constant	1.229***		
	(11.78)		
$NYSE \times (\mathbb{1}^{3:55} - \mathbb{1}^{3:54})$	-20.92***	-20.94***	-21.01***
	(-50.30)	(-50.31)	(-50.38)
SE Clustering	Symbol-Date	Symbol-Date	Symbol-Date
Fixed Effects	None	None	Symbol, Date
N	1,931,645	1,931,455	1,931,455
Adj. R^2	0.289	0.293	0.321

Panel B: Absolute Dollar Order Imbalance ($M)

	(1)	(2)	(3)
$NYSE \times \mathbb{1}^{3:54}$	2.571***	2.738***	1.950***
	(13.68)	(16.70)	(14.28)
$NYSE \times \mathbb{1}^{3:55}$	2.063***	2.241***	1.471***
	(12.82)	(15.70)	(13.18)
$NYSE \times \mathbb{1}^{3:59}$	0.627***	0.793***	
	(11.40)	(7.93)	
$\mathbb{1}^{3:54}$	0.268***	0.276***	0.292***
	(5.50)	(5.67)	(5.84)
$\mathbb{1}^{3:55}$	0.250***	0.249***	0.249***
	(6.07)	(6.07)	(6.07)
Constant	0.204***		
	(6.26)		
Fixed Effects	None	None	Symbol, Date
Controls	No	Yes	Yes
N	1,931,645	1,931,455	1,931,455
Adj. R^2	0.0419	0.0925	0.196

Panel C: Imbalance Sign Change

	(1)	(2)	(3)
$NYSE \times \mathbb{1}^{3:54}$	0.0020***	0.0029***	-0.178***
	(17.76)	(2.98)	(-53.55)
$NYSE \times \mathbb{1}^{3:55}$	0.157***	0.158***	-0.0226***
	(59.85)	(59.61)	(-7.35)
$NYSE \times \mathbb{1}^{3:59}$	0.181***	0.182***	
	(53.98)	(54.36)	
$\mathbb{1}^{3:54}$	-0.0001***	-0.0001	0.0015***
	(-2.64)	(-1.28)	(5.03)
$\mathbb{1}^{3:55}$	0.0070***	0.0070***	0.0070***
	(5.70)	(5.70)	(5.69)
Constant	0.0002***		
	(5.33)		
Fixed Effects	None	None	Symbol, Date
Controls	No	Yes	Yes
N	1,931,645	1,931,455	1,931,455
Adj. R^2	0.100	0.102	0.123

Table 6:
Closing Price Quality on NYSE versus Nasdaq.
This table reports the quality of closing prices on NYSE versus Nasdaq. $|r^{lc}|$ is the absolute difference between the closing price and the last reference price in the closing auction (in basis points). $|r^{mc}|$ is the absolute difference between the closing price and the NBBO midpoint just before 4:00pm (in basis points). r^{co} is the difference between the next-day opening price and today's closing price (in basis points). Standard errors are double-clustered by symbol and date. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

	$y = \|r^{lc}\|$	$y = \|r^{mc}\|$	$y = r^{co}$
	(1)	(2)	(3)
$NYSE$	0.297***	0.627***	
	(6.70)	(11.49)	
$NYSE \times r^{mc}$			-0.385***
			(-3.35)
r^{mc}			-0.274***
			(-2.75)
log(Volume)	0.291***	0.129***	-0.156
	(12.91)	(4.72)	(-0.41)
Volatility	-0.00284***	-0.00502***	-0.00382*
	(-7.02)	(-9.42)	(-1.82)
Eff. Spread	0.407***	0.571***	0.220
	(12.44)	(17.48)	(1.09)
Lambda	-0.00284***	-0.00502***	0.798**
	(-7.02)	(-9.42)	(2.06)
SE Clustering	Symbol-Date	Symbol-Date	Symbol-Date
Fixed Effects	Date	Date	Symbol, Date
N	638,989	638,989	638,536
Adj. R^2	0.133	0.312	0.376

