COVID-19 and the Stock Market: Liquidity, Pricing Efficiency, and Trading

Kee H. Chung [a,b*] and Chairat Chuwonganant [c]

[a] *School of Management, University at Buffalo, The State University of New York (SUNY)*
[b] *SKK Business School, Sungkyunkwan University*
[c] *College of Business Administration, Kansas State University*

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* Corresponding author: Department of Finance, School of Management, University at Buffalo, The State University of New York (SUNY), Buffalo, NY 14260, USA. Tel.: +1 716 645 3262.
E-mail address: keechung@buffalo.edu (K.H. Chung).

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Abstract

This paper shows that COVID-19 is associated with a decrease in liquidity and increased pricing efficiency and trading activities before the NYSE closed its trading floor. The closure of the trading floor led to a reduction of liquidity, pricing efficiency, and trading activities on the NYSE. Its subsequent reopening led to increases in these variables. The effects of COVID-19 and the trading floor on pricing efficiency can be explained, at least in part, by their impacts on liquidity and informed trading. The effects of COVID-19 on liquidity and pricing efficiency are fully reversed after the NYSE reopened its trading floor.

JEL classification: G10, G14

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1. Introduction

In this paper we study the effects of COVID-19 and the closing and reopening of the NYSE trading floor on various measures of stock market liquidity, pricing efficiency, and trading in the U.S. stock market. The novel coronavirus outbreak SARS-COV-2 has spread across the globe and killed more than three million people. The U.S. had the first confirmed case of the virus on January 21, 2020. The World Health Organization declared a public health emergency over the pandemic on January 30 and announced the virus's formal name, COVID-19, on February 11. News related to COVID-19 had been the dominant driver of large daily U.S. stock-market movements for several months since February 24.

Figure 1 and Figure 2 show the daily data of the S&P 500 index and the Chicago Board Options Exchange (CBOE) Volatility Index (VIX) from January 22, 2020 through June 25, 2020. These figures underscore the unprecedented impact of the pandemic on the U.S. stock market. Baker et al. (2020) report that 18 out of 22 trading days from February 24 to March 24 had a change (up or down) in the S&P 500 index greater than 2.5%, which is higher than any other period in history with the same number of trading days. As the spread of the coronavirus causes massive drops in stock prices and extreme market volatility, the NYSE closed its trading floor on March 23 when the market, as it turned out, reached near the bottom. The NYSE subsequently began reopening its trading floor on May 26, 2020, allowing floor brokers and market makers an opportunity to resume their business operations.

The closure of its trading floor has implications for two major players on the NYSE: designated market makers (DMMs) and floor brokers. DMMs have obligations for maintaining fair and orderly markets for their assigned securities. Ordinarily, DMMs operate both manually and electronically to facilitate price discovery during market openings, closings, and during periods of substantial trading imbalances or instability. Without the trading floor, DMMs execute all orders electronically and cannot submit pre-opening indications from the trading floor to the Securities Information Processor (SIP) before the open or during trading halts.

Floor brokers are employees of member firms who execute trades on the exchange floor on behalf of their clients. They act as agents, buying and selling stocks for the public (institutions, hedge funds, and broker/dealers). During normal times, floor brokers are physically present on the trading floor and actively participate in trading throughout the day, including opening and closing auctions. With no trading floor, floor brokers can no longer provide these functions (e.g., they cannot participate in Exchange-facilitated auctions). However, they still can execute trades electronically by routing electronic orders to the Exchange systems.

Although the NYSE has fewer traders and market makers on the floor than it did a decade ago, it maintains that human beings are still an essential element of its operations. On its website, the NYSE states:

> *"Though all of our markets operate electronically using cutting edge, ultrafast technology, we believe nothing can take the place of human judgment and accountability. It is this human connection that helps ensure our strength, creating orderly opens and closes, lower volatility, deeper liquidity, and improved prices. For over 200 years, we have maintained a steadfast commitment to stronger, more orderly financial markets. And we intend to keep that tradition going for the next 200."*

The closure of the NYSE's trading floor provides an excellent opportunity to examine the value of the trading floor and human involvement (by DMMs and floor brokers) in improving execution quality and pricing efficiency. Also, as noted above, the disruptions brought by COVID-19 (e.g., rapid declines in share prices and explosions in market volatility) provide an opportunity to explore how these disruptions affected NYSE- and Nasdaq-listed stocks even before the NYSE closed its trading floor. Prior research suggests that financial crises decrease liquidity for at least two reasons. Gorton and Metrick (2010) suggest that liquidity is lower during financial crises because they aggravate adverse selection problems. Nagel (2012) shows that financially-constrained liquidity providers reduce the supply of liquidity during financial crises because they require higher returns during such periods.[1] Furthermore, our data and research design allow us to explore how the reopening of the NYSE trading floor affects liquidity, pricing efficiency, and trading activities on the NYSE and Nasdaq and whether the reopening fully reverses the effect of the pandemic on these metrics.

[1] Chung and Chuwonganant (2014, 2018) find evidence consistent with these views.

We show that COVID-19 is accompanied by an economically significant increase in the bid-ask spread and the price impact of trades and a significant decrease in the quoted depth for both NYSE-listed and Nasdaq-listed stocks before the NYSE closed its trading floor. The pandemic-led decrease in liquidity for the NYSE stocks is smaller than that for the Nasdaq stocks. One possible interpretation of the latter finding is that the NYSE trading floor mitigated the negative effect of COVID-19 on liquidity.

We find a significant increase in pricing efficiency (i.e., a decrease in variance ratios) in the COVID period relative to the pre-COVID period on the NYSE and Nasdaq, and the increase is larger for the NYSE stocks. To the extent that pricing efficiency increases with liquidity (Chordia, Roll, and Subrahmanyam, 2008), the larger increase in pricing efficiency on the NYSE could be explained, at least in part, by the smaller pandemic-led decrease in liquidity for the NYSE stocks. We also find a significant increase in trading activities (i.e., the number of trades, total dollar volume, intermarket sweep order trades, and odd-lot trades) in the COVID period relative to the pre-COVID period on both the NYSE and Nasdaq, and the increase is larger for the NYSE stocks. Because share prices become informationally efficient through informed investors' trading (Kyle, 1985; Easley, Kiefer, and O'Hara, 1997), the larger increase in pricing efficiency on the NYSE could also be explained by the larger increase in informed trading on the NYSE.

The closure of the NYSE trading floor is associated with a decrease in liquidity on the NYSE and Nasdaq. The difference-in-differences result shows that the decrease in liquidity for the NYSE stocks is greater than the decrease in liquidity for the Nasdaq stocks, suggesting that the closure of the NYSE trading floor led to a reduction in liquidity for the NYSE stocks after controlling for the market-wide decrease in liquidity. The reopening of the NYSE trading floor led to an increase in liquidity for the NYSE stocks after controlling for the market-wide increase in liquidity.

The closure (reopening) of the NYSE trading floor led to a decrease (an increase) in pricing efficiency for the NYSE stocks after controlling for the market-wide decline (increase) in pricing efficiency. These results could be explained by the decrease (increase) in liquidity for the NYSE stocks associated with the closure (reopening) of its trading floor, given that pricing efficiency increases with liquidity. The effects of COVID-19 on liquidity and pricing efficiency are fully reversed after the NYSE reopened its trading floor.

We show that the closure (reopening) of the NYSE trading floor led to a decrease (an increase) in trading activities (e.g., intermarket sweep order trading and odd-lot trading) for the NYSE stocks after controlling for the market-wide decrease (increase) in trading activities. Prior research (e.g., Chakravarty, Jain, Upson, and Wood, 2012; O'Hara, Yao, and Ye, 2014) shows that intermarket sweep orders and odd-lot orders are frequently used in algorithmic trading by institutional investors, market makers, and high-frequency traders who are likely to trade on private information. Hence, the decrease (increase) in pricing efficiency for the NYSE stocks associated with the closure (reopening) of its trading floor could also be explained by a concurrent decrease (increase) in intermarket sweep order trading and odd-lot trading.

There are a number of papers that analyze the effect of COVID-19. Glossner et al. (2020) show that the adverse impact of COVID-19 on stock prices is more severe in stocks held by active, short-term, and exposed institutions. Heyden and Heyden (2020) analyze short-term market reactions during the COVID-19 pandemic. They show that the stock market reacts negatively to country-specific fiscal policy measures, while monetary measures have the effect of calming the market. Baker et al. (2020) analyze the impact of COVID-19 on stock prices and explain why the U.S. stock market reacted more strongly to COVID-19 than to previous pandemics using text-based methods. In contrast to these papers' focus on the effect of COVID-19 on stock returns, our study explores its impact on liquidity, pricing efficiency, and trading activities.

O'Hara and Zhou (2020), Kargar et al. (2020), and Nozawa and Qiu (2020) analyze the effect of COVID-19 on bond markets. O'Hara and Zhou (2020) analyze liquidity provision in corporate bond markets during the COVID-19 crisis. The authors show that the pandemic led to an increase in trading costs and provide evidence on the Federal Reserve's efforts to curtail the liquidity crisis. Similarly, Kargar et al. (2020) show that liquidity in the corporate bond market declined significantly at the height of the crisis, and the announcements of the Federal Reserve's interventions led to substantial improvements in liquidity (e.g., lower bid-ask spreads). Nozawa and Qiu (2020) examine the reaction of corporate credit spreads to the Federal Reserve's monetary policy announcements using transaction data during the COVID-19 period. They find that the bond markets are segmented across credit ratings, which led to different initial reactions across bonds with different credit ratings. Our study contributes to the literature by exploring the effect of COVID-19 on the stock market.

Three contemporaneous papers are closely related to our study. Hu and Murphy (2020) show that closing auction market quality generally improved when the NYSE halted floor trading during the COVID-19 pandemic. Foley, Kwan, Philip, and Ødegaard (2020) show that the pandemic caused a sharp increase in transaction costs across global markets. Brogaard, Ringgenberg, and Rösch (2021) show that the closure of the NYSE trading floor led to higher effective and quoted spreads and larger pricing errors. In contrast, our study provides evidence regarding how COVID-19 influenced liquidity, pricing efficiency, and trading on the NYSE and Nasdaq before the NYSE closed its trading floor. In addition, we explore how the reopening of the NYSE trading floor influenced these variables and whether the effects of the pandemic on these market metrics are partially or fully reversed after the NYSE reopened its trading floor. More broadly, our study makes a unique contribution to the literature by analyzing these three variables (i.e., liquidity, pricing efficiency, and trading) across four distinct subperiods, thereby providing robust evidence that COVID-19 and the closure and reopening of the NYSE trading floor affected pricing efficiency through the channels of (or its effects on) liquidity and informed trading.

Prior studies have analyzed the role of DMMs in different markets. Venkataraman and Waisburd (2007) find that stocks with designated dealers exhibit higher liquidity on the Paris Bourse. Panayides (2007) provides evidence that NYSE specialists' affirmative obligations improve market quality. Menkveld and Wang (2013) show that DMMs improve liquidity, reduce liquidity risk, and decrease pricing errors on Euronext. Anand and Venkataraman (2016) show that DMMs on the Toronto Stock Exchange improve liquidity, especially when market conditions are unfavorable. Clark-Joseph, Ye, and Zi (2017) analyze the role of DMMs using exogenous variations provided by trading halts on U.S. exchanges and show that DMMs play a significant role as liquidity providers. As noted earlier, DMMs operate both manually and electronically to facilitate price discovery during normal times. With no trading floor, DMMs execute orders electronically only. Our study provides further evidence on the role of traders and DMMs on the floor by comparing liquidity and pricing efficiency between when the floor is open and when it is closed.

The rest of the paper is organized as follows. Section 2 explains our research design and sample selection. Section 3 analyzes how COVID-19 and the closure and reopening of the NYSE trading floor affected various measures of liquidity. Section 4 examines how pricing efficiency is related to COVID-19 and the closure and reopening of the NYSE trading floor. Section 5 explores the effects of COVID-19 and the trading floor on trading activities. Section 6 investigates whether the effects of the pandemic on liquidity, pricing efficiency, and trading activity are partially or fully reversed after the reopening of the NYSE trading floor. Section 7 explores whether liquidity and informed trading are channels through which COVID-19 and the closure and reopening of the NYSE trading floor led to changes in pricing efficiency. Section 8 finishes the paper with a summary and concluding remarks.

2. Research design and sample selection

Figure 1 and Figure 2 show that our study period (January 22, 2020 – June 25, 2020) could be divided into four distinct subperiods according to the S&P 500 index and the CBOE Volatility Index (VIX). The first subperiod (January 22 to February 21) is a period before the effect of COVID-19 manifests in the stock market (via the S&P 500 index or VIX). For expositional convenience, we call this period "the pre-COVID period." The second subperiod (February 22 to March 22) is when the S&P 500 index plummeted and the market volatility index (VIX) exploded. We call this period "the pre-NTF period," where NTF stands for **n**o **t**rading **f**loor. The third subperiod (March 23 to May 25) is when the NYSE trading floor was closed. We call this period "the NTF period." The fourth subperiod (May 26 to June 25) is when the NYSE trading floor was reopened partially or fully. We call this subperiod "the post-NTF period." Figure 1 and Figure 2 show that the effects of COVID-19 on the S&P 500 index and the CBOE Volatility Index are limited mainly to the pre-NFT period and the NTF period. Hence, we summarize the potential effects of COVID-19 and the trading floor for each subperiod as follows:

	COVID-19		Trading floor	
	NYSE	Nasdaq	NYSE	Nasdaq
Pre-COVID period	No	No	Yes	No
Pre-NTF period	Yes	Yes	Yes	No
NTF period	Yes	Yes	No	No
Post-NTF period	No	No	Yes	No

Note that the difference in a variable (e.g., the effective spread) between the pre-NTF period and the pre-COVID period (i.e., Pre-NTF period – Pre-COVID period) measures the effect of COVID-19 on the variable for both the NYSE and Nasdaq stocks. Similarly, the difference between the NTF period and the pre-NTF period (i.e., NTF period – Pre-NTF period) measures the effect of no trading floor (NTF) for the NYSE stocks; the difference between the post-NTF period and the NTF period measures the impacts of COVID-19 and the trading floor for the NYSE stocks and the effect of COVID-19 for the Nasdaq stocks; and the difference between the NTF period and the pre-COVID period measures the effects of no trading floor and COVID-19 for the NYSE stocks and the effect of COVID-19 for the Nasdaq stocks.

We use stock attributes in December 2019 to construct a matched sample of NYSE and Nasdaq stocks. For a particular NYSE stock, we first match it with Nasdaq stocks in the same two-digit North American Industry Classification System (NAICS) code. We compute the composite match score (CMS) for each NYSE stock against each Nasdaq stock as $\mathrm{CMS} = \sum_{k=1}^{4}\left[\frac{X_k^{NYSE} - X_k^{Nasdaq}}{\left(\frac{X_k^{NYSE} + X_k^{Nasdaq}}{2}\right)}\right]^2$, where X_k represents share price, dollar volume, return, or volatility, and superscripts NYSE and Nasdaq represent NYSE and Nasdaq stocks.

To obtain the matched pair similar in stock attributes, we then select the Nasdaq stock with the lowest CMS score. We repeat the matching procedure for the remaining NYSE stocks in our sample. Once we match a Nasdaq stock to a particular NYSE stock, we no longer use the Nasdaq stock for subsequent matches. We exclude the pairs of NYSE and Nasdaq stocks if the composite match score is greater than three to ensure that the matched pairs have similar stock attributes such that differences in stock attributes do not drive our results. Our study sample consists of 1,816 matched pairs of NYSE and Nasdaq stocks with similar attributes. The mean value of share price, trading volume, stock return, and return volatility for the matched NYSE (Nasdaq) stocks is \$45.99 (\$46.12), \$47.5 million (\$46.6 million), 0.0020 (0.0019), and 0.0166 (0.0170), respectively. Across all stock attributes, the difference in the mean value between the NYSE and Nasdaq stocks is not significantly different from zero.[2]

[2] The difference (NYSE – Nasdaq) in share price, trading volume, stock return, and return volatility is \$–0.13, \$0.9 million, 0.0001, and –0.0004, with the t-value of –0.04, 0.15, 0.46, and –0.68, respectively.

3. Effects of COVID-19 and the trading floor on liquidity

In this section, we explore the effects of COVID-19 and the trading floor on various measures of liquidity. Figures 1 and 2 show dramatic changes in the S&P 500 index and VIX brought by the pandemic. We expect COVID-19 to have significant effects on stock market liquidity as well (Gorton and Metrick, 2010; Nagel, 2012). Moreover, we conjecture that the impact of COVID-19 on liquidity can be different between the NYSE and Nasdaq due to their different market structures.

We use the following variables as our empirical proxies for liquidity: quoted spread (QSP), effective spread (ESP), value-weighted effective spread (ESP_VW), realized spread (RSP), value-weighted realized spread (RSP_VW), price impact (PIMPACT), value-weighted price impact (PIMPACT_VW), quoted depth (DEPTH), price impact coefficient with intercept (LAMBDA_1), and price impact coefficient without intercept (LAMBDA_2). Appendix A provides the definition of these variables. The quoted and effective spreads are measures of liquidity and total trading costs, price impacts are measures of adverse selection costs, and quoted depth is a measure of liquidity available at the national bid and offer price (NBBO). The realized spread is a measure of the market maker's revenue (i.e., the difference between the effective spread and the price impact of a trade). We obtain daily values of these variables from the WRDS Intraday Indicator Database (IID). Our final study sample comprises the panel data of 395,888 firm-day observations. Figure 3 and Figure 4 show the time-series patterns of quoted spreads (QSP) and effective spreads (ESP) for the matched NYSE and Nasdaq stocks.[3] These figures indicate that our data meet the parallel trends assumption required for the difference-in-differences test.

3.1. Effects of COVID-19 on liquidity

Panel A in Table 1 shows the mean values of each variable in the pre-COVID, pre-NTF, NTF, and post-NTF periods for the matched NYSE and Nasdaq stocks. Panel A also shows the differences in mean values between the pre-NTF and pre-COVID periods (i.e., Pre-NTF – Pre-COVID = ΔP_1 for the NYSE stocks and ΔP_2 for the Nasdaq stocks), between the NTF and pre-NTF periods (i.e., NTF – Pre-NTF = ΔC_1 for the

[3] We find similar patterns for other liquidity measures. The results are available from the authors upon request.

NYSE stocks and ΔC_2 for the Nasdaq stocks), and between the Post-NTF and NTF periods (i.e., Post-NTF – NTF = ΔR_1 for the NYSE stocks and ΔR_2 for the Nasdaq stocks). Panel B shows the difference-in-differences, i.e., $\Delta P_1 - \Delta P_2$ [(Pre-NTF – Pre-COVID)$_{NYSE}$ – (Pre-NTF – Pre-COVID)$_{Nasdaq}$], $\Delta C_1 - \Delta C_2$ [(NTF – Pre-NTF)$_{NYSE}$ – (NTF – Pre-NTF)$_{Nasdaq}$], and $\Delta R_1 - \Delta R_2$ [(Post-NTF – NTF)$_{NYSE}$ – (Post-NTF – NTF)$_{Nasdaq}$], where the subscripts NYSE and Nasdaq represent NYSE and Nasdaq stocks.

As noted earlier, the difference in liquidity between the pre-COVID period and the pre-NTF period measures the effect of COVID-19 on liquidity before the NYSE closed its trading floor. The results show that COVID-19 is accompanied by a significant increase ($\Delta P_1 > 0$) in the spreads (QSP, ESP, ESP_VW, and RSP) and price impacts (PIMPACT, PIMPACT_VW, LAMBDA_1, and LAMBDA_2) and a significant decrease ($\Delta P_1 < 0$) in the quoted depth (DEPTH) for the NYSE stocks. These changes are economically significant. For instance, the effective spread (ESP) increases by 0.0762 (a 30% increase) and LAMBDA_1 increases by 1.262 (a 33.5% increase). These results indicate that COVID-19 is associated with a decrease in liquidity for the NYSE stocks. The results for the Nasdaq stocks (ΔP_2) are qualitatively similar to those for the NYSE stocks. The difference-in-differences result (i.e., $\Delta P_1 - \Delta P_2$) in Panel B shows that the decrease in liquidity for the NYSE stocks is smaller than the decrease in liquidity for the Nasdaq stocks.[4]

To more accurately measure how COVID-19 affects liquidity after controlling for stock attributes and the effects of other factors, we estimate the following regression model using the matched NYSE and Nasdaq stocks in the pre-COVID period and the pre-NTF period:

$$\begin{aligned} \mathrm{VAR}_{i,t} = {} & \beta_0 + \beta_1 \mathrm{NYSE\ x\ D}^{\mathrm{Pre-NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} \\ & + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \qquad (1) \end{aligned}$$

where subscripts i and t denote stock i and time t, VAR denotes each liquidity variable, NYSE is a dummy variable equal to one for the NYSE stocks and zero for the Nasdaq stocks, D^{Pre_NTF} is a dummy variable equal to one for the pre-NTF period and zero for the pre-COVID period. PRICE is the stock price,

[4] For instance, the values of $\Delta P_1 - \Delta P_2$ for the effective spread and LAMBDA_1 are –0.0182 and –0.1996.

VOLUME denotes the trading volume, RET is the stock return, VOLA is the return volatility, VIX is the CBOE Volatility Index, λ_i denotes the firm fixed effects which capture the effect of time-invariant firm attributes on VAR, θ_t denotes the time fixed effects which control for the effect of firm-invariant (common or economy-wide) temporal changes in VAR, and ε denotes the error term.[5] Appendix A provides the definition of these variables. We use clustered standard errors by firm in the regressions.

In regression model (1), the coefficient (β_3) on $D^{\text{Pre-NTF}}$ (which captures the difference in liquidity between the pre-NTF period and the pre-COVID period for the Nasdaq stocks) measures the effect of COVID-19 on liquidity for the Nasdaq stocks. Likewise, the coefficient (β_1) on NYSE x $D^{\text{Pre-NTF}}$ measures the differential effect of COVID-19 on liquidity for the NYSE stocks relative to the Nasdaq stocks. Panel A in Table 2 shows that the estimates of β_3 are positive and significant in the regression models of the spreads and price impacts, and negative and significant in the regression model of the depth. These results indicate that COVID-19 is associated with a decrease in liquidity for the Nasdaq stocks.[6] More important, the estimates of β_1 are negative and significant in the regression models of the spreads and price impacts, and positive and significant in the regression model of the depth.[7] These results indicate that the negative effect of COVID-19 on liquidity for the NYSE stocks is smaller than that for the Nasdaq stocks. One possible explanation for this finding is that the NYSE trading floor mitigated the negative effect of COVID-19 on liquidity, given the fact that the NYSE has the trading floor while Nasdaq does not during the pre-NTF period. Most likely, other differences between the NYSE and Nasdaq may also have contributed to the differential effects of COVID-19 on liquidity between the two markets.

The coefficients (β_2) on NYSE are not significantly different from zero in all regression models, indicating no difference in liquidity between the NYSE and Nasdaq stocks during the pre-COVID period

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[5] We drop fixed effects for one stock and one day to avoid perfect multicollinearity. This does not affect our main inference because our primary variable of interest is the coefficient (β_1) on the interaction variable, i.e., NYSE x $D^{\text{Pre-NTF}}$.

[6] Because we include VIX in the regression model, the negative effect of COVID-19 on liquidity cannot be attributed to the high market volatility brought by the pandemic reflected in large VIX values. Hence, VIX may be an imperfect measure of the uncertainty brought by the pandemic or the pandemic affects liquidity through other channels than market volatility.

[7] As expected, the estimates of β_1 are similar to the corresponding values of $\Delta P_1 - \Delta P_2$ in Table 1.

(i.e., before the pandemic). The coefficients on the control variables are consistent with the findings of prior research.[8] For instance, we observe lower liquidity for stocks with lower prices, smaller trading volume, and higher return volatility.

3.2. Effects of the closure of the NYSE trading floor on liquidity

To examine how the closure of the NYSE trading floor affected liquidity, we compare the above liquidity measures between the pre-NTF period and the NTF period. Panel A in Table 1 shows that the closure of the NYSE trading floor is accompanied by a significant increase ($\Delta C_1 > 0$) in the spreads and price impacts and a significant decrease ($\Delta C_1 < 0$) in the quoted depth for the NYSE stocks. These changes are economically significant. For instance, the effective spread increases by 0.0763 (a 23.1% increase) and LAMBDA_1 increases by 1.291 (a 25.4% increase). These results indicate that the closure of the NYSE trading floor is associated with a decrease in liquidity for the NYSE stocks. The results for the Nasdaq stocks are qualitatively similar to those for the NYSE stocks. The difference-in-differences result (i.e., $\Delta C_1 - \Delta C_2$) in Panel B shows that the decrease in liquidity for the NYSE stocks is greater than the decrease in liquidity for the Nasdaq stocks, suggesting that the closure of the NYSE trading floor led to a decrease in liquidity for the NYSE stocks after controlling for the market-wide decrease in liquidity between the pre-NTF period and the NTF period.[9]

To measure how the absence of the trading floor on the NYSE affects liquidity after controlling for stock attributes and the effects of other factors, we estimate the following regression model using the matched NYSE and Nasdaq stocks in the pre-NTF and NTF periods:

$$\begin{aligned} \mathrm{VAR}_{i,t} = {} & \beta_0 + \beta_1 \mathrm{NYSE\ x\ D^{NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D^{NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} \\ & + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \qquad (2) \end{aligned}$$

[8] See, e.g., Chung, Lee, and Rösch (2020).
[9] For instance, the values of $\Delta C_1 - \Delta C_2$ for the effective spread and LAMBDA_1 are 0.0621 and 0.7950 which are economically significant.

where D^{NTF} is a dummy variable equal to one for the NTF period and zero for the pre-NTF period and all other variables are the same as defined in regression model (1).

Panel B in Table 2 shows that the coefficients (β_1) on NYSE x $D^{NTF}$are positive and significant in the regression models of the spreads and price impacts, and negative and significant in the regression model of the depth.[10] For instance, the closure of the NYSE trading floor is associated with an increase of 6.17 basis points in the mean effective spread of the NYSE stocks.[11] These results indicate that the closure of the NYSE trading floor is associated with a decrease in liquidity for the NYSE stocks after controlling for stock attributes and any market-wide change in liquidity. The coefficients (β_3) on D^{NTF} are qualitatively identical to the estimates of β_1, indicating a contemporaneous decrease in liquidity for the Nasdaq stocks as well. The coefficients (β_2) on NYSE are negative and significant in the regression models of the spreads and price impacts and positive and significant in the regression model of the depth, indicating that the NYSE stocks have, on average, higher liquidity than the Nasdaq stocks during the pre-NTF period.

3.3. Effects of the reopening of the NYSE trading floor on liquidity

We compare liquidity measures between the NTF period and the post-NTF period to assess the effect of the reopening of the NYSE trading floor on liquidity. Table 1 shows that the reopening of the NYSE trading floor is accompanied by a significant decrease ($\Delta R_1 < 0$) in the spreads and price impacts and a significant increase ($\Delta R_1 > 0$) in the quoted depth for the NYSE stocks. These results suggest that the restoration of the NYSE trading floor is associated with an increase in liquidity for the NYSE stocks. The results for the Nasdaq stocks are qualitatively similar, indicating that the restoration of the NYSE trading floor is also accompanied by an increase in liquidity on Nasdaq.

Figure 1 and Figure 2 show that the reopening of the NYSE trading floor occurs after the stock market has gone through the shock of the pandemic. Hence, the difference in liquidity between the NTF period and the post-NTF period for the NYSE stocks is likely to capture both the effect of the reopening of the NYSE

[10] As expected, the estimates of β_1 are similar to the corresponding values of $\Delta C_1 - \Delta C_2$ in Table 1.
[11] Brogaard, Ringgenberg, and Rösch (2021) show that the mean effective spread of the NYSE stocks increased 9 basis points more than that of the matched sample of NASDAQ stocks as a result of COVID-19.

trading floor and the change in the stock market environment between the two periods. In contrast, the difference in liquidity between the NTF period and the post-NTF period for the Nasdaq stocks is likely to capture only the latter effect because Nasdaq had no trading floor during both periods. The difference-in-differences result (i.e., $\Delta R_1 - \Delta R_2$) in Panel B shows that the increase in liquidity for the NYSE stocks is greater than the increase in liquidity for the Nasdaq stocks, suggesting that the reopening of the NYSE trading floor led to an increase in liquidity for the NYSE stocks after controlling for the market-wide increase in liquidity between the NTF period and the post-NTF period.[12]

We estimate the following regression model using the data in the NTF and the post-NTF periods to measure how the reopening of the NYSE trading floor affects liquidity after controlling for stock attributes and the effect of other factors:

$$\mathrm{VAR}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{Post-NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{Post-NTF}} + \beta_3 \mathrm{PRICE}_{i,t} + \beta_4 \mathrm{VOLUME}_{i,t} + \beta_5 \mathrm{RET}_{i,t} + \beta_6 \mathrm{VOLA}_{i,t} + \beta_7 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \quad (3)$$

where $\mathrm{D}^{\mathrm{Post-NTF}}$ is a dummy variable equal to one for the post-NTF period and zero for the NTF period, and all other variables are the same as previously defined.

Panel C in Table 2 shows that the coefficients (β_1) on $\mathrm{NYSE} \times \mathrm{D}^{\mathrm{Post-NTF}}$ are negative and significant in the regression models of the spreads and price impacts, and positive and significant in the regression model of the depth.[13] For instance, the reopening of the NYSE trading floor is associated with a decrease of 4.29 basis points in the mean effective spread of the NYSE stocks. These results indicate that the restoration of the NYSE trading floor is associated with an increase in liquidity for the NYSE stocks after controlling for any market-wide change in liquidity. The coefficients (β_3) on $\mathrm{D}^{\mathrm{Post-NTF}}$ are qualitatively identical to the estimates of β_1, indicating a contemporaneous increase in liquidity for the Nasdaq stocks due to the change in the stock market environment between the NTF period and the post-NTF period discussed above. The estimates of β_2 are positive and significant in the regression models of the spreads

[12] For instance, the values of $\Delta R_1 - \Delta R_2$ for the effective spread and LAMBDA_1 are –0.0434 and –0.611, which are economically significant.
[13] The estimates of β_1 are similar to the corresponding values of $\Delta R_1 - \Delta R_2$ in Table 1.

and price impacts and negative and significant in the regression model for the depth, indicating that the NYSE stocks have, on average, lower liquidity than the Nasdaq stocks during the NTF period.

4. Effects of COVID-19 and the trading floor on pricing efficiency

This section explores the effects of COVID-19 and the trading floor on pricing efficiency. (In Section 5, we explore possible explanations for these effects.) We use multiple versions of the variance ratio (VR) as empirical proxies for pricing efficiency: variance ratios based on 15-second / 3 x 5-second (VR_1), 1-minute / 4 x 15-second (VR_2), 5-minute / 5 x 1-minute (VR_3), 15-minute / 3 x 5-minute (VR_4), and 30-minute / 2 x 15-minute (VR_5). Appendix A provides the definition of these variables. The variance ratio is an inverse measure of pricing efficiency, reflecting non-randomness in price changes. We obtain daily values of these variables from the WRDS Intraday Indicator Database. Figure 5 shows the time-series patterns of VR_1 for the matched NYSE and Nasdaq stocks.[14]

4.1. Effects of COVID-19 on pricing efficiency

To examine how COVID-19 affected pricing efficiency, we replicate Table 1 using the above pricing efficiency measures and show the results in Table 3. Panel A shows that COVID-19 is accompanied by a significant decrease in all five variance ratios ($\Delta P_1 < 0$). These changes are economically significant. For instance, VR_1 decreases by 0.0305 (an 8.1% decrease) and VR_3 decreases by 0.0163 (a 5.2% decrease). These results suggest that COVID-19 is associated with an increase in pricing efficiency for the NYSE stocks. The results for the Nasdaq stocks are qualitatively similar. The difference-in-differences result (i.e., $\Delta P_1 - \Delta P_2$) in Panel B shows that the decrease (increase) in variance ratios (pricing efficiency) for the NYSE stocks is larger than the decrease (increase) in variance ratios (pricing efficiency) for the Nasdaq stocks.

Panel A in Table 4 provides the results of regression model (1) when we use pricing efficiency as the dependent variable. The estimates of β_3 are negative and significant in all regression models, indicating

[14] This figure indicates that our data meet the parallel trends assumption required for the difference-in-differences test. We find similar patterns for other variance ratios.

that COVID-19 is associated with an increase in pricing efficiency on Nasdaq. The estimates of β_1 are negative and significant in all regression models, indicating that the positive effect of COVID-19 on pricing efficiency for the NYSE stocks is greater than that for the Nasdaq stocks. Given the positive relation between pricing efficiency and liquidity (Chordia, Roll, and Subrahmanyam, 2008), this result could be explained, at least in part, by the smaller negative effect of COVID-19 on liquidity for the NYSE stocks.

The results for the control variables show that variance ratios are larger for stocks with higher prices, smaller trading volumes, and higher return volatility and when the market volatility index (VIX) is lower, indicating lower pricing efficiency for these stocks. These results are consistent with the finding of Chung, Lee, and Rösch (2020) that autocorrelations in stock returns are larger for stocks with higher prices, smaller trading volumes, and higher return volatility and when the market volatility index is lower.[15]

4.2. Effects of the closure of the NYSE trading floor on pricing efficiency

Panel A in Table 3 shows that the closure of the NYSE trading floor is accompanied by a significant increase ($\Delta C_1 > 0$) in all five variance ratios for the NYSE stocks. For instance, VR_1 and VR_2 increase by 0.0628 (an 18% increase) and 0.0560 (a 17.7% increase). These results suggest that the closure of the NYSE trading floor is associated with a decrease in pricing efficiency for the NYSE stocks. The difference-in-differences result (i.e., $\Delta C_1 - \Delta C_2$) in Panel B shows that the decrease in pricing efficiency for the NYSE stocks is greater than the decrease in pricing efficiency for the Nasdaq stocks, suggesting that the closure of the NYSE trading floor led to a decrease in pricing efficiency for the NYSE stocks after controlling for the market-wide decrease in pricing efficiency between the pre-NTF period and the NTF period.

To examine how the absence of the trading floor on the NYSE affects pricing efficiency after controlling for stock attributes and the effects of other variables, we estimate regression model (2) using pricing efficiency as the dependent variable. Panel B in Table 4 shows that the estimates of β_1 (0.0162, 0.0211, 0.0170, 0.0133, and 0.0178) are positive and significant in all regression models, indicating that the closure of the NYSE trading floor is associated with a decrease in pricing efficiency for the NYSE

[15] Note that both variance ratios and autocorrelations measure non-randomness in stock returns.

stocks. To the extent that pricing efficiency increases with liquidity, this result could be explained by the decrease in liquidity on the NYSE associated with the closure of its trading floor. This result is consistent with the finding of Brogaard, Ringgenberg, and Rösch (2021) that the closure of the NYSE trading floor is associated with a 2% increase in pricing errors (which implies a 2% decrease in pricing efficiency).[16] The estimates of β_2 are negative and significant in all regression models, indicating that the NYSE stocks have higher pricing efficiency than Nasdaq stocks during the pre-NTF period.

4.3. Effects of the reopening of the NYSE trading floor on pricing efficiency

Panel A in Table 3 shows that the reopening of the NYSE trading floor is accompanied by a significant decrease ($\Delta R_1 < 0$) in all five variance ratios. The difference-in-differences result (i.e., $\Delta R_1 - \Delta R_2$) in Panel B shows that the decrease in variance ratios for the NYSE stocks is greater than the decrease in variance ratios for the Nasdaq stocks, suggesting that the reopening of the NYSE trading floor led to an increase in pricing efficiency for the NYSE stocks. Panel C in Table 4 provides the results when we estimate regression model (3) using each measure of pricing efficiency as the dependent variable. The estimates of β_1 are negative and significant in all regression models, indicating that the restoration of the NYSE trading floor is associated with an increase in pricing efficiency for the NYSE stocks after controlling for other determinants of pricing efficiency. The estimates of β_2 are positive and significant in all regression models, indicating that the NYSE stocks have, on average, lower pricing efficiency than the Nasdaq stocks while its trading floor is closed.

5. Effects of the trading floor and COVID-19 on trading activities

In the previous section, we showed that COVID-19 and the closure and reopening of the NYSE trading floor had significant effects on pricing efficiency on the NYSE and Nasdaq. For example, we showed that the positive impact of COVID-19 on pricing efficiency for the NYSE stocks is greater than that for the Nasdaq stocks, and the closure (reopening) of the NYSE trading floor is associated with a decrease

[16] Brogaard, Ringgenberg, and Rösch (2021) measure pricing errors using the method developed by Hasbrouck (1993).

(increase) in pricing efficiency for the NYSE stocks. Because share prices become informationally efficient through informed investors' trading (Kyle, 1985; Easley, Kiefer, and O'Hara, 1997), the effects of COVID-19 and the trading floor on pricing efficiency may be attributed to their impact on informed investors' trading activities. This section explores how COVID-19 and the closure and reopening of the NYSE trading floor affected trading activities to help better understand their effects on pricing efficiency presented in the previous section.

For trading activity variables, we use the number of trades (NTRADE), total dollar volume (DVOL), number of intermarket sweep order trades (NISO), total intermarket sweep order dollar volume (DVISO), number of odd-lot trades (NODDLOT), and total odd-lot dollar volume (DVODDLOT). Appendix A provides the definition of these variables. We obtain daily values of these variables from the WRDS Intraday Indicator Database. We use intermarket sweep order trading and odd-lot trading as empirical proxies for informed trading. An intermarket sweep order (ISO) is a limit order sent to multiple exchanges simultaneously. Intermarket sweep orders are used mostly in algorithmic trading by institutional investors or market makers.[17] Chakravarty, Jain, Upson, and Wood (2012) show that ISO trades have a significantly larger information share than non-ISO trades. Odd-lot trades are trades for less than 100 shares in a given security. O'Hara, Yao, and Ye (2014) suggest that odd-lots are frequently used in algorithmic and high-frequency trading. In their study sample, odd-lot trades account for more than 60% in some stocks and contribute 35% of price discovery. O'Hara, Yao, and Ye (2014) interpret these results as evidence that informed traders split orders into odd lots to avoid detection. Figures 6, 7, and 8 show the time-series patterns of DVOL, DVISO, and DVODDLOT for the matched NYSE and Nasdaq stocks.[18]

5.1. Effects of COVID-19 on trading activities

To examine how COVID-19 affected trading activities, we replicate Table 1 using the above trading activity measures and provide the results in Table 5. Panel A shows that COVID-19 is accompanