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

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Abstract

Closing auctions are an increasingly important trading mechanism for passive funds that require closing price execution. However, differences in auction mechanism design on NYSE and Nasdaq may affect closing auction price efficiency. In particular, NYSE floor brokers can submit orders later than other traders, and these orders remain hidden until minutes before auction clearance. We show that NYSE closing prices are less efficient and NYSE pre-auction information is less accurate due to the late submission option. However, auction quality improved when NYSE halted floor trading during the COVID-19 pandemic. Our results highlight an important tradeoff between auction flexibility and efficiency.

JEL classification: G12, G14, D44
Keywords: closing auctions, floor brokers, auction efficiency, D-Orders, COVID-19

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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.

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. As a result, the rules for closing auctions on NYSE and Nasdaq reflect their own unique histories. While Nasdaq 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 have the discretion to enter or cancel their orders (also called D-Orders, short for "discretionary orders") until 3:59:59pm (one second before the auction clears), which is significantly later than the cutoff time of 3:45pm for regular orders. A second advantage is that publicly-disseminated auction information, such as the indicative closing price and indicative order imbalance, does not incorporate floor brokers' orders until 3:55pm. Thus, most ordinary investors remain in the dark about true auction interest until 3:55pm, ten minutes after the cutoff time for submitting regular orders to the auction.[1]

We study how these differences in closing auction mechanism design affect closing auction

[1]During our main sample period of 2011 to 2018, the cutoff times for regular orders and D-Orders on NYSE were 3:45pm and 3:59:59pm, respectively. However, these cutoff times have since been updated to 3:50pm and 3:59:50pm. Unless otherwise stated, this study will assume the auction rules from the 2011 to 2018 period.

market quality, particularly the accuracy of the pre-auction indicative statistics and the efficiency of the closing price. Nearly three-quarters of institutional investors rely on accurate auction information to trade in the close (Markets Media, 2017), yet they do not have complete information in NYSE closing auctions due to hidden orders and delayed orders from floor brokers. Even still, the advantages provided to floor brokers may enhance auction efficiency if they provide floor brokers with more latitude to respond to new information during the final minutes of the trading day. On the other hand, these advantages may reduce closing auction efficiency if floor brokers are not able to offset liquidity imbalances, or if they submit unexpectedly large orders during the final seconds of the trading day. In light of these potential effects, our study focuses on the accuracy of closing auction information, the efficiency of closing prices, and the interplay between auction information and efficiency on NYSE relative to Nasdaq.

We first test for differences in closing auction market quality on NYSE versus Nasdaq using novel exchange auction feed data from May 2011 to October 2018. In this setting, we measure closing auction market quality using several metrics: the likelihood of overnight price reversal, the near price difference (the absolute percentage difference between the indicative closing auction price and the realized closing auction price; the indicative closing auction price is commonly referred to as the near price), the paired volume ratio (indicative closing auction volume as a percentage of realized closing auction volume), and the imbalance ratio (absolute indicative order imbalance as a percentage of indicative volume). The first metric is used to measure closing auction price efficiency, and the last three metrics are used to measure pre-auction information accuracy. Underlining its importance for the marginal auction participant, pre-auction 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

[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 (https://www.tradersmagazine.com/departments/ecns_and_exchanges/closing-volume-discovery/). In response to recent industry feedback, the TMX group began disseminating closing auction indicative price, volume, and imbalance information at ten second intervals on its Toronto Stock Exchange and Venture Exchange (https://app.tmx.com/new-moc/).

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 significant lower on NYSE compared to Nasdaq. First, the average overnight reversal of price changes in the closing auction, while common to both exchanges, is 22% stronger on NYSE, suggesting that the NYSE auction structure produces less efficient closing auction prices and greater risks for passive investors that rely on closing prices. Second, the average near price difference just before 3:55pm is approximately 100 basis points on NYSE, compared to only 10 basis points on Nasdaq. Even after the incorporation of D-Orders at 3:55pm, the average near price difference on NYSE relative to Nasdaq remains fairly large at approximately 50 basis points, suggesting that D-Order delay significantly reduces the informativeness of the near price. Third, the average paired volume ratio before 3:55pm is only 58% on NYSE compared to 98% on Nasdaq. The remaining 42% of still-unmatched NYSE volume is equivalent to \$4 million in trading interest per auction, or \$2.7 trillion in trading interest across all auctions, that is eventually matched by floor brokers with late access to the auction. Fourth, the average imbalance ratio before 3:55pm is 53% on NYSE, and only 3% on Nasdaq. Just prior to 4:00pm, the average NYSE imbalance ratio remains high at 7% compared to 1% on Nasdaq, suggesting that floor broker activity is not sufficient to offset imbalances in most cases. We also find that the sign of the order imbalance flips in one out of every six auctions on NYSE during the last minute of the trading day when D-Orders can still be modified or cancelled, suggesting that D-Orders create novel deadline effects that can lead to significant unpredictability in NYSE auctions. Taken together, the last three results suggest that the indicative statistics reported by NYSE are less indicative of realized closing auction outcomes compared to Nasdaq due to hidden floor broker orders and delayed floor broker orders.

We also find that the closing auction indicative statistics are significant predictors of actual closing prices, and thus important for execution outcomes of passive funds and other investors that rely on closing prices for purchases and redemptions. In particular, we find that near prices and indicative order imbalances are strong predictors of price changes at the close. Interestingly, near price is a stronger predictor of closing price changes on Nasdaq, while indicative order imbalance is a stronger predictor of closing price changes on NYSE. The former result suggests that indicative price information is more complete on Nasdaq, where all traders have equal access to the auction, while the latter result suggests that imbalances are especially relevant for auction outcomes on NYSE, where imbalances tend to be larger throughout the dissemination process and at auction clearance. That said, the larger imbalance-induced price changes on NYSE may not be a problem for closing price efficiency if they reflect informed order flow. However, our previous evidence of stronger overnight reversals on NYSE suggests that indicative order imbalances on NYSE are actually less likely to reflect informed order flow. Notably, we find that the stronger overnight reversals on NYSE appear to be entirely explained by price pressures from residual order imbalances just after 3:55pm, when D-Orders have already been incorporated into the indicative auction statistics, but also when floor brokers still have the flexibility to alter their auction orders. That is, the stronger overnight reversals on NYSE appear to be entirely explained by late orders from NYSE floor brokers. In general, our results highlight an important tradeoff between order flexibility and price efficiency for auction design, and the costs to passive funds and other investors that need to trade in closing auctions but receive less efficient prices.

We use the novel NYSE floor closure during the COVID-19 pandemic to isolate 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. Electronic trading, meanwhile, 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. We find that closing auction market quality significantly improved on NYSE during the floor closure. First, closing price efficiency significantly improved on NYSE compared to Nasdaq, with overnight reversals becoming significantly weaker during the closure. Second, the average paired volume ratio on NYSE at 3:55pm jumped from approximately 55% to 80%, suggesting that orders were being matched early in the auction process, much like on Nasdaq. Third, the average near price difference on NYSE at 3:55pm decreased by 99 basis points, or 29% of the near price difference at the same time of day just before the floor closure (342 basis points). Lastly, the average imbalance ratio on NYSE at 3:55pm decreased by 13 percentage points relative to the pre-closure average ratio of 39%, suggesting that a larger percentage of auction participants were having their orders matched earlier during the floor closure. All of these changes are measured relative to Nasdaq, which did not experience significant changes in auction quality during this period. Importantly, all of these changes reverted after NYSE reopened its trading floor on May 26, 2020. The improvements in NYSE closing auction market quality 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 shocks in demand for closing auction liquidity. Demand shocks are more likely to produce large order imbalances on NYSE and Nasdaq. On NYSE, however, non-floor traders cannot easily trade against these imbalances because of the early cutoff time for regular auction orders. Consistent with this intuition, we find that the average near price difference on NYSE is about 7 basis points higher for every standard deviation increase in pre-3:55pm abnormal indicative matched volume relative to Nasdaq, compared to only 1 basis point on Nasdaq. We also use "triple witching" days as instruments for abnormal indicative matched volume to establish a causal connection between auction interest and closing auction 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; Barclay, Hendershott, and Jones, 2008). In our first stage regression, we find that pre-3:55pm abnormal indicative matched volume is about 3.7 standard deviations higher on NYSE on triple witching days. In our second stage regression, we find that the average near price difference on NYSE is about 56 basis points higher due to the predicted increase in abnormal indicative matched volume from the first stage. While there is a similar increase in abnormal indicative matched volume on Nasdaq on triple witching days, we do not observe any economically significant changes in the average near price difference on Nasdaq in the second-stage regression compared to NYSE. Therefore, our evidence suggests that the auction structure on NYSE makes the auction less resilient to liquidity demand shocks.

Our findings highlight the complexities and tradeoffs associated with operating a single-price auction that accepts orders during regular trading hours. Many traders value the flexibility to modify their orders during the final minutes of the trading day in response to new information. NYSE caters to this demand by allowing traders to modify their orders through floor brokers until one second before the close. However, our findings suggest that there are significant downsides to an auction model that provides late access to a subset of auction participants, including reduced price efficiency, less informative auction feeds, and less resiliency to liquidity demand shocks. In an attempt to mitigate auction price inefficiencies in extreme cases, the in-house regulatory arm at NYSE has even stepped up enforcement efforts to prevent large order submissions from floor brokers during the final minutes of the submission period (WSJ, 2019a). By contrast, Nasdaq does not allow auction participants to modify orders during the final minutes of the trading day, thereby sacrificing order submission flexibility for greater closing price efficiency, more informative auction feeds, and stronger resiliency to liquidity demand shocks. Our findings suggest that researchers and regulators should apply more scrutiny to trading mechanisms which offer greater order submission flexibility through specialized access, a practice that is still found across global equities, commodities, and fixed income markets.[3]

[3]Eight German markets still have floor trading, including two operated by Deutsche Börse AG (Xetra and the Frankfurt Stock Exchange) which are among the largest German and global cash equities markets. According to Gomber (2015), floor traders on regional German exchanges are provided with exclusive order book transparency, and have benefited from political protections at the cost of market reforms. The London Metal Exchange scrapped its plans to eliminate floor trading after pushback from brokers, who have been "setting daily official prices for metals from the floor's distinctive red sofas" since 1877 (https://www.ft.com/content/a21bd2d3-850c-4e33-9e55-0b9c88940c99). The SEC's Fixed Income Market Structure Advisory Committee recommends that it examine the potentially anti-competitive practice of "pennying" in corporate and municipal bond auctions, wherein dealers use their special position to review auction information and internalize customer orders at prices that either match or slightly improve the best priced auction response (https://www.finra.org/rules-guidance/notices/20-29).

2 Contribution and Related Literature

Our study contributes to an important and developing literature on market design and conflicts of interest. Markets are not designed in a vacuum. The economic incentives of exchanges, intermediaries, and market participants shape market design in ways that are largely underappreciated in the literature. Recent theoretical work has examined exchanges' incentives to extract rents by selling high-speed trading technology, arguing that although this is socially wasteful, it is privately profitable (Budish, Cramton, and Shim, 2015). Spatt (2020) argues that the complex trading rebate and fee structures on exchanges such as NYSE and Nasdaq, which provide larger discounts for higher volume traders that are intricately tied to the pricing of their proprietary data feeds, reflect profit-maximizing, anti-competitive behavior on the part of the exchanges. Even now, Nasdaq and the NYSE are suing the Securities and Exchange Commission (SEC) over proposed regulations to promote more competition in the market for public data feeds. Our paper provides novel evidence that the NYSE and NYSE floor brokers have maintained a less efficient market through a listing monopoly and rules that favor floor traders. This makes little economic sense from a market efficiency perspective, especially given the importance of the closing price for an increasingly large subset of investors such as index investors. We make an important contribution to this broader literature by showing how closing price efficiency has been shaped by closing auction market design, with a highlight on the conflicts of interest between floor brokers and other market participants.

Our study also contributes to the literature on optimal market design in financial markets. Several studies have shown that market quality improves after an exchange introduces a call auction to determine the stock price at the beginning or end of the trading day (Pagano and Schwartz, 2003; Hillion and Suominen, 2004; Comerton-Forde, Lau, and McInish, 2007; Kandel, Rindi, and Bosetti, 2012; Pagano, Peng, and Schwartz, 2013).[4] Liquidity and price efficiency are also generally higher on exchanges which operate fully-electronic or hybrid auctions instead of purely

[4]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 et al., 2015; Jagannathan, 2020). Periodic auctions can also aggregate information more efficiently and are more robust to problems arising from information asymmetries (Madhavan, 1992). However, closing auctions are not necessarily free from manipulation (Comerton-Forde and Putniņš, 2011), even with the robustness to information asymmetries.

dealer-driven auctions (Ellul, Shin, and Tonks, 2005; Hendershott and Moulton, 2011; Onur and Reiffen, 2018), and 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; Aspris, Foley, and O'Neill, 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 in continuous markets may also be able to facilitate better price discovery because they can see individual orders in addition to aggregated supply and demand schedules (Madhavan and Panchapagesan, 2000), and may also reduce intraday volatility and effective spreads (Brogaard, Ringgenberg, and Rösch, 2021). 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 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 many other modern exchanges.

Lastly, our study contributes to the literature that documents the benefits and drawbacks of mechanisms that are meant to supplement liquidity in continuous auctions. For example, Battalio, Jennings, and McDonald (2021) examine the NYSE "parity" rule, a vestige of the NYSE hybrid model that allows floor brokers to trade ahead of previously entered electronic orders (NYSE, 2022a). 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 tail" of NYSE market structure that benefits some investors at the expense of reduced closing auction efficiency for all investors. 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.

A contemporaneous study by Jegadeesh and Wu (2022) (JW) also compares closing auction outcomes on NYSE and Nasdaq. In particular, they show that first-disseminated order imbalances have a stronger relationship with closing price changes on Nasdaq compared to NYSE, suggesting that floor traders provide more depth in NYSE closing auctions. Furthermore, they show that closing price changes induced by first-disseminated imbalances are completely reversed on both NYSE and Nasdaq after several days, indicating that imbalance-induced closing price changes are temporary. By contrast, we focus on order imbalance levels and changes at 3:55pm in order to tease out the effects of delayed D-Orders and hidden D-Orders on closing price efficiency, thereby highlighting an economic mechanism, namely the closing auction design, that is distinct from but complementary to JW. We find that delayed D-Orders and hidden D-Orders are both highly predictive of closing price changes on NYSE compared to Nasdaq, suggesting that deadline effects and incomplete auction feeds are both relevant for closing price outcomes. Importantly, we show that overnight price reversals on NYSE became significantly weaker during the NYSE floor closure in early 2020, which further indicates that delayed D-Orders and hidden D-Orders from floor brokers impair closing price efficiency.[5]

Another important difference between our study and JW is that we focus on S&P 500 stocks,

[5]Several contemporaneous studies use the NYSE floor closure to examine the effect of floor trading on market quality. JW show that closing price changes on NYSE were larger during the NYSE floor closure, suggesting that NYSE floor traders may be important for providing closing auction liquidity during stressful periods. By contrast, we focus on the effect of the NYSE floor closure on overnight price reversals, which is more direct to the economic mechanism proposed in our study. Importantly, we show that overnight reversals on NYSE became weaker during the NYSE floor closure, suggesting that special advantages provided to NYSE floor traders in the closing auction reduce closing price efficiency. Other related contemporaneous studies find that market quality in the continuous trading session on NYSE worsened during the NYSE floor closure relative to Nasdaq (Brogaard et al., 2021; Kye and Mizrach, 2021; Chung and Chuwonganant, 2022). By contrast, we focus on market quality changes in the closing auction, an increasingly important and economically distinct mechanism for executing large trades, especially for passive funds that are required to purchase and redeem shares at the closing price.

where closing auctions successfully run for 99.997% of the stock-days during our sample period. By contrast, JW include non-S&P 500 stocks in their sample (excluding stocks priced less than $5 on the previous day), where closing auctions do not run for 29.1% of the associated stock-days, and stocks in the lowest quartile of average daily volume, where closing auctions do not run for 65.3% of the associated stock-days. When the closing auction does not run, NYSE chooses a closing auction price that is based on a combination of the last trade price and the time-weighted average midquote price in the last five minutes, while Nasdaq chooses a closing auction price that is based on the volume-weighted average trade price in the last five minutes (NYSE, 2022b; Nasdaq, 2022). By design, Nasdaq will see more overnight reversion in the closing price due to bid-ask bounce when there is no auction interest and little trading volume in the last five minutes of the trading day because the closing price is based on traded prices. In light of the differences in sample selection, one interpretation of our results, in combination with the results from JW, is that floor traders are largely unnecessary for closing auctions with high participation rates, but may be useful for providing depth in closing auctions with low participation rates.

Finally, two contemporaneous studies examine overnight price reversals to answer different research questions about closing prices. Bogousslavsky and Muravyev (2022) provide causal evidence that the rapid growth in closing auction volume since 2010 is attributable to index funds and ETFs (particularly leveraged ETFs). Importantly, they show that closing price changes relative to the last traded price or midquote entirely revert overnight, suggesting that price pressure in the closing auction is uninformed. Our results suggest that the auction design itself can reduce auction efficiency by precluding traders from leaning against uninformed imbalances.[6] Comerton-Forde and Rindi (2022) focus on closing auctions in Europe and find that only 35% of closing price changes in large stocks revert overnight. Unlike U.S. markets, there is a randomized time delay between the end of the continuous trading session and the closing auction in the European markets studied in Comerton-Forde and Rindi (2022). Their evidence suggests that this innovation in

[6]In a robustness test, Bogousslavsky and Muravyev (2022) also state that the strength of these reversals on NYSE and Nasdaq are comparable. Like JW, we focus on closing price changes relative to the midquote prior to the first dissemination of auction information. This is important for our research design because the continuous trading session runs parallel to the closing call auction.

closing auction market structure could mitigate auction deadline effects and reduce closing price inefficiencies. By contrast, for NYSE-listed stocks, floor brokers can submit D-Orders until the final seconds of the trading day and can also use these D-Orders to increase late auction imbalances, thereby potentially exacerbating closing auction price inefficiencies.

3 Institutional Background

The closing auction is 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 3:45pm 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 3:45pm and the Nasdaq closing auction until 3:58pm. After 3:45pm on NYSE and 3:50pm 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-only (IO) 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 3:59:59pm. D-Orders are handled manually by NYSE floor brokers on behalf of their clients. D-Orders can be submitted with or without a limit price, which is analogous to submitting an LOC or MOC order. Up until 3:59:59pm, these 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, ten 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 at 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 some traders value the flexibility associated with adding, modifying, or cancelling orders in the last fifteen minutes of the trading day, and the allocation priority that D-Orders receive over earlier, same-priced LOC orders, even with the higher fees and potential latencies associated with submitting orders through manual floor brokers (Bacidore, Polidore, and Xu, 2014).

The closing auctions on NYSE and Nasdaq both clear at 4:00pm. The closing price is determined by the intersection of the supply and demand curves populated by the MOC, LOC, and IO 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 exchange typically chooses a closing price from this set that minimizes the price change relative to the continuous market. If there is a non-zero order imbalance at the final closing price, then orders are filled based on price-time priority on Nasdaq,

[7]On NYSE, IO orders are also known as "closing imbalance offset orders." On both exchanges, IO orders are considered limit orders that never receive priority over non-IOC orders (e.g., MOC and LOC orders) that would otherwise execute in the closing auction. Because of this low priority, IO orders appear to be less commonly used in closing auctions (NYSE, 2020b). For more information about the closing auctions and closing auction order types on NYSE and Nasdaq, see NYSE (2021) and Nasdaq (2019).

and price-floor-time priority on NYSE, in that D-Orders receive priority over non-floor orders with the same limit price, even if the non-floor order was entered earlier. The final print contains the closing price and matched volume, and is typically published to the public tape immediately after the close.

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 indicative order imbalance.[8] 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 number 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.

[8]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.

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 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.[9] 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 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). 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, and index funds are required to trade in closing auctions to minimize daily tracking error. Meanwhile, other investors may selectively participate in the closing auction if they believe that they can execute at better prices than those offered in the continuous market ("flexible investors"). D-Orders on NYSE are popular because they provide flexible investors with the option to add, modify, or cancel closing auction orders in response to new auction information during the

[9] 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, footnote 10.

last fifteen minutes of the trading day. For example, if the NYSE auction feed at 3:59pm indicates a large buy side imbalance (thus indicating that the closing auction would clear at a price that is higher than the continuous market price), then some flexible traders may want to submit sell D-Orders to capitalize on the expected price differential, while other flexible traders may want to cancel existing buy D-Orders.

Conceptually, we can think of benchmark investors as "impatient" since they are required to trade at the closing price and cannot wait for a potentially better execution price at a later time. The concept of "impatience" in a continuous auction setting is formalized in Foucault, Kadan, and Kandel (2005) and Roşu (2009), who show that impatient traders will submit aggressive limit orders to maximize their probability of execution and thus minimize large non-execution penalties. In a closing call auction setting, MOC orders are guaranteed execution as long as the auction clears. Therefore, a dominant strategy for benchmark investors is to submit MOC orders to guarantee execution. Furthermore, benchmark investors will also prefer to immediately submit their MOC orders because they can pre-announce their trading intentions through the indicative auction statistics and help to coordinate auction supply and demand, potentially leading to better execution prices (Admati and Pfleiderer, 1991). Lastly, benchmark investors will prefer non-floor MOC orders to MOC D-Orders on NYSE because the auction fees for non-floor MOC orders are generally lower, and because benchmark investors have no incentive to cancel or modify their orders during the final minutes of the trading day. Overall, from a theoretical perspective, we would expect benchmark investors to submit non-floor MOC orders as early as possible.

Conversely, we can think of flexible investors as "patient" since they are not required to trade at the closing price, but will choose to participate in the closing auction if they expect to earn positive rents. In particular, suppose that the continuous market price is seen as the efficient price. If the indicative order imbalance is positive at 3:55pm, then, based on the orders currently submitted to the auction, the closing auction will clear at a price that is higher than the current market price. Therefore, flexible investors will have incentive to submit LOC orders to sell shares in the closing auction. If enough flexible investors arrive with sell orders and sufficiently compete on price, then the indicative order imbalance will converge to zero. Complicating matters is the possibility that the continuous market price changes in the meantime. In this case, the order imbalance statistic will be pushed away from zero, and flexible investors may want to modify their orders to again exploit the imbalance-implied discrepancy between the auction price and the continuous market price (if the auction rules allow for order modification at that time). Overall, from a theoretical perspective, flexible investors will want to trade against indicative order imbalances, although their timing will depend on the rules of the auction.

With benchmark investors and flexible investors defined, we now consider a hypothetical closing auction on Nasdaq. As discussed above, benchmark investors will submit early MOC orders to maximize execution probability. Suppose that the indicative order imbalance from these benchmark investor orders at 3:50pm, when the auction statistics on Nasdaq are first disseminated, equals +15,000 shares. Flexible investors now see that the closing auction would clear at a price that is higher than the continuous market price. Because Nasdaq follows price-time priority, flexible investors will want to quickly submit LOC orders to sell at a price that is no less than the continuous market price in order to exploit the price differential. As a result, indicative order imbalance will quickly converge to zero after first dissemination, near price will quickly converge to the continuous market price, and indicative auction volume will quickly reflect realized auction volume at the close. If the continuous market price changes in the meantime, thereby recreating a non-zero order imbalance, then flexible investors can use LOC orders until 3:58pm, or IO orders until auction clearance, to correct the imbalance (although they cannot cancel or modify existing LOC orders). As long as flexible investors sufficiently compete to offset time-varying imbalances, the closing auction price should remain close to the continuous market price.

Next, consider a hypothetical closing auction on NYSE. Similar to Nasdaq, benchmark investors will submit early MOC orders to maximize execution probability. Suppose that the indicative order imbalance from these benchmark investor orders at 3:50pm, when the auction statistics on Nasdaq are first disseminated, equals +15,000 shares. Flexible investors now see that the closing auction would clear at a price that is higher than the continuous market price. Flexible investors will want to quickly submit LOC *D-Orders* to sell for no less than the continuous market price to exploit the price differential. Flexible investors choose LOC D-Orders over non-floor LOC orders because NYSE follows price-broker-time priority, and because flexible investors can cancel or modify D-Orders until one second before auction clearance. Flexible investors also recognize that the efficient price in the continuous market could change from 3:50pm to 4:00pm, meaning that indicative order imbalance would also change. In this case, flexible investors will quickly modify their D-Order limit prices to obtain price-time priority on the new imbalance, and to avoid overpaying in the closing auction relative to the continuous market price. Iterating forward, flexible investors will continuously modify their orders to follow the continuous market price. However, because D-Order cancellations and modifications are costly, some flexible investors may wait until later in the submission window to submit their first LOC D-Orders instead of constantly modifying their orders, although a downside to waiting is that the early LOC D-Orders will receive time priority when the continuous market price does not deviate from the indicative closing auction price. As a result, flexible investors arrive to the auction with their first D-Orders at different times, depending on their tolerance for monitoring and modifying their LOC D-Orders. (The early D-Orders will also not show up in the indicative auction statistics until 3:55pm, providing further incentive for some D-Order users to delay their orders until much later.) Therefore, unlike Nasdaq, we would expect to observe slow convergence of the auction statistics to their realized values at the close because of the threat that existing D-Orders are constantly undercut by new or modified D-Orders as the continuous market price changes. Furthermore, if flexible investors delay their orders until the final seconds of the auction, then we would also expect late imbalances and the closing price to be more unpredictable, especially if other flexible investors cannot react in time to the late imbalances.[10]

[10] In a related theoretical study, Ockenfels and Roth (2006) show that rational bidders in a second-price fixed deadline auction may delay their orders until the final seconds of the submission window in equilibrium, thereby generating higher profits than an alternative equilibrium in which everybody immediately submits their orders to the auction. Order delay generates higher expected profits because a late order may fail to arrive before the auction deadline; in this case, the participant who successfully submitted a late order receives the second-highest bid price, which is assumed to be a minimal placeholder bid from the beginning of the auction. Although our setting is a first-price fixed deadline auction, participants would still have incentive to delay their orders to avoid costly modifications of early D-Orders, and because there is a chance that last-second orders will not be undercut by other auction participants, thereby generating better execution prices or a larger share allocation in the auction.

Having laid out the intuition for the trading behaviors in the Nasdaq and NYSE closing auctions, we now present our null and alternative hypotheses on the accuracy of the closing auction indicative statistics:

> **Hypothesis 1 ("Null Hypothesis"):** The accuracy of the closing auction indicative statistics on NYSE is not significantly different from Nasdaq.
>
> **Hypothesis 1(a) ("Disclosure Hypothesis"):** The closing auction indicative statistics on NYSE are less accurate than Nasdaq because floor brokers orders are not incorporated into NYSE auction feeds until 3:55pm.
>
> **Hypothesis 1(b) ("Delay Hypothesis"):** The closing auction indicative statistics on NYSE are less accurate than Nasdaq because floor brokers delay finalizing their orders until the final minutes of the auction.

We should note that Hypotheses 1(a) and 1(b) are not mutually exclusive, as both undisclosed orders and delayed orders can decrease the accuracy of the auction statistics. To test these hypotheses, we focus on the near price difference, paired volume ratio, and imbalance ratio. The near price is most accurate when the near price difference equals zero, indicative paired volume is most accurate when the paired volume ratio equals 100, and indicative order imbalance is most accurate when the imbalance ratio equals zero. We test for evidence of the disclosure and delay hypotheses by focusing on auction statistic changes at 3:55pm (when hidden orders are incorporated into the auction statistics), and auction statistic levels after 3:55pm.[11]

Based on our intuition about the trading behaviors in the Nasdaq and NYSE closing auctions, we further hypothesize that the efficiency of the realized closing auction price is negatively affected by the auction rules:

[11]Mechanically, the accuracy of the pre-3:55pm auction statistics on NYSE should decrease as the proportion of pre-3:55pm D-Orders increases. However, what is not clear is the extent to which hidden D-Orders contribute to auction statistic inaccuracy, and how these hidden D-Orders ultimately affect closing price efficiency, which we explore in later tests.

Hypothesis 2 ("Null Hypothesis"): Closing auction price efficiency on NYSE is not significantly different from Nasdaq.

Hypothesis 2(a) ("Disclosure Hypothesis"): Closing auction price efficiency on NYSE is worse than Nasdaq because floor brokers orders are hidden from NYSE auction feeds until 3:55pm.

Hypothesis 2(b) ("Delay Hypothesis"): Closing auction price efficiency on NYSE is worse than Nasdaq because floor brokers delay their orders until the final minutes of the auction.

Intuitively, flexible investors on NYSE are able to delay their orders until the final seconds of the auction submission window using D-Orders, and have incentive to delay their orders because they want to condition those orders on the continuous market price and current auction imbalances. Hidden D-Orders on NYSE could also negatively affect closing price efficiency because some investors may prefer to wait until the hidden D-Orders are revealed to submit their orders. A second reason is that pre-3:55pm auction participants may submit orders to trade against imbalances that are not actually there, as hidden D-Orders may have already "crossed" with those imbalances. In both cases, the hidden D-Orders induce behavior that leads to greater swings in auction imbalances and thus closing auction prices.

Our tests of Hypothesis 2 will proceed in two steps. In our first step, we will examine whether the directional closing auction indicative statistics, specifically the near price difference and the imbalance ratio, predict the closing price. If all auction orders are accounted for, then near prices should predict closing prices, as the near price reflects the intersection of the supply and demand curves across both the auction and continuous order books. Near prices will not be predictive of the closing price if the auction order book is incomplete, however. On the other hand, if order imbalance is predictive of the closing price, then this would suggest that there is residual demand from buyers or sellers that is not being met by floor brokers. We test the predictability of these auction statistics before and after 3:55pm to identify how hidden D-Orders and late D-Orders contribute to auction prices. In our second step, we will test if price changes in the closing auction are reversed at the open of the following trading day, as imbalances in the closing auction could be due to temporary price pressures which reverse overnight or permanent price changes due to orders from informed traders. If overnight price reversals are stronger on one exchange versus another, then this would indicate that the closing price is less efficient.

The remainder of this paper will focus on testing the hypotheses outlined in this section and establishing mechanism causality using the NYSE floor closure during the COVID-19 pandemic.

5 Data and Methodology

Indicative closing auction information from 2011 to 2018 is collected, aggregated, and normalized by MayStreet, a leading market data provider for banks, asset managers, hedge funds, and the SEC. We access closing auction data from 2011 to 2018 using the SEC's MIDAS platform, which was created in response to the Flash Crash in May 2010 as a market monitoring tool. Closing auction information reported on the MIDAS platform 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. For many stocks outside of the S&P 500, indicative auction information is also fairly sparse, and closing auctions often do not run due to a lack of auction interest. We exclude missing and extreme near price observations, which reflect trading days with low auction interest and indicative crosses at extreme limit order prices. We also exclude observations in which the near price difference, paired volume ratio, or imbalance ratio is in the top percentile of its distribution. We obtain an additional sample of closing auction imbalance message data covering the period February 19, 2020 to July 7, 2020 from MayStreet 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 quote-level midpoint returns; and (4) intraday trading volume. We use these variables as controls in our multivariate regressions later in the paper.[12] From the same database, we also collect stock-day after-hours trading volume as an additional control for our overnight reversal tests.

Panels A and B of Table 1 provide stock-level 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 $118 million on NYSE and $126 million on Nasdaq. Trading volume in the closing auction is approximately equal on both exchanges at $16 million to $18 million. Across our sample period, closing volume on NYSE represents 9% of daily volume, about two percentage points higher than Nasdaq. Compared to NYSE, the percentage effective spread on Nasdaq is 0.7 basis points higher and Kyle's lambda is 2% higher, indicating that Nasdaq stocks are slightly less liquid. These differences are likely due to the types of stocks that tend to be listed on Nasdaq—primarily technology stocks—which have historically had higher volatility. Intraday volatility and average absolute open-to-close returns are also slightly higher on Nasdaq compared to NYSE. In this study, we largely focus on changes in closing auction indicative statistics around 3:55pm and observed prices at 4:00pm, thereby subsuming the stock-level fixed effects that are unrelated to the closing auction mechanism.[13]

We also provide auction-level summary statistics at 3:54:55pm and 3:55pm on NYSE and

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

[13]Table 1 also indicates that the upper percentiles for daily volume and effective spread, and the standard deviation for market capitalization, are higher in the Nasdaq sample than the NYSE sample. This is partially due to Nasdaq-listed stocks with extremely high volume and market values such as the FAANG stocks (i.e., Facebook, Amazon, Apple, Netflix, and Google). Therefore, the distributional properties of the NYSE stocks do not perfectly match the Nasdaq stocks in our overall sample. In robustness tests, we account for these distributional differences by employing weighted regressions that re-weight the sample of Nasdaq stocks so that these distributions for NYSE and Nasdaq are similar. In effect, we employ a matched sample analysis by re-weighting the sample of stocks to match the distributions.

Nasdaq to illustrate how the late incorporation of D-Orders at 3:55pm on NYSE reduces the informativeness of NYSE auction feeds. Table 2, Panel A documents significant changes in the NYSE auction statistics at 3:55pm, when D-Orders are incorporated into the auction statistics. In particular, at 3:55pm, the average absolute percentage change in the near price is 56 basis points, the average change in paired volume is $1.9 million, and the average change in absolute order imbalance is -$0.7 million. For about 15% of stock-days on NYSE, we also find that the order imbalance changes sign at 3:55pm. By contrast, Table 2, Panel B shows that there are no economically significant changes in the auction statistics on Nasdaq at 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 strongly affected by the hidden orders from floor brokers, who have near-exclusive access to the closing auction after 3:45pm. Notably, we also find that the average imbalance ratio remains fairly high and the average paired volume ratio remains fairly low on NYSE after D-Orders have been incorporated into the auction statistics at 3:55pm, suggesting that delayed D-Orders will also play a large role in shaping the auction statistics and the closing auction price on NYSE. In the next section, we explore the relative effects of hidden floor broker orders and delayed floor broker orders on the quality of the indicative auction statistics and closing prices on NYSE relative to Nasdaq.

6 Main Results

We hypothesize that the closing auction indicative statistics on NYSE are less accurate than Nasdaq due to the non-disclosure of D-Orders before 3:55pm and the delay of additional D-Orders until the final minutes of the auction submission window. In the next subsection, we test this hypothesis by examining the accuracy of these statistics over time on NYSE compared to Nasdaq, with a focus on 3:55pm, when D-Orders are incorporated into the auction statistics, and after 3:55pm, when additional D-Orders are submitted to the auction. In the last two subsections, we test our second hypothesis that realized closing auction prices are also less efficient on NYSE compared to Nasdaq by focusing on the predictability of auction statistics for the realized closing price, and the likelihood of price changes at the close to be reversed overnight.

6.1 Accuracy of Indicative Auction Statistics

Panel A of Figure 2 graphs the average near price difference, which we define as the equal-weighted average absolute percentage difference between the near price and the realized closing auction price (expressed in basis points), for each five-second period from 3:45pm to 4:00pm for NYSE, and from 3:50pm to 4:00pm for Nasdaq. When Nasdaq first reports the near price at 3:50pm, the average near price difference equals about 50 basis points. Five seconds later, the average near price difference quickly shifts downward to 20 basis points, indicating that auction participants competitively trade in the closing auction in response to information revealed by the closing auction statistics. Following that shift, the average near price difference then monotonically converges toward zero as 4:00pm approaches. Overall, the graphical evidence for Nasdaq suggests that its auction is efficient at aggregating supply and demand and providing an accurate indication of the closing price.

By contrast, when NYSE first reports the near price at 3:45pm, the average near price difference equals a much larger 120 basis points. Over the next ten minutes, the near price difference (and other indicative auction statistics) remains fairly stable, which is mostly unsurprising because MOC and LOC orders cannot be entered, modified, or cancelled after 3:45pm, and D-Orders are not incorporated into the auction statistics until 3:55pm. The small changes in the auction statistics that do occur from 3:45pm to 3:54:55pm are likely due to small changes in the continuous market limit order book, which is used as an input to calculate the near price. At exactly 3:55pm, we find that the average near price difference shifts downward by about 40 basis points due to the incorporation of D-Orders into the near price. However, even after this incorporation, the average near price difference still remains fairly large at approximately 60 basis points, suggesting that auction supply and demand still have not been fully aggregated into the auction. We also find that there is no subsequent shift in the average near price difference immediately after 3:55pm in response to the new D-Order information. Our graphical results suggest that 40% of the average near price difference just before 3:55pm (100 basis points) is due to hidden D-Orders, while the remaining 60% is due to late D-Orders.

Panel B of Figure 2 graphs the average paired volume ratio, which we define as the equal-weighted average indicative closing auction volume as a percentage of realized closing auction volume, on NYSE versus Nasdaq over time. On NYSE, the average paired volume ratio remains fairly low at about 58% from 3:45pm to 3:54:55pm. That is, 42% of final auction volume is still not represented in the closing auction indicative statistics during this time period. At exactly 3:55pm, the ratio jumps by 15 percentage points to about 73%, and then converges to 100% as 4:00pm approaches. The higher convergence rate during the final minute of the auction also indicates that many D-Orders are delayed until this time. 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 final closing auction volume. On NYSE, hidden D-Orders appear to account for about 36% of pre-3:55pm unmatched volume (15%/42%), and late D-Orders account for the remaining 64% of unmatched volume (27%/42%).

Panel A of Figure 3 graphs the average imbalance ratio, which we define as the equal-weighted average absolute indicative order imbalance as a percentage of indicative volume, on NYSE versus Nasdaq over time. On NYSE, the average imbalance ratio remains stable at about 51% from 3:45pm to 3:55pm. The large imbalance ratio represents an opportunity for floor brokers to trade against imbalances by submitting, modifying, or cancelling D-Orders on the buy or sell side during the final minutes of the trading day. At exactly 3:55pm, the imbalance ratio jumps down to about 31% due to the incorporation of D-Orders. As 4:00pm approaches, the imbalance ratio then converges toward about 7% (which represents the unfilled orders at the final reference price), with a greater convergence rate during the final minute of the auction. By contrast, on Nasdaq, the imbalance ratio starts at about 31%, immediately jumps down to 5%, and then monotonically converges to 1% as the close approaches. Thus, NYSE appears to have persistent order imbalances compared to

Nasdaq, suggesting that floor brokers are not meeting auction demand.[14] In relative terms, hidden D-Orders appear to account for about 39% of the pre-3:55pm order imbalance ($20\%/51\%$), and late D-Orders account for about 47% of the pre-3:55pm order imbalance ($24\%/51\%$). The remaining 14% of the pre-3:55pm order imbalance ($7\%/51\%$) is still not filled by the time the auction clears at 4:00pm.

Panel B of Figure 3 graphs the imbalance sign change probability on NYSE versus Nasdaq. For each minute, we construct an indicator variable that equals one if indicative order imbalance changes sign relative to the previous minute. Imbalance sign change probability is then calculated as the average value of this indicator variable for each exchange-minute. For NYSE, we find that order imbalance never changes sign prior to 3:55pm. However, at exactly 3:55pm, the hidden D-Orders flip the order imbalance sign in about 15% of all NYSE auctions. In these cases, the indicative order imbalance previously suggested that the price should increase (decrease) in the closing auction, but now suggests that the price should decrease (increase). From 3:56pm to 3:59pm, the order imbalance sign also flips in about 5% of all auctions. Most importantly, we find that the order imbalance sign flips in about 18% of all NYSE auctions just before 4:00pm, suggesting that the ability to add or cancel D-Orders until seconds before the auction clears can lead to novel deadline effects. By contrast, the order imbalance sign never changes on Nasdaq, which is unsurprising because the available order types on Nasdaq preclude order imbalances from being flipped during the final minutes of the auction. Overall, this evidence suggests that D-Orders on NYSE can lead to unexpected price outcomes in the closing auction due to the ability to flip order imbalances.

We also formally test for differences in the closing auction indicative statistics on NYSE versus Nasdaq in a multivariate regression setting. For each stock-day-minute (i,d,t), we construct a panel of indicative closing auction quality statistics (y) that includes the near price difference, paired volume ratio, imbalance ratio, and order imbalance sign change indicator variable. We then test

[14]We also observe a small uptick in order imbalances on NYSE in the final seconds leading into the close which is likely due to last-second D-Order modifications or cancellations. The motivations for these last-second modifications and cancellations remain unclear in the data, although they suggest that closing prices are subject to an additional source of uncertainty from these last-second orders.

the following ordinary least squares (OLS) regression model:

$$y_{i,d,t} = \sum_{t=3:51}^{4:00} \beta_t^N \cdot NYSE_i \times \mathbb{1}^t + \sum_{t=3:51}^{4:00} \beta_t \cdot \mathbb{1}^t + \alpha + NYSE_i + \varepsilon_{i,d,t}, \tag{1}$$

where $NYSE$ is an indicator variable that equals one if stock i is listed on NYSE, $\mathbb{1}^t$ is an indicator variable for minute t, $t = 4{:}00$ represents the the last reported closing auction quality statistic before the auction runs at 4:00pm, and α is a constant term which captures the baseline estimate for Nasdaq at 3:50pm. The β_t^N coefficient represents the difference in closing auction market quality on NYSE relative to Nasdaq on minute t. We are primarily interested in the differences in market quality at 3:54pm (before D-Orders are included in the NYSE auction statistics), 3:55pm (exactly when D-Orders are included in the NYSE auction statistics), and just before the closing auction clears. For brevity, we only report the coefficients for $NYSE \times \mathbb{1}^{3:54}$, $NYSE \times \mathbb{1}^{3:55}$, and $NYSE \times \mathbb{1}^{4:00}$.

The results of these regressions are reported in Table 3. In column (1), we show that the near price difference on NYSE is significantly higher than Nasdaq at 3:54pm and 3:55pm (87 basis points and 32 basis points, respectively), suggesting that hidden D-Orders and delayed D-Orders both contribute to lower near price accuracy on NYSE. Even just before 4:00pm, the near price difference is still about 1 basis point higher on NYSE, suggesting that last-second orders may still affect the closing price. Columns (2) and (3) indicate that the paired volume ratio is consistently lower and the imbalance ratio is consistently higher on NYSE compared to Nasdaq. Even seconds before the auction clears, about 4% of realized auction volume is still not incorporated into the auction statistics on NYSE relative to Nasdaq, and indicative order imbalance is still about 6 percentage points higher on NYSE. Finally, in column (4), we show that the probability of an order imbalance sign change is significantly positive on NYSE relative to Nasdaq even during the final seconds of the auction, suggesting that the auction structure on NYSE can lead to novel deadline effects and larger transitory pricing errors in the closing auction. In an alternative specification, we include a vector of lagged stock-day control variables X which contains the natural log of dollar trading volume, midquote return volatility, average percent effective spread, and Kyle's lambda and find similar results. In a second alternative specification, we also include a vector of stock and date fixed effects and again find similar results. Overall, the evidence from these regressions is consistent with our graphical evidence showing that the indicative auction statistics are consistently less accurate on NYSE relative to Nasdaq. Furthermore, our finding that the statistics remain significantly less accurate even after the incorporation of D-Orders suggests that hidden D-Orders and late D-Orders both contribute to a reduction in the accuracy of the closing auction indicative statistics, which is consistent with Hypotheses 1(a) and 1(b).[15]

In supporting tests, we re-test the same regressions from Table 3, except that we re-weight the sample so that the NYSE and Nasdaq stocks have similar volume and percentage spread distributions. The weighted regressions address the concern that the Nasdaq stocks have higher average volume and lower average percentage effective spreads than the NYSE stocks, and thus may indirectly affect the comparison of auction statistics on NYSE and Nasdaq. In this case, we find similar results to Table 3. For example, if we examine the indicative auction statistics at 3:55pm using the weighted regression, we find that the NYSE near price difference is 32.7 basis points higher, the paired volume ratio is 23.8 percentage points lower, the imbalance ratio is 28.3 percentage points higher, and the probability of an order imbalance sign change is 12.6 percentage points higher. The similar results suggest that the distributional differences in volume and spread do not affect the relative accuracy of the auction statistics throughout the auction dissemination period.

Lastly, in additional supporting tests, we compare closing auction statistics on NYSE at 3:55pm and Nasdaq at 3:58pm, when closing auction participants can no longer submit MOC or LOC orders to Nasdaq. These tests allow us to isolate the effect of delayed orders on the accuracy of the indicative auction statistics, as delayed orders are no longer allowed on Nasdaq, but are still allowed

[15] In an additional test, we show that transmission latency, defined as the amount of time it takes for a message to travel from an exchange to the end user, also significantly increases on NYSE at 3:55pm and just before the close. In particular, we find that NYSE transmission latency increases by 142 microseconds at 3:55pm relative to the baseline of 1,144 microseconds at 3:54pm (12.4%), and by 49 microseconds just before 4:00pm (4.2%). Nasdaq, by contrast, does not observe any increases in latency at these times. Therefore, high-bandwidth subscribers to auction feeds may also have an informational advantage over low-bandwidth subscribers at these times, potentially reducing market quality (Menkveld and Zoican, 2017; Shkilko and Sokolov, 2020).

on NYSE through floor brokers. Based on these clock times and our earlier graphical evidence, we find that the NYSE near price difference, paired volume ratio, and imbalance ratio are approximately 50 basis points higher, 34 percentage points lower, and 26 percentage points higher than Nasdaq, respectively. Therefore, this alternative comparison supports our earlier results that closing auction statistics are significantly less accurate on NYSE compared to Nasdaq due to delayed D-Orders.

6.2 Do Indicative Auction Statistics Matter?

According to Markets Media (2017), nearly three out of every four traders use closing auction feeds to determine if their orders can be executed in the closing auction with minimal price impact. Traders may be worse off in NYSE closing auctions because inaccurate auction statistics provide an incomplete picture of liquidity at the close, thus increasing the risk of executing at inferior prices. As shown in the previous section, one reason for the inaccurate statistics on NYSE is that D-Orders are hidden from the auction feeds until 3:55pm.[16] Another reason is that floor brokers can delay their D-Orders or even cancel existing D-Orders until 3:59:59pm, thereby precluding a complete picture of auction supply and demand until seconds before the auction clears. On the other hand, if closing auction indicative statistics do not contain any price-relevant information that is not already reflected in the continuous market, then these statistics may not matter at all for market quality or execution outcomes. In light of the differences in the closing auction structures on NYSE and Nasdaq, and the possibility that auction statistics may not matter for closing price outcomes, in this section we explore the predictive power of indicative auction statistics on NYSE and Nasdaq for closing prices.

We begin by testing whether indicative auction statistics on NYSE and Nasdaq can predict price changes at the close. Our main outcome variable, closing price change, is calculated as the percentage difference between the closing auction clearing price and the bid-ask midpoint at 3:55pm (r^{355c}) (expressed in basis points), just after D-Orders are incorporated into the NYSE

[16]Indeed, a research report by Cantor Fitzgerald points out that "at 15:55 when NYSE d-Quotes are initially included in imbalance messages, the average Absolute Prediction Error [for closing volume] drops significantly to 12%." See: https://www.fixglobal.com/closing-volume-discovery/.

auction statistics. For the indicative statistics, we focus on near price and order imbalance because they can contain directional information about potential price changes at the close. In particular, we construct the following four predictor variables: (1) abnormal near price, calculated as the percentage difference between the near price and bid-ask midpoint just before 3:55pm ($\widetilde{Near}_{3:55}$); (2) abnormal near price change, calculated as the change in the near price at 3:55pm, and expressed as a percentage of the bid-ask midpoint ($\widetilde{\Delta Near}_{3:55}$); (3) abnormal order imbalance, calculated as the closing auction indicative order imbalance just before 3:55pm ($\widetilde{OIB}_{3:55}$); and (4) abnormal order imbalance change, calculated as the change in indicative order imbalance at 3:55pm ($\widetilde{\Delta OIB}_{3:55}$). All four variables are standardized by subtracting their rolling 20-day mean and then dividing the difference by the rolling 20-day standard deviation. The change variables represent the component of the auction statistics attributable to hidden D-Orders, and the level variables represent the component attributable to the accumulation of all closing auction orders at that time, which importantly excludes D-Orders that are submitted between 3:55pm and the close. Using these variables, we can separately test Hypotheses 2(a) and 2(b) to see how indicative auction statistics, hidden D-Orders, and late D-Orders matter for closing price predictability.

Formally, we test the following model for closing price change predictability on NYSE versus Nasdaq:

$$
\begin{aligned}
r_{i,d}^{355c} &= \beta_1 \cdot \widetilde{Near}_{i,d}^{3:55} + \beta_2 \cdot \widetilde{Near}_{i,d}^{3:55} \times NYSE_i \\
&+ \beta_3 \cdot \widetilde{\Delta Near}_{i,d}^{3:55} + \beta_4 \cdot \widetilde{\Delta Near}_{i,d}^{3:55} \times NYSE_i \\
&+ \gamma_1 \cdot \widetilde{OIB}_{i,d}^{3:55} + \gamma_2 \cdot \widetilde{OIB}_{i,d}^{3:55} \times NYSE_i \\
&+ \gamma_3 \cdot \widetilde{\Delta OIB}_{i,d}^{3:55} + \gamma_4 \cdot \widetilde{\Delta OIB}_{i,d}^{3:55} \times NYSE_i \\
&+ \gamma V_{i,d} + \delta_{i,d} + \varepsilon_{i,d},
\end{aligned} \tag{2}
$$

where V is a vector of controls that includes standardized indicative paired volume just before 3:55pm and standardized change in indicative paired volume at 3:55pm, and δ is a set of stock and day fixed effects. In a second test, we regress the absolute closing price change on the standardized absolute auction statistics to determine if volatility in the auction statistics affects closing price volatility. For both regressions, we trim closing price changes in the upper and lower 1% of the closing price change distribution to account for large fundamental price movements that are unrelated to the auction feeds.

The results of the regression in equation (2) are reported in column (1) of Table 4. First, we find that $\widetilde{Near}_{3:55}$ and $\widetilde{\Delta Near}_{3:55}$ are both significant predictors of closing price changes on both NYSE and Nasdaq. However, the predictive power of $\widetilde{Near}_{3:55}$ for closing price changes is about 72% weaker for NYSE compared to Nasdaq, indicating that the NYSE near price is significantly less informative of the closing price due to delayed D-Orders. The near price change at 3:55pm, on the other hand, has some positive predictive power for the closing price on NYSE relative to Nasdaq, indicating that hidden D-Orders, once revealed, are also useful for predicting the closing price. In the same column, we also find that the predictive powers of $\widetilde{OIB}_{3:55}$ and $\widetilde{\Delta OIB}_{3:55}$ are weaker for Nasdaq compared to NYSE. These results suggest that imbalances on NYSE tend to persist until the closing auction clears (thereby pushing the closing auction price away from the continuous market price), while imbalances on Nasdaq tend to be less relevant for closing auction prices, likely because Nasdaq imbalances are already fairly small during the auction dissemination window. Furthermore, because NYSE floor brokers have near-exclusive access to the closing auction by 3:55pm, these results suggest that floor brokers are not sufficiently leaning against late imbalances. Finally, in column (2) of Table 4, we test the same regression model with absolute closing price changes and standardized measures of the four absolute closing auction statistics. Analogous to column (1), we find that abnormal near price volatility is most relevant to closing price change volatility on NYSE, while abnormal order imbalance volatility is most relevant to closing price change volatility on Nasdaq. The latter result suggests that large swings in order imbalances lead to large swings in realized closing prices, and further suggests that floor brokers insufficiently lean against unexpected imbalances and dampen closing price volatility.

In robustness tests, we use 3:55pm and 3:58pm as the reference prices for closing price changes on NYSE and Nasdaq, respectively. As discussed earlier, this allows for a more direct test of the delay hypothesis since MOC or LOC orders on Nasdaq cannot be entered after 3:58pm. Repeating the regression from column (1) of Table 4 with this alternative definition of closing price change, we obtain similar results, with pre-3:55pm near prices having more predictive power on Nasdaq compared to NYSE, and pre-3:55pm imbalances having more predictive power on NYSE compared to Nasdaq. These results are consistent with our previous findings and interpretation that D-Order delay is associated with inaccurate indicative auction prices and imbalances that persist into the close. Repeating the regression from column (2) of Table 4 with the alternative definition of closing price change, we also obtain similar results for absolute imbalances, in that larger absolute imbalances are associated with larger absolute closing price changes on NYSE. However, one difference is that the predictive power of the pre-3:55pm absolute near price for absolute closing price changes on NYSE is slightly stronger than Nasdaq, whereas before it was slightly weaker. We attribute this difference to the smaller time window over which closing price changes are measured in this alternative specification. Overall, our results indicate that D-Order delay on NYSE reduces the informativeness of indicative auction prices, and leads to persistent imbalances that produce larger price changes at the close.

Overall, our results suggest that order imbalance information matters for closing price changes on NYSE, while near price information does not matter as much. As we have shown in Figure 3, order imbalances on NYSE are large and persistent throughout the auction process, likely because trading interest from floor brokers alone is insufficient to minimize these imbalances. There is also no reason to expect that NYSE near prices accurately predict the closing price because floor broker orders are hidden from the auction feed until 3:55pm, and many other floor broker orders are delayed until the final minutes and seconds of the auction process. By contrast, Nasdaq matches and discloses orders from all traders at the same time, and imbalances are usually minimized within the first few seconds of the auction process. As a result, near prices on Nasdaq quickly reflect all available auction orders, and imbalances on Nasdaq provide no additional information. Our results also suggest that both hidden information and delayed orders on NYSE are relevant to closing prices and order imbalances. However, the efficiency of the closing price on NYSE depends crucially on whether the imbalances reflect the orders of informed traders or liquidity traders coalescing on one side of the market. Therefore, in the next section we examine subsequent reversals in price changes at the close to see whether closing prices on NYSE are more or less efficient than on Nasdaq.

6.3 Closing Price Efficiency

We have shown that Nasdaq consistently reports near prices that are close to the realized closing price, and order imbalances that are close to zero, suggesting that the indicative statistics reported by Nasdaq are fairly complete. By contrast, order imbalances on NYSE are large and persistent, even seconds before the auction clears, because D-Order users can cancel or modify their orders up until 3:59:59pm. However, it is important to note that a large imbalance does not necessarily imply that the closing price is inefficient if the imbalances are due to informed traders and not liquidity traders. Therefore, in this section, we test the efficiency of closing prices on NYSE relative to Nasdaq by examining overnight price reversals. In particular, we examine the relationship between the closing price change and subsequent overnight price change on NYSE versus Nasdaq. If the closing auction clears at an efficient price which incorporates all relevant information during the closing period, then we would expect no change in prices overnight, on average. However, if the auction tends to clear at an inefficient price due to imbalances from uninformed traders, then we would expect to observe overnight reversals of the closing price.

We test the following regression model to compare closing price efficiency on NYSE and Nasdaq:

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

where r^{cx} is the close-to-x percentage price change based on the closing price on day t and an observed price after the close that is based on either after-hours trading on day t or early-hours trading on day $t+1$. In particular, we use the following dependent variables in the above regression model to test the strength of closing price reversals on NYSE versus Nasdaq: the close-to-after hours volume weighted average price (VWAP) percentage price change (r^{ca}), the close-to-9:00am midquote percentage price change (r^{c900}), the close-to-9:15am midquote percentage price change (r^{c915}), and the close-to-opening auction percentage price change at 9:30am (r^{co}), where all percentage price changes are expressed in basis points.[17] Our main independent variable is r^{mc}, the 3:45pm midquote-to-close percentage price change (expressed in basis points), which spans the NYSE closing auction dissemination period of 3:45pm to 4:00pm. In our earlier tests, we focused on indicative auction statistics around 3:55pm because our goal was to test the effect of hidden D-Orders and delayed D-Orders on auction quality, and 3:55pm represents the time that D-Orders are included in the auction statistics. Here, our goal is to test for reversals in price changes at the close, which requires a reference price that is independent of the closing auction. We use 3:45pm as the reference time because this is the last time in the trading day before closing auction statistics are transmitted from either exchange. X represents the stock-day control variables used in our previous tests, after-hours trading volume, and the current intraday market return, and $\delta_{i,d}$ is a vector of stock and date fixed effects. Similar to our previous tests, r^{mc} and r^{cx} are trimmed at the upper and lower 1% of their distributions to account for large fundamental price movements that are unrelated to the auction process. 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.

The results of the reversal tests are reported in Panel A of Table 5. Across specifications, we find that subsequent reversals of closing price changes are stronger on NYSE than Nasdaq. In particular, column (1) shows that the average reversal in the closing price change is approximately 17% stronger on NYSE during after-hours trading (0.02/0.12), while columns (2) and (3) show that the average reversal in the closing price change is approximately 30% to 33% stronger on NYSE during the pre-opening session times of 9:00am and 9:15am of the following trading day, respectively. Finally, column (4) shows that the average reversal is approximately 22% stronger on NYSE at the opening auction of the following trading day (0.21/0.97). Taken together with

[17]We observe price reversals as soon as 4:30pm, but because not all stocks have trades within the first thirty minutes of the after-hours period, we opt to use all after-hours trades for sample consistency.

our findings from the previous section, our results suggest that excess order imbalances on NYSE contain no more information than those on Nasdaq.[18] Therefore, the imbalance-induced closing price changes documented in the previous section for NYSE are likely due to liquidity pressures that are not sufficiently met by floor brokers.

In Panel B of Table 5, we directly examine whether the stronger overnight reversals on NYSE are related to the order imbalances analyzed in the previous section. Hence, we augment Equation 3 with an indicator variable that equals one if the order imbalance level at 3:55pm (when D-Orders have been included in the auction statistics) has the same sign as the subsequent price change at the close, and interact this variable with $NYSE$, r^{mc}, and $NYSE \times r^{mc}$. Comparing column (4) of Panel A to column (1) of Panel B, we find that the stronger overnight price reversals on NYSE are explained entirely by the presence of persistent order imbalances. We also augment Equation 3 with an indicator variable which equals one if the order imbalance change at 3:55pm has the same sign as the subsequent price change at the close. We find in column (2) of Panel B that order imbalance change at 3:55pm (which represents the hidden D-Orders that are incorporated into the auction feed) has no statistically significant explanatory power for NYSE overnight reversals. Finally, in column (3) of Panel B, we include both the order imbalance level and change variables and find that only the order imbalance level explains the greater NYSE overnight reversals, which is consistent with our result in column (1). Overall, these results are consistent with our Hypothesis 2(b) that closing price efficiency on NYSE is worse because floor brokers delay their orders and do not sufficiently minimize order imbalances.

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 August 2022, there have been approximately 600 million reported cases worldwide

[18]We obtain a similar conclusion if we use 3:45pm as the reference price on NYSE and 3:50pm as the reference price on Nasdaq, when auction statistics are first disseminated on the respective exchanges. However, we use 3:45pm as the reference price for both exchanges in our main specifications because this allows us to compare closing price changes over the same time window of 15 minutes on both exchanges.

and one million deaths in the U.S. alone. The economic impact has also been enormous, with many businesses and entire states shutting down for months. As a result, financial markets have experienced drastic increases in volatility and declines in market value and liquidity. NYSE was also 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 completely halted the usage of D-Orders (which are designed to replicate traditional face-to-face interactions with floor brokers) on NYSE, providing a unique natural experiment to study closing auction market quality on NYSE without floor broker D-Orders.[19] 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 daily average pre-3:55pm paired volume ratio from February 19, 2020 to July 7, 2020 on NYSE versus Nasdaq. The daily averages are entropy balance-weighted so that the daily volume and percentage effective spread distributions for the treated NYSE stocks and control Nasdaq stocks are similar (based on observations outside of the floor closure period). As we have already seen, pre-3:55pm indicative auction statistics on NYSE are significantly off from their realized values at 4:00pm because D-Orders are hidden from the auction feeds, and additional D-Orders have yet to arrive. Hidden D-Order volume is also maximized just before 3:55pm due to the ongoing accumulation of hidden D-Orders. Therefore, we test whether the floor closure makes the auction feeds more informative using pre-3:55pm auction statistics. Figure 4 indicates that the average pre-3:55pm paired volume ratio on NYSE hovers around 56% for most of February and

[19]In supporting tests, we find that the floor closure did not affect trading volume or the proportion of odd lot volume on NYSE relative to Nasdaq. Therefore, the floor closure is likely to affect auction quality through the D-Order channel, and not through alternative channels such as trader composition.

March, and then suddenly jumps to about 82% starting on March 23, which is now comparable to the paired volume ratio on Nasdaq at this time. The ratio then remains at approximately that level until the floor reopens on May 26. After that, the ratio jumps back to the pre-closure level of about 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 larger percentage of orders were being matched earlier in the auction process on NYSE during the floor closure.[20]

We also test the effect of the NYSE floor closure and subsequent reopening on the pre-3:55pm paired volume ratio, near price difference, and imbalance ratio in a multivariate regression framework with entropy balance weights to account for differences in the spread and volume distributions for NYSE and Nasdaq. The key independent variables are $NYSE \times Closure$, where $Closure$ is an indicator variable that equals one if the closing auction occurs on or after March 23, 2020, and $NYSE \times Reopen$, where $Reopen$ is an indicator variable that equals one if the closing auction occurs on or after May 26, 2020. (The standalone $Closure$ and $Reopen$ indicator variables are absorbed by the date fixed effects.) $NYSE \times Closure$ and $NYSE \times Reopen$ represent the relative effects of the floor closure and subsequent reopening on the treatment group of NYSE stocks relative to the control group of Nasdaq stocks.

The results of these regression tests are reported in Table 6. In column (1) of Panel A, we show that the pre-3:55pm paired volume ratio on NYSE increases by about 23.2 percentage points during the floor closure, and subsequently reverts by about 20.6 percentage points after the

[20]Figure 4 also indicates a partial increase in pre-3:55pm matched volume immediately prior to the NYSE floor closure. In particular, for three of the pre-closure days, the NYSE paired volume ratio is slightly larger than and statistically significant from the pre-closure average. One possible reason for this increase is that the COVID-19 pandemic reduced the presence of some floor traders, even prior to the official floor closure. As a result, some investors may have substituted D-Orders for MOC orders. However, the structural break on March 23, 2020 indicates that the floor closure was directly responsible for most of the changes in order submission behavior and the paired volume ratio. The second structural break on May 26, 2020, the day that the floor re-opened, further suggests that the floor closure directly caused these changes, and that the NYSE paired volume ratio would not have reached the level of the Nasdaq paired volume ratio without the floor closure. Supremum Wald tests also indicate that the structural breaks for NYSE occur exactly on March 23, 2020 and May 26, 2020, with associated p-values of 0.000 for each of the dates.

reopening, corroborating our evidence from Figure 4. After the floor reopens, the NYSE paired volume ratio remains about 2.6 percentage points higher than the pre-closure period, suggesting that the pandemic may have continued to have a small effect on floor trading operations and order submission behavior. Column (2) of Panel A examines the effect of $Closure$ and $Reopen$ on the near price difference. Following the floor closure, the near price difference on NYSE decreases by 99.5 basis points (relative to the pre-closure average of 342 basis points for NYSE), and then increases by 82.1 basis points after the floor reopens. Finally, in column (3) of Panel A, we show that the imbalance ratio decreases by about 12.8 percentage points after the floor closure on NYSE relative to Nasdaq, and then increases by 11.8 percentage points after the floor reopens, further suggesting that the floor closure reduced order imbalances on NYSE. (Partial F-tests also indicate that the effects of the floor closure on the NYSE near price difference and imbalance ratio are not statistically different from the effects of the floor reopening.) When we run these regressions without date fixed effects, we do not find economically significant changes in the auction statistics on Nasdaq, which is consistent with the shock being specific to the NYSE trading floor.

Finally, we test the effect of the NYSE floor closure and subsequent reopening on closing price efficiency. Similar to our tests in Panel A of Table 5, we examine price reversals on NYSE versus Nasdaq using several post-auction time windows. In column (1) of Table 6, Panel B, we find that the average reversal in the after-hours market for NYSE relative to Nasdaq is significantly weaker during the floor closure, indicating an improvement in NYSE closing price efficiency. In columns (2) and (3), we test for changes in reversals during the floor closure and subsequent reopening using the quote midpoint prices at 9:00am and 9:15am, respectively, to calculate the overnight percentage price change. Similar to column (1), we find that the NYSE reversal becomes weaker during the closure, and then becomes stronger after the floor reopens. Finally, in column (4), we test for changes in reversals during the floor closure and subsequent reopening using the opening auction price at 9:30am to calculate the overnight percentage price change. Similar to the previous columns, we find that the NYSE reversal weakens during the floor closure, and then gets stronger again after the floor reopens.[21] Overall, our evidence indicates that closing price efficiency improved on NYSE relative to Nasdaq during the floor closure amid the early days of the COVID-19 pandemic.

8 Closing Auction Resiliency

We have shown that the quality of closing auction feeds and the efficiency of closing prices are worse on NYSE compared to Nasdaq because of differences in the design of the closing auction process, particularly the non-disclosure of floor broker orders before 3:55pm, and the ability of floor brokers to delay additional orders until the final minutes and seconds of the trading day. The pre-3:55pm auction feeds on NYSE are especially inaccurate because the auction statistics only reflect the orders from passive investors who require execution at the closing price and thus tend to submit price-insensitive MOC orders. In this last section, we test the resiliency of the NYSE and Nasdaq auction mechanisms by exploring how closing auction market quality is affected by shocks to demand from passive investors for closing auction liquidity on NYSE relative to Nasdaq.

8.1 Auction Quality Over Time

The importance of closing auctions has only increased over time. According to Figure 5, 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. The trends are similar for NYSE and Nasdaq-listed securities, suggesting that the increasing demand for closing auction liquidity is not specific to either exchange. Some attribute the overall upward trend to the rise of passive investment funds (WSJ, 2019b; Bogousslavsky and Muravyev, 2022), 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 average pre-3:55pm

[21] The negative coefficient on $NYSE \times r^{mc}$ in each of our four specifications suggests that NYSE reversals were also stronger than Nasdaq reversals in the month prior to the closure, which is consistent with the evidence from our main sample period. However, for each of our specifications, the negative coefficient on $NYSE \times r^{mc}$ is statistically insignificant. The lack of significance is possibly due to the extreme volatility brought on by the COVID-19 pandemic before the NYSE floor closure. However, even with this volatility, it is notable that there are statistically significant changes in the strength of overnight price reversals on NYSE after the floor closure and subsequent reopening.

near price difference on NYSE. In particular, we find that the average near price difference has increased from about 40 basis points in 2011 to 265 basis points in 2018. By contrast, the average near price difference on Nasdaq has remained below 25 basis points for the entire sample period. Although we make no causal claims from this evidence, the correlation between closing auction volume and the average near price difference on NYSE (but not Nasdaq) is notable. 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.

We also formally test for divergence in near price differences on NYSE versus Nasdaq over time. In particular, we test a multivariate regression model with the near price difference as the dependent variable and $NYSE$, $NYSE \times MidPeriod$, and $NYSE \times LatePeriod$ as the key independent variables. As in the previous section, we focus on the pre-3:55pm near price difference, when indicative auction information reported by NYSE is especially incomplete due to the accumulation of hidden D-Orders. $MidPeriod$ is an indicator variable that equals one if the closing auction took place from January 2014 to June 2016, and $LatePeriod$ 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 vector of liquidity control variables X from our previous regressions. The results of this regression are reported in Table 7, and are largely consistent with the graphical results in Figure 5. 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, 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 the indicative closing auction price 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 passive 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 20 trading day observations at 3:54:55pm. We test the effect of $Z(Volume)$ on the near price difference for NYSE versus Nasdaq to determine the resiliency of indicative auction prices to passive investor demand shocks under different closing auction structures.

Table 8 presents the results of our regression tests of the near price difference on $Z(Volume)$ and $Z(Volume) \times NYSE$. According to column (1), the unconditional near price difference on NYSE is about 111 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 8 basis points higher for every unit increase in $Z(Volume)$ on NYSE. In other words, the near price is about 7% less accurate (8 basis points divided by 111 basis points) 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 shocks to passive 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 run in contrast to our prediction that closing auction market quality on NYSE is worse when there is greater demand for closing auction liquidity from passive investors. We examine two recurring events characterized by market turbulence brought on by high liquidity demand from passive 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 (Etula, Rinne, Suominen, and Vaittinen, 2020). Triple witching days are relevant for our study because they generate some of the largest closing auction volumes of the year, second only to Russell rebalance days (Nasdaq, 2020).[22] 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 high-volume auctions are less frequent.

We use triple witching days as instruments for passive investor trading interest to identify the resiliency of closing auctions to liquidity demand shocks on NYSE and Nasdaq. In particular, we test the following instrumental variables (IV) regression model:

$$\begin{aligned}
\text{1}^{\text{st}}\text{ Stage:}\quad & NYSE_i \times Z(Vol)_{i,d} = \psi_1 \cdot NYSE_i \times Witch_d + \psi_2 \cdot Witch_d + \gamma_1 X_{i,d-1} + \varepsilon_{i,d} \\
& Z(Vol)_{i,d} = \lambda_1 \cdot NYSE_d \times Witch_d + \lambda_2 \cdot Witch_d + \gamma_2 X_{i,d-1} + e_{i,d} \\
\text{2}^{\text{nd}}\text{ Stage:}\quad & |r_{i,d}| = \beta_1 \cdot NYS\widehat{E_d \times Z(V}ol)_{i,d} + \beta_2 \cdot \widehat{Z(Vol)_{i,d}} + \gamma_3 X_{i,d-1} + u_{i,d}.
\end{aligned}$$

In the above set of equations, $|r_{i,d}|$ is the 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 represent the same set of liquidity control variables and stock and date 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 near price difference is affected by abnormal indicative matched volume induced by triple witching days.

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

Panel A of Table 9 presents the results from the above IV regression model. The first-stage regressions in columns (1) and (2) show that indicative matched volume is 3.7 standard deviations higher on NYSE and 3.5 standard deviations higher on Nasdaq. Importantly, in the second stage regression, we find that a unit increase in $Z(Volume)$ induced by triple-witching days increases the near price difference by 13.4 basis points on NYSE relative to Nasdaq, and only 1.7 basis points on Nasdaq. Thus, our IV regression indicates that an increase in auction volume from passive investors is associated with less accurate indicative closing auction prices on NYSE, thereby suggesting that NYSE closing auctions are less resilient to liquidity demand shocks than Nasdaq.

Panel B of Table 9 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 passive 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 1.8 standard deviations on NYSE and 1.5 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 near price difference by 22.6 basis points on NYSE relative to Nasdaq, but only 3.9 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 passive investors.

9 Conclusion

Closing auctions have become increasingly important events 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 affect the accuracy of auction information and the efficiency of the closing price. We show that indicative closing auction statistics on NYSE are significantly less accurate than Nasdaq. When floor brokers' D-Orders are incorporated into the close at 3:55pm, we document large changes in indicative auction prices, matched volume, and order imbalances, highlighting a large discrepancy between observed and true auction demand before 3:55pm. However, even after D-Orders are disclosed at 3:55pm, NYSE auction statistics still remain inaccurate compared to Nasdaq because floor brokers can and do delay finalizing their orders until the last minutes and seconds of the submission window. By contrast, the indicative closing auction statistics reported by Nasdaq converge almost immediately to their eventual realized values at 4:00pm. We further show that these auction statistics matter for the execution outcomes of passive funds and other investors that need to trade at the closing price, and that closing price inefficiencies, as measured by the strength of overnight price reversals, are greater on NYSE. The stronger overnight reversals on NYSE are explained by persistent order imbalances after 3:55pm. Therefore, while floor brokers and their clients are given more flexibility to trade late in the auction process, this comes at a cost of reduced price efficiency and large order imbalances that are unmet by floor brokers. Finally, we find that closing auction quality on NYSE actually improved when NYSE closed its trading floor during the COVID-19 pandemic, suggesting that a level playing field for all auction participants may promote more accurate auction information and, perhaps most importantly, greater price efficiency. Currently, last-mover advantages for a subset of auction participants such as floor brokers, specialists, or dealers still exist around the globe in a variety of asset classes such as cash equities, commodities, and fixed income securities. Exchange operators or regulators that want to maximize price efficiency and minimize information asymmetries may want to review exchange rules which provide such advantages to a select group of auction participants.

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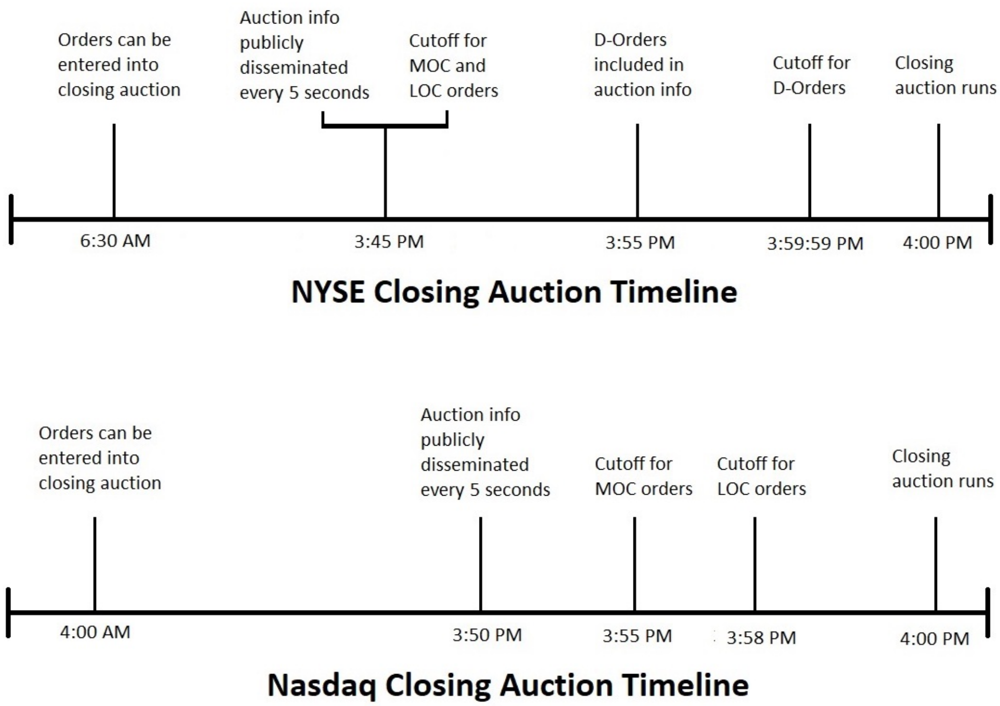

Figure 1: Closing Auction Timelines for NYSE and Nasdaq. The closing auction timelines for NYSE and Nasdaq are presented in the upper and lower halves of the figure, respectively.

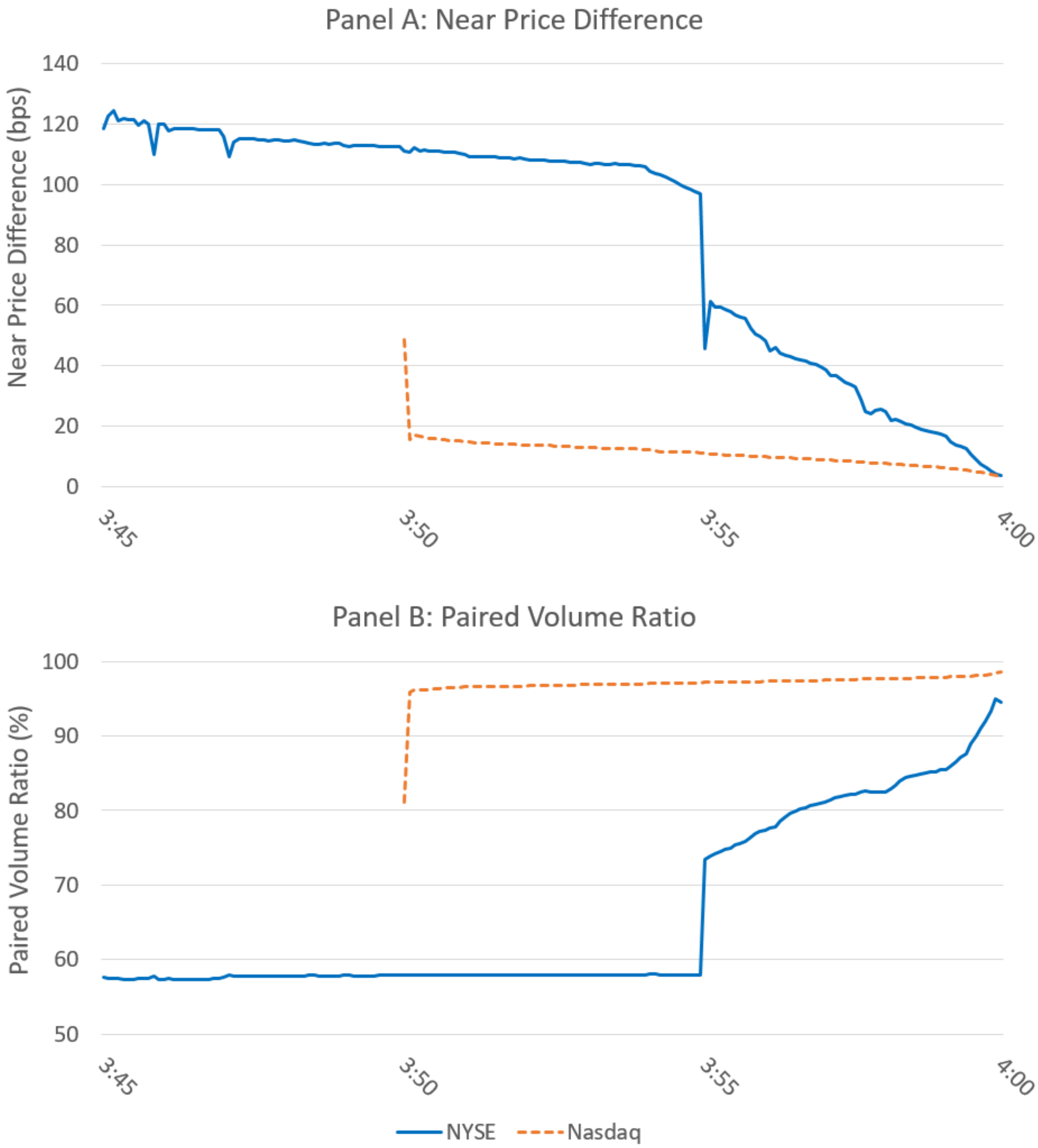

Figure 2: Evolution of Near Price Difference and Paired Volume Ratio on NYSE and Nasdaq. Panel A reports the equal-weighted average near price difference (in basis points) over time for NYSE and Nasdaq. Panel B reports the equal-weighted average paired volume ratio (in percentage points) over time for NYSE and Nasdaq. D-Orders are included in the near price and paired volume statistics starting at 3:55pm.

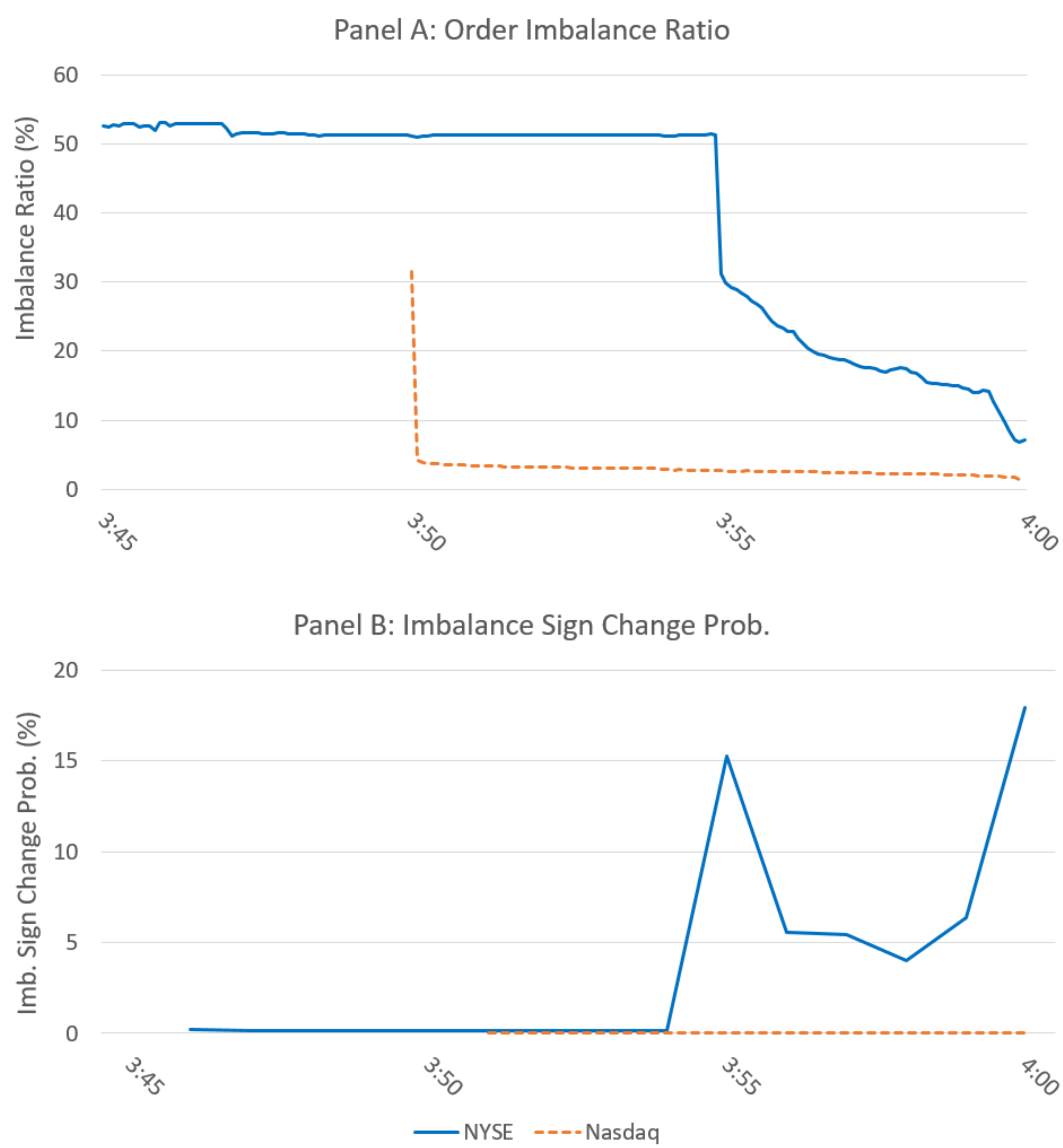

Figure 3: Evolution of Order Imbalance on NYSE and Nasdaq. Panel A reports the equal-weighted average imbalance ratio (in percentage points) over time for NYSE and Nasdaq. Panel B reports the probability of an order imbalance sign change over time for NYSE and Nasdaq. D-Orders are included in the order imbalance and paired volume statistics starting at 3:55pm.

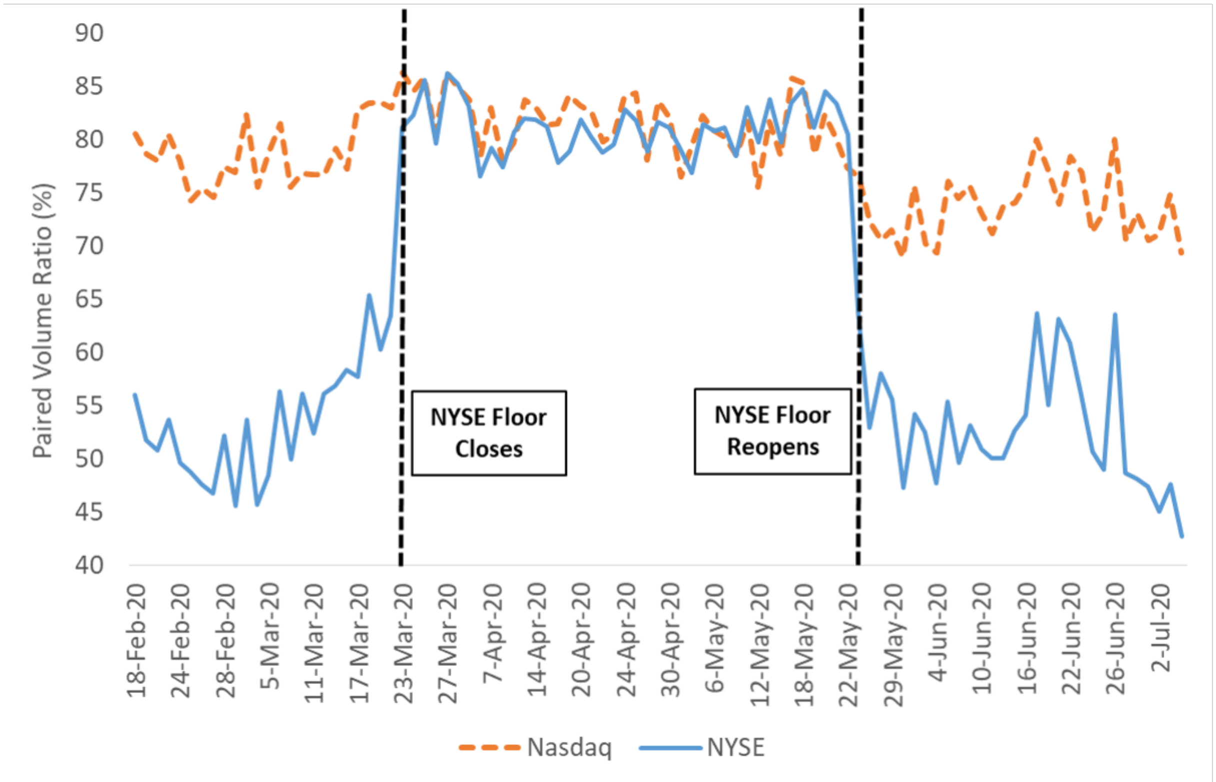

Figure 4: Paired Volume Ratio around COVID-19 NYSE Floor Closure. This figure reports estimates of the entropy balance-weighted average paired volume ratio around the NYSE floor closure caused by the COVID-19 pandemic. During our 2020 sample period, NYSE closed their trading floor and went fully electronic 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.

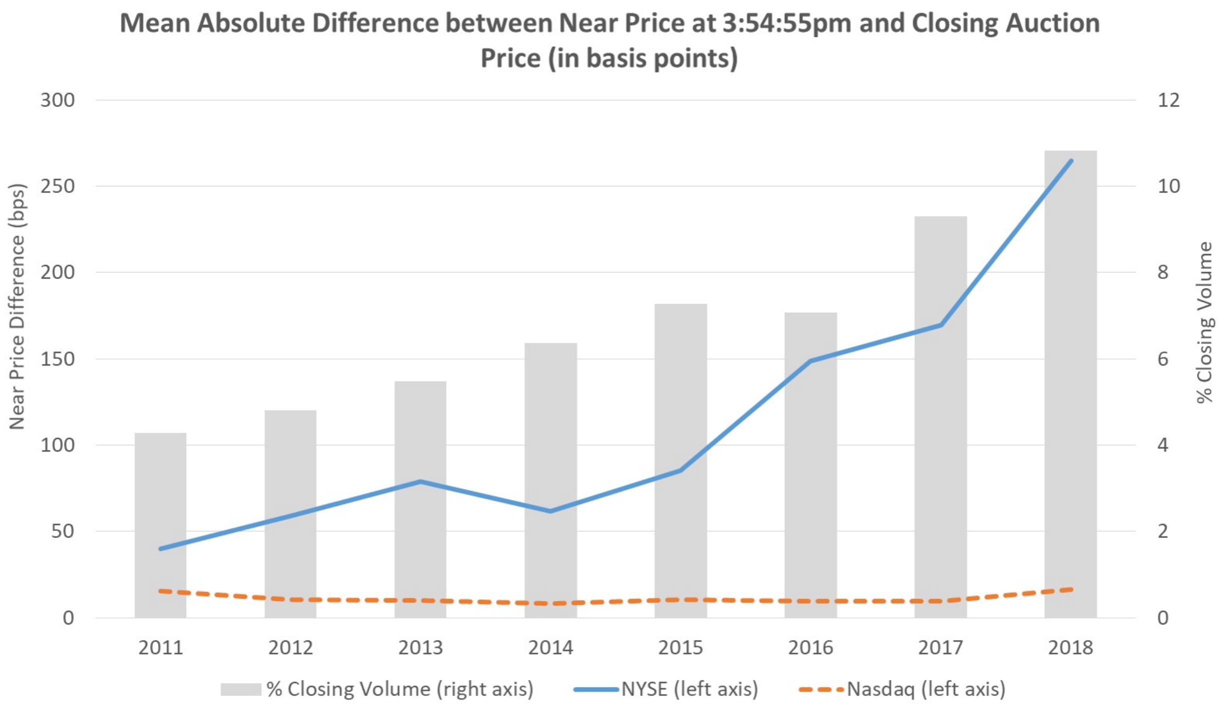

Figure 5: Average Near Price Difference on NYSE and Nasdaq by Year. This figure reports the equal-weighted average near price difference (in basis points) for NYSE and Nasdaq during each year of our sample period. D-Orders are included in the near price calculation starting at 3:55pm. The left y-axis represents the average near price difference for NYSE and Nasdaq. The right y-axis represents total closing auction volume as a percentage of all trading volume.

Table 1:
Stock-Level Summary Statistics for NYSE and Nasdaq Stocks.
Panels A and B report summary statistics for NYSE and Nasdaq stocks. % Close Volume is the ratio of volume in the closing auction to daily volume (multiplied by 100). Close Price is the closing price determined in the closing auction at 4:00pm. Eff. Spread ($) is the stock-day average dollar effective spread, where dollar effective spread is twice the absolute difference between the transaction price and the national best bid and offer (NBBO) midpoint. Eff. Spread (bps) is the stock-day average ratio of the effective spread to the NBBO midpoint, measured in basis points. Lambda is the stock-day coefficient resulting from a regression of transaction-level price change on signed order imbalance. Intraday Volatility is a stock-day measure of midpoint return volatility. Market Cap ($B) is the closing stock price multiplied by the number of shares outstanding. Abs. Open-Close Return is the absolute percentage difference between the tomorrow's opening price and today's closing price (expressed in basis points).

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 10^9$)	5.283	3.043	0.520	1.493	5.696	15.41	11.16
Market Cap ($B)	35.2	17.0	4.5	9.7	35.1	152.6	51.5
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 10^9$)	7.150	3.878	0.513	1.935	7.518	22.34	13.82
Market Cap ($B)	42.9	15.7	4.4	9.3	35.6	152.9	91.3
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 price. Near price difference is the absolute percentage difference between the near price and the realized closing auction price (expressed in basis points). Δ represents the change in the auction statistic in the current time period relative to the auction statistic reported five seconds earlier. Paired volume is the number of shares that would match at the current reference price. Paired volume ratio is the ratio of indicative closing auction volume to realized closing auction volume (multiplied by 100). Order imbalance is the signed share imbalance if the auction were to clear at the current reference price. Imbalance ratio is the ratio of absolute indicative order imbalance to indicative paired volume (multiplied by 100). Order imbalance sign change is the percentage of stock-days in which order imbalance switches signs. For the difference columns, ***, **, 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)
ΔNear Price Difference (bps)	4.99	56.29	51.31***
Paired Volume ($M)	8.49	10.43	1.93***
Paired Volume Ratio (%)	57.58	73.22	15.64***
ΔPaired Volume Ratio	0.04	14.85	14.82***
|Order Imbalance| ($M)	3.04	2.33	-0.71***
|Imbalance Ratio| (%)	51.86	31.10	-20.76***
|ΔImbalance Ratio|	0.22	28.33	28.10***
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)
ΔNear Price Difference (bps)	0.78	1.07	0.29***	51.02***
Paired Volume ($M)	16.66	16.68	0.02	1.91***
Paired Volume Ratio (%)	97.52	97.61	0.09***	15.55***
ΔPaired Volume Ratio	0.06	0.15	0.09***	14.73***
|Order Imbalance| ($M)	0.40	0.36	-0.04***	-0.66***
|Imbalance Ratio| (%)	2.48	2.39	-0.10***	-20.67***
|ΔImbalance Ratio|	0.10	0.20	0.10***	28.00***
Imbalance Sign Change (%)	0.00	0.01	0.01	14.71***

Table 3:
Indicative Auction Statistic Accuracy on NYSE versus Nasdaq.
This table reports the near price difference, paired volume ratio, imbalance ratio, and imbalance sign change probability on NYSE relative to Nasdaq at different times during the closing auction period. Near price difference is the absolute percentage difference between the near price and the realized closing auction price (expressed in basis points). Paired volume ratio is the ratio of indicative matched volume to realized closing auction volume (multiplied by 100). Imbalance ratio is the ratio of absolute indicative order imbalance to indicative paired volume (multiplied by 100). Imbalance sign change is an indicator variable that equals one if the sign of the order imbalance changed relative to the previous minute. D-Orders are incorporated into the auction statistics at 3:55pm. Standard errors are clustered by symbol. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

	Near Price Difference	Paired Vol. Ratio	Imbalance Ratio	Imb. Sign Change
	(1)	(2)	(3)	(4)
$NYSE \times \mathbb{1}^{3:54}$	87.34***	-38.91***	48.39***	0.00130***
	(66.12)	(-181.31)	(97.08)	(17.78)
$NYSE \times \mathbb{1}^{3:55}$	32.27***	-23.48***	27.86***	0.126***
	(59.98)	(-120.10)	(97.88)	(107.33)
$NYSE \times \mathbb{1}^{4:00}$	0.954***	-4.017***	5.842***	0.160***
	(15.17)	(-25.27)	(39.90)	(80.74)
$NYSE \times (\mathbb{1}^{3:55} - \mathbb{1}^{3:54})$	-55.08***	15.43***	-20.53***	0.125***
	(-57.20)	(172.24)	(-70.17)	(106.83)
N	6,378,107	6,378,107	6,378,107	6,120,200
Adj. R^2	0.136	0.615	0.266	0.072

Table 4:
Indicative Auction Statistics and Closing Price Changes.
This table reports the predictability of closing price changes on NYSE versus Nasdaq. The closing price change is calculated as the percentage difference between the 4:00pm closing price and the midquote at 3:55pm (expressed in basis points). $Near$ is the percentage difference between the near price and midquote price just before 3:55pm (expressed in basis points), and $\Delta Near$ is the change in $Near$ at 3:55pm after D-Orders are incorporated into the auction statistics. OIB is the signed indicative order imbalance just before 3:55pm, and ΔOIB is the change in OIB at 3:55pm after D-Orders are incorporated into the auction statistics. All four variables are standardized by subtracting the rolling 20-day mean and dividing the difference by the rolling 20-day standard deviation (standardization is denoted by the tilde symbol above the variable name). In each specification, we control for standardized indicative paired volume just before 3:55pm and change in indicative paired volume at 3:55pm, and we include symbol and date fixed effects. Standard errors are clustered by symbol. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

	$y = r^{355c}$ (1)		$y = \lvert r^{355c} \rvert$ (2)
$\widetilde{Near}_{3:55}$	1.396***	$\lvert\widetilde{Near}\rvert_{3:55}$	0.206***
	(24.70)		(9.00)
$NYSE \times \widetilde{Near}_{3:55}$	-1.012***	$NYSE \times \lvert\widetilde{Near}\rvert_{3:55}$	-0.059***
	(-15.85)		(-2.23)
$\widetilde{\Delta Near}_{3:55}$	-0.045*	$\lvert\widetilde{\Delta Near}\rvert_{3:55}$	-0.038***
	(-1.95)		(-2.75)
$NYSE \times \widetilde{\Delta Near}_{3:55}$	0.086***	$NYSE \times \lvert\widetilde{\Delta Near}\rvert_{3:55}$	0.042**
	(2.82)		(2.41)
$\widetilde{OIB}_{3:55}$	-0.184***	$\lvert\widetilde{OIB}\rvert_{3:55}$	-0.095***
	(-3.88)		(-4.27)
$NYSE \times \widetilde{OIB}_{3:55}$	0.976***	$NYSE \times \lvert\widetilde{OIB}\rvert_{3:55}$	0.309***
	(15.88)		(10.50)
$\widetilde{\Delta OIB}_{3:55}$	0.114***	$\lvert\widetilde{\Delta OIB}\rvert_{3:55}$	-0.056*
	(3.03)		(-1.85)
$NYSE \times \widetilde{\Delta OIB}_{3:55}$	0.410***	$NYSE \times \lvert\widetilde{\Delta OIB}\rvert_{3:55}$	0.195***
	(9.17)		(5.88)
Controls	Yes	Controls	Yes
Fixed Effects	Symbol, Date	Fixed Effects	Symbol, Date
N	478,834	N	473,695
Adj. R^2	0.424	Adj. R^2	0.302

Table 5:
Closing Price Reversals on NYSE versus Nasdaq.
Panel A reports the magnitude of subsequent reversals in the closing price on NYSE relative to Nasdaq. r^{mc} is the percentage difference between the closing price and the midquote price at 3:45pm (expressed in basis points), when closing auction statistics are first publicly disseminated. The dependent variable for each respective column is the percentage difference between the after-hours volume-weighted average price and the current closing price (r^{ca}), the percentage difference between the next-day midquote price at 9:00am and the current closing price (r^{c900}), the percentage difference between the next-day midquote price at 9:15am and the current closing price (r^{c915}), and the percentage difference between the next-day opening auction price and the current closing price (r^{co}) (all of which are expressed in basis points). Panel B reports the magnitude of reversals in the closing price on NYSE relative to Nasdaq as a function of indicative order imbalance at 3:55pm. $\mathbb{1}_{\{OIB \times r>0\}}$ ($\mathbb{1}_{\{\Delta OIB \times r>0\}}$) is an indicator variable that equals one if the indicative order imbalance level (change) at 3:55pm and subsequent price movement in the closing auction have the same sign. For each specification, we control for the previous day's dollar volume, dollar effective spread, intraday midpoint return volatility, and Kyle's lambda, the current day intraday market return, and the after-hours dollar trading volume. Standard errors are clustered by symbol. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Overnight Reversals

	r^{ca}	r^{c900}	r^{c915}	r^{co}
	(1)	(2)	(3)	(4)
r^{mc}	-0.120***	-0.142***	-0.144***	-0.0967***
	(-28.22)	(-7.48)	(-7.67)	(-13.08)
$NYSE \times r^{mc}$	-0.0201***	-0.0447*	-0.0470**	-0.0210**
	(-3.81)	(-1.86)	(-2.05)	(-2.50)
Controls	Yes	Yes	Yes	Yes
Fixed Effects	Symbol, Date	Symbol, Date	Symbol, Date	Symbol, Date
N	563,913	474,027	481,465	566,133
Adj. R^2	0.278	0.211	0.203	0.473

Panel B: Overnight Reversals and Indicative Order Imbalances

	(1) r^{co}	(2) r^{co}	(3) r^{co}
r^{mc}	-0.0977***	-0.0921***	-0.0963***
	(-12.45)	(-11.65)	(-11.93)
$NYSE \times r^{mc}$	-0.00337	-0.0213**	-0.00299
	(-0.32)	(-2.11)	(-0.24)
$NYSE \times r^{mc} \times \mathbb{1}_{\{OIB \times r>0\}}$	-0.0366**		-0.0376**
	(-2.00)		(-2.02)
$r^{mc} \times \mathbb{1}_{\{OIB \times r>0\}}$	0.0169		0.0175
	(1.07)		(1.09)
$NYSE \times r^{mc} \times \mathbb{1}_{\{\Delta OIB \times r>0\}}$		0.0178	0.0160
		(0.62)	(0.55)
$r^{mc} \times \mathbb{1}_{\{\Delta OIB \times r>0\}}$		-0.0179	-0.0191
		(-0.67)	(-0.71)
Controls	Yes	Yes	Yes
Fixed Effects	Symbol, Date	Symbol, Date	Symbol, Date
N	559,481	559,481	559,481
Adj. R^2	0.472	0.472	0.472

Table 6:
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. 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, near price difference, and imbalance ratio just before 3:55pm for NYSE versus Nasdaq. Paired Volume Ratio is the ratio of indicative matched volume to final closing auction volume (multiplied by 100). Near Price Difference is the absolute percentage difference between the near price and the final closing auction price (expressed in basis points). Imbalance Ratio is the ratio of absolute indicative order imbalance to paired volume (multiplied by 100). In Panel B, we examine overnight price change reversals. r^{ca} (r^{co}) is the percentage difference between the after-hours VWAP price (next-day opening auction price) and today's closing price (expressed in basis points). r^{c900} (r^{c915}) is the percentage difference between the next day's midquote price and today's closing price at 9:00am (9:15am) (expressed in basis points). Standard errors are clustered by symbol. 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)
$NYSE \times Closure$	23.15***	-99.48***	-12.75***
	(66.12)	(-12.04)	(-17.29)
$NYSE \times Reopen$	-20.56***	82.08***	11.77***
	(-35.49)	(8.31)	(9.59)
$NYSE \times (Closure + Reopen)$	2.590***	-17.40	-0.975
	(3.91)	(-1.46)	(-0.72)
Controls	Yes	Yes	Yes
Fixed Effects	Symbol, Date	Symbol, Date	Symbol, Date
N	40,286	36,872	40,657
Adj. R^2	0.520	0.241	0.215

Panel B: COVID-19 Closing Price Efficiency Regressions

	r^{ca} (1)	r^{c900} (2)	r^{c915} (3)	r^{co} (4)
r^{mc}	-0.0268***	-0.0693	-0.115*	-0.138***
	(-4.33)	(-1.05)	(-1.95)	(-3.00)
$NYSE \times Closure \times r^{mc}$	0.0188***	0.205**	0.138*	0.123**
	(2.81)	(2.47)	(1.79)	(2.05)
$NYSE \times Reopen \times r^{mc}$	-0.0479***	-0.604***	-0.480***	-0.570***
	(-3.90)	(-3.45)	(-2.82)	(-4.25)
$NYSE \times r^{mc}$	-0.0072	-0.0891	-0.0464	-0.0181
	(-1.23)	(-1.49)	(-0.83)	(-0.42)
$Closure \times r^{mc}$	-0.0019***	-0.153*	-0.0557	-0.0436
	(-0.25)	(-1.82)	(-0.72)	(-0.71)
$Reopen \times r^{mc}$	0.0190***	0.262	0.104	0.0095
	(2.79)	(1.61)	(0.69)	(0.08)
Controls	Yes	Yes	Yes	Yes
Fixed Effects	Symbol, Date	Symbol, Date	Symbol, Date	Symbol, Date
N	35,557	28,158	28,612	35,968
Adj. R^2	0.088	0.622	0.629	0.727

Table 7:
Near Price Difference at 3:54:55pm over Time.
This table reports the average near price difference on NYSE versus Nasdaq during different time periods. $MidPeriod$ ($LatePeriod$) is an indicator variable representing the period from January 2014 to June 2016 (July 2016 to the end of 2018). Near Price Difference is the percentage difference between the near price and the final closing auction price (expressed in basis points). D-Orders are included in the near price starting at 3:55pm. Standard errors are clustered by symbol. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Near Price Difference at 3:54:55pm (bps)			
	(1)	(2)	(3)
$NYSE$	51.87***	54.16***	54.76***
	(44.97)	(39.79)	(7.04)
$NYSE \times MidPeriod$	12.67***	13.18***	7.969***
	(8.78)	(8.75)	(4.86)
$NYSE \times LatePeriod$	151.3***	151.1***	137.3***
	(55.25)	(54.74)	(45.01)
$MidPeriod$	-0.567***	-1.589***	
	(-3.58)	(-3.59)	
$LatePeriod$	1.452***	0.675	
	(6.19)	(1.04)	
$log(Dayvol)$		7.176***	9.122***
		(9.24)	(9.26)
$Volatility$		-0.0218***	-0.0202***
		(-5.67)	(-5.00)
$ESpread$		2.357***	2.160***
		(6.24)	(4.72)
$Lambda$		-1.098	0.968
		(-1.38)	(1.37)
Fixed Effects	None	None	Symbol, Date
N	556,424	555,505	555,505
Adj. R^2	0.162	0.163	0.204

Table 8:
Near Price Difference at 3:54:55pm and Abnormal Matched Volume.
This table reports the effect of abnormal indicative matched volume on near price difference. Near price difference is the percentage difference between the near price and the final closing auction price (expressed in basis points). D-Orders are included in the near price starting at 3:55pm. $Z(Volume)$ 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 20 trading days within each stock. Standard errors are clustered by symbol. t-statistics are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Near Price Difference at 3:54:55pm (bps)

	(1)	(2)	(3)
$NYSE \times Z(Volume)$	7.15***	7,17***	6.83***
	(18.66)	(18.67)	(16.93)
$Z(Volume)$	1.07***	0.81***	-2.23***
	(25.84)	(15.18)	(-11.58)
$NYSE$	110.9***	113.1***	126.3***
	(69.75)	(60.6)	(9.27)
$log(Dayvol)$		10.51***	6.12***
		(8.74)	(3.53)
$Volatility$		-0.012**	-0.026***
		(-2.39)	(-3.81)
$ESpread$		0.920*	2.98***
		(1.81)	(3.55)
$Lambda$		-16.71***	0.158
		(-11.80)	(0.18)
Fixed Effects	None	None	Symbol, Date
N	543,631	543,152	543,151
Adj. R^2	0.0755	0.0802	0.188

Table 9:
IV Regression of Near Price Difference at 3:54:55pm on Abnormal Volume.
Panel A reports the effect of abnormal indicative matched volume on near price difference, where abnormal indicative matched volume is instrumented on "triple-witching" days ($Witch$). Panel B reports the same effect, except that abnormal indicative matched volume is instrumented on the last trading day of each month ($LastDay$). The two first-stage regressions are reported in the first two regression columns. The second-stage regression is reported in the last regression column. Near price difference is the percentage difference between the near price and the final closing auction price (expressed in basis points). $Z(Volume)$ 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 20 trading days within each stock. Standard errors are clustered by symbol. 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
	$x = NYSE \times Z(Vol.)$	$x = Z(Volume)$	$y = Near\ Price\ Diff$
$NYSE \times Witch$	3.699***	0.207***	
	(88.45)	(2.77)	
$Witch$	0.004	3.495***	
	(0.90)	(56.55)	
$NYSE \widehat{\times Z(Volume})$			13.35***
			(11.34)
$Z(\widehat{Volume})$			1.690***
			(7.53)
$log(Dayvol)$	0.080***	0.125***	25.47***
	(17.76)	(29.11)	(12.24)
$Volatility$	-0.0001***	-0.0001***	-0.0182**
	(-5.94)	(-4.07)	(-2.52)
$ESpread$	0.014***	0.019***	1.857**
	(7.44)	(8.54)	(2.07)
$Lambda$	0.011***	0.017**	-12.77***
	(2.99)	(3.78)	(-9.90)
Fixed Effects	Symbol	Symbol	Symbol
N	543,151	543,151	543,151

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

	First Stage (1)	First Stage (2)	Second Stage
	$x = NYSE \times Z(Vol.)$	$x = Z(Volume)$	$y = Near\ Price\ Diff$
$NYSE \times LastDay$	1.800***	0.319***	
	(89.85)	(8.63)	
$LastDay$	0.0062***	1.490***	
	(5.31)	(47.88)	
$NYSE \times \widehat{Z(Volume)}$			22.63***
			(19.87)
$\widehat{Z(Volume)}$			3.900***
			(11.05)
$log(Dayvol)$	0.095***	0.145***	24.43***
	(18.76)	(30.40)	(11.95)
$Volatility$	-0.0001***	-0.0001***	-0.017**
	(-5.16)	(-3.43)	(-2.37)
$ESpread$	0.012***	0.015***	1.693*
	(7.19)	(8.04)	(1.90)
$Lambda$	0.022***	0.030***	-12.95***
	(5.90)	(6.76)	(-9.98)
Fixed Effects	Symbol	Symbol	Symbol
N	543,151	543,151	543,151