Table 7:
Closing Auction Market Quality around COVID-19 NYSE Floor Closure
This table reports the effect of the NYSE floor closure (*Closure*) and the subsequent reopening (*Reopen*) on closing auction market quality metrics. NYSE closed its trading floor on March 23, 2020 and reopened it on May 26, 2020. In Panel A, we examine the effects of *Closure* and *Reopen* on paired volume ratio, absolute near price difference, and absolute order imbalance ratio at 3:55pm for NYSE versus Nasdaq. Paired Volume Ratio is the ratio of indicative matched volume at 3:55pm to final closing auction volume at 4:00pm (multiplied by 100). Absolute Near Price Difference is the absolute difference between the near price at 3:55pm and the final closing auction price at 4:00pm (in basis points). Absolute Order Imbalance Ratio is the ratio of absolute indicative order imbalance at 3:55pm divided by indicative paired volume at 3:55pm (multiplied by 100). In Panel B, we examine absolute price changes in the closing auction and overnight reversals. $|r^{lc}|$ ($|r^{mc}|$) is the absolute difference between the closing price and the reference price (NBBO midpoint) just before 4:00pm. r^{co} is the difference between the next-day opening price and today's closing price. All differences are measured in basis points. We include the same liquidity control variables as our previous tests. Standard errors are double-clustered by symbol and date. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: COVID-19 Closing Auction Feed Regressions

	Paired Volume Ratio (%)	Abs. Near Price Diff. (bps)	Abs. Order Imb. Ratio (%)
	(1)	(2)	(3)
$NYSE \times Closure$	28.09***	-123.8***	-5.896***
	(25.32)	(-6.33)	(-4.00)
$NYSE \times Reopen$	-29.04***	104.3***	16.89***
	(-23.71)	(5.78)	(11.17)
$NYSE$	-36.63***	343.4***	21.35***
	(-33.96)	(18.44)	(15.32)
$Closure$	-1.230***	5.081	1.315**
	(-2.96)	(0.40)	(2.45)
$Reopen$	0.471	-4.934	0.246
	(1.27)	(-0.56)	(0.46)
Constant	85.63***	227.4***	15.15***
	(58.96)	(5.53)	(5.67)
SE Clustering	Symbol-Date	Symbol-Date	Symbol-Date
Controls	Yes	Yes	Yes
N	42,380	42,380	42,380
Adj. R^2	0.671	0.168	0.186

Panel B: COVID-19 Closing Price Efficiency Regressions

	$y = \lvert r^{lc} \rvert$	$y = \lvert r^{mc} \rvert$	$y = r^{co}$
	(1)	(2)	(3)
$NYSE \times Closure$	4.039***	3.672***	24.62
	(4.70)	(3.80)	(1.52)
$NYSE \times Reopen$	-1.894***	-2.169***	2.641
	(-6.71)	(-8.46)	(0.16)
$NYSE \times Closure \times r^{mc}$			1.023
			(1.10)
$NYSE \times Reopen \times r^{mc}$			-0.604
			(-0.68)
SE Clustering	Symbol-Date	Symbol-Date	Symbol-Date
Fixed Effects	Symbol, Date	Symbol, Date	Symbol, Date
Controls	Yes	Yes	Yes
N	44,579	44,562	44,557
Adj. R^2	0.165	0.182	0.707

Table 8:
Absolute Near Price Differences from 3:54:55pm to 4:00:00pm over Time.
This table reports the average absolute near price difference on NYSE versus Nasdaq during different time periods. *MidPeriod* is an indicator variable representing the period from January 2014 to June 2016. *LatePeriod* is an indicator variable representing the period from July 2016 to the end of 2018. The remaining observations appear in the early period of May 2011 to December 2013. Near price is the indicative closing auction clearing price using the orders currently submitted to the closing auction and the orders currently in the continuous limit order book. D-Orders are included in the near price starting at 3:55pm. Reference price is the last transaction price. The absolute near price difference is measured in basis points (bps) and evaluated as the difference between the near price at 3:54:55pm and the official closing price at 4:00pm. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Abs. Near Price Difference, 3:54:55pm to 4:00pm (bps)

	(1)	(2)	(3)
$NYSE$	43.21***	44.59***	43.13***
	(28.65)	(28.16)	(10.46)
$NYSE \times MidPeriod$	21.29***	21.27***	18.51***
	(9.68)	(9.62)	(7.76)
$NYSE \times LatePeriod$	160.0***	159.7***	148.4***
	(38.38)	(38.29)	(32.77)
$MidPeriod$	-1.795***	-2.336***	
	(-4.69)	(-4.89)	
$LatePeriod$	0.214	-0.599	
	(0.44)	(-0.94)	
log(Volume)		5.657***	7.697***
		(7.62)	(8.53)
Volatility		-0.00302	-0.00206
		(-1.39)	(-1.25)
Eff. Spread		0.486	0.415
		(1.34)	(1.22)
Lambda		0.768	1.951***
		(0.89)	(3.48)
SE Clustering	Symbol-Date	Symbol-Date	Symbol-Date
Fixed Effects	None	None	Symbol, Date
N	655,635	655,608	655,608
Adj. R^2	0.170	0.171	0.212

Table 9:
Absolute Near Price Difference from 3:54:55pm to 4:00:00pm and Abnormal Matched Volume.
This table reports the effect of within-stock abnormal indicative matched volume on near price differences. Near price differences are measured daily from 3:54:55pm to 4:00pm. Near price is the indicative closing auction clearing price using the orders currently submitted to the closing auction and the orders currently in the continuous limit order book. D-Orders are included in the near price starting at 3:55pm. Reference price is the last transaction price. Z(Volume) is the difference between indicative matched volume at 3:54:55pm and its mean, divided by its standard deviation. Mean and standard deviation are calculated on a rolling basis based on the last year. Standard errors are double-clustered by symbol and date. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Abs. Near Price Difference, 3:54:55pm to 4:00pm (bps)

	(1)	(2)	(3)
$NYSE \times$ Z(Volume)	14.99***	15.00***	13.12***
	(11.94)	(12.17)	(13.05)
Z(Volume)	1.993***	1.102***	-5.830***
	(9.20)	(4.25)	(-7.42)
$NYSE$	100.7***	102.0***	
	(38.84)	(38.26)	
log(Volume)		8.459***	4.569***
		(7.50)	(2.77)
Volatility		-0.000984	-0.00281
		(-0.81)	(-1.38)
Eff. Spread		0.114	0.559
		(0.75)	(1.22)
Lambda		-17.46***	1.075
		(-11.93)	(1.53)
SE Clustering	Symbol-Date	Symbol-Date	Symbol-Date
Fixed Effects	None	None	Symbol, Date
N	655,635	655,608	655,608
Adj. R^2	0.0754	0.0810	0.193

Table 10:
IV Regression of Abs. Near Price Difference from 3:54:55pm to 4:00pm on Abnormal Volume. Panel A reports the effect of within-stock abnormal indicative matched volume on near price differences, where volume is instrumented on "triple-witching" days ($Witch$), the third Friday of every March, June, September, and December. Panel B reports the effect of within-stock abnormal indicative matched volume on near price differences, where volume is instrumented on $LastDay$, the last trading day of each month. The two first-stage regressions are reported in the first and second regression columns. The second-stage regression is reported in the last regression column. Near price differences are measured daily from 3:54:55pm to 4:00pm. Near price is the indicative closing auction clearing price using the orders currently submitted to the closing auction and the orders currently in the continuous limit order book. D-Orders are included in the near price starting at 3:55pm. Reference price is the last transaction price. Z(Volume) is the difference between indicative matched volume at 3:54:55pm and its mean, divided by its standard deviation. Mean and standard deviation are calculated on a rolling basis based on the last year. Standard errors are double-clustered by symbol and date. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: IV Regression with Triple Witching Day as Instrument

	First Stage (1)	First Stage (2)	Second Stage
	x = NYSE × Z(Vol.)	x = Z(Volume)	y = Near Price Diff.
$NYSE \times Witch$	2.822***	0.193**	
	(22.36)	(2.12)	
$Witch$	0.00189	2.627***	
	(0.73)	(28.30)	
Pred. $NYSE$ × Z(Volume)			13.73***
			(4.38)
Pred. Z(Volume)			2.607***
			(4.56)
log(Volume)	0.110***	0.179***	20.50***
	(12.83)	(18.71)	(9.11)
Volatility	0.00000407	-0.0000118	-0.000737
	(1.01)	(-0.86)	(-0.71)
Eff. Spread	-0.000985	0.00104	0.0733
	(-1.43)	(0.76)	(0.53)
Lambda	-0.0251***	-0.0257***	-12.35***
	(-4.12)	(-3.35)	(-9.15)
SE Clustering	Symbol-Date	Symbol-Date	Symbol-Date
Fixed Effects	Symbol	Symbol	Symbol
N	655,608	655,608	655,608
F-Statistic	122.8	197.0	34.73

Panel B: IV Regression with Last Day of Month as Instrument

	First Stage (1)	First Stage (2)	Second Stage
	x = NYSE × Z(Volume)	x = Z(Volume)	y = Near Price Diff.
$NYSE \times LastDay$	1.145***	0.163***	
	(14.59)	(2.60)	
$LastDay$	0.00682**	0.992***	
	(2.07)	(15.44)	
Pred. $NYSE$ × Z(Volume)			32.95***
			(3.79)
Pred. Z(Volume)			5.630***
			(4.31)
log(Volume)	0.121***	0.192***	17.81***
	(13.98)	(21.10)	(7.67)
Volatility	0.00000433	-0.0000108	-0.000764
	(1.03)	(-0.76)	(-0.70)
Eff. Spread	-0.00106	0.000926	0.0895
	(-1.41)	(0.62)	(0.59)
Lambda	-0.0206***	-0.0209***	-11.80***
	(-3.67)	(-2.95)	(-8.82)
SE Clustering	Symbol-Date	Symbol-Date	Symbol-Date
Fixed Effects	Symbol	Symbol	Symbol
N	655,608	655,608	655,608
F-Statistic	72.89	132.0	32.39

Internet Appendix for Vestigial Tails? Floor Brokers at the Close in Modern Electronic Markets

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October 1, 2020

Internet Appendix A: Closing Auction Reference Prices

Figure A-1 shows the evolution of the average reference price difference, which we define as the absolute difference (in basis points) between the reference price and the final closing auction price, on NYSE versus Nasdaq. The reference price is typically the last sale price from the continuous market, and is used to calculate indicative matched volume and order imbalance in the auction feeds. In contrast to the near prices in Figure 2 of the main paper, we find that reference prices on NYSE and Nasdaq behave similarly, suggesting that the continuous market efficiently incorporates price-relevant information on both exchanges. For both exchanges, the reference price difference equals about 12 to 14 basis points at 3:50pm, and then monotonically converges to approximately zero as 4:00pm approaches. On NYSE, there is no change in the reference price at 3:55pm, suggesting that D-Orders do not contain any information that is relevant to the efficient price in the continuous market. Thus, the closing auction can largely be seen as a "volume discovery" mechanism for large liquidity traders and floor brokers.

Internet Appendix B: Latency Effects at 3:55pm

Latency can also play a significant role in market quality outcomes because it affects the ability of traders to interact with an exchange in a timely manner. There are several potential sources of latency in a trading environment: geographic latency, processing latency, and transmission latency. Reducing geographic latency by co-locating near an exchange's matching engine can reduce displayed bid-ask spreads because market makers can quickly withdraw liquidity before being adversely selected by incoming market orders from informed traders. By the same token, however, co-location can create challenges in accessing displayed liquidity (Brogaard, Hagströmer, Nordén, and Riordan, 2015). Similarly, processing latency, which is based on the rate at which exchanges can process orders, has an ambiguous effect on spreads because it depends on the degree to which faster traders use their speed to avoid adverse selection or favorably select standing limit orders

(Menkveld and Zoican, 2017). We focus on transmission latency, which is defined as the amount of time it takes for a message to travel from an exchange to the end user. Transmission latency is bound by the speed of light, but it is also affected by communications technology (e.g., wireless or fiber optic), weather and humidity (Shkilko and Sokolov, 2020), and, most importantly, bandwidth (Buchanan, 2015). When message traffic is high, bandwidth becomes a capacity constraint, and hence transmission latencies increase.

We measure latency as the number of microseconds between the timestamp published by the stock exchange and the timestamp recorded by the data provider (MIDAS). We hypothesize that latencies spike on NYSE at 3:55pm due to the increased floor broker activity at this time. Table A-1 presents estimates from difference-in-differences regressions of transmission latency on the right hand side variables from our baseline regression model in Section 6.2 of the main text. First, we find that latency for NYSE messages is about 860 microseconds higher than latency for Nasdaq messages at 3:54pm, on average. This is unsurprising because the MIDAS servers are co-located in the Nasdaq data center. More importantly, our results also indicate that latency on NYSE further increases to about 1,000 microseconds when D-Orders are incorporated into the indicative closing auction statistics at 3:55pm. Thus, high-bandwidth subscribers may have an informational advantage over low-bandwidth subscribers at 3:55pm in both the closing auction and the continuous market due to their advanced knowledge about liquidity imbalances in the closing auction. By contrast, Nasdaq transmission latency remains fairly constant over the same period during the auction.

References

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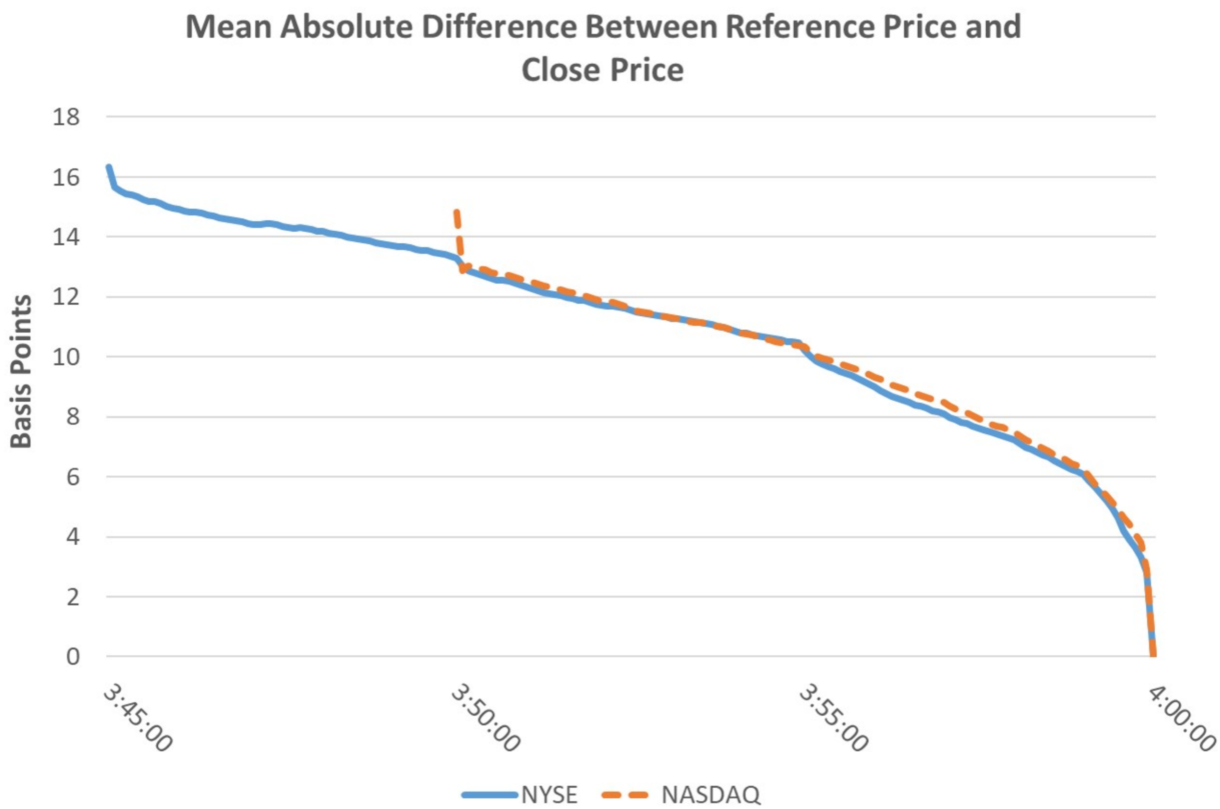

Figure A-1: Reference Price Evolution on NYSE and Nasdaq. This figure reports the mean absolute difference (in basis points) between the reference price and the final closing auction price over time for NYSE and Nasdaq. Reference price is the last transaction price in the continuous market and is used to calculate indicative paired volume and indicative order imbalance for the closing auction.

Table A-1:
Transmission Latency on NYSE versus Nasdaq.
This table reports average transmission latency on NYSE versus Nasdaq at different times in the closing auction. Transmission latency is the number of microseconds between the timestamp provided by the stock exchange and the timestamp recorded by the data provider. Standard errors are double-clustered by symbol and date. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Dep. Variable: Transmission Latency (μs)

	(1)	(2)	(3)
$NYSE \times \mathbb{1}^{3:54}$	860.8***	864.3***	-87.90***
	(31.84)	(31.66)	(-13.34)
$NYSE \times \mathbb{1}^{3:55}$	1007.0***	1003.9***	67.89***
	(34.27)	(33.88)	(13.22)
$NYSE \times \mathbb{1}^{3:59}$	910.9***	911.5***	
	(31.68)	(31.28)	
$\mathbb{1}^{3:54}$	1.613	1.215	-17.01***
	(0.54)	(0.41)	(-6.49)
$\mathbb{1}^{3:55}$	-2.719	-2.733	-4.920**
	(-0.98)	(-0.99)	(-2.51)
log(Volume)		-51.66***	21.24*
		(-5.38)	(1.66)
Volatility		-0.0154	0.00633
		(-0.68)	(1.26)
Eff. Spread		7.060*	-0.998
		(1.70)	(-0.97)
Lambda		13.34	5.043
		(0.82)	(1.18)
Constant	282.0***	624.6***	
	(13.76)	(7.89)	
$NYSE \times (\mathbb{1}^{3:55} - \mathbb{1}^{3:54})$	146.22***	139.67***	155.80***
	(16.17)	(15.68)	(23.45)
SE Clustering	Symbol-Date	Symbol-Date	Symbol-Date
Fixed Effects	None	None	Symbol, Date
N	1,480,199	1,480,055	1,480,055
Adj. R^2	0.241	0.247	0.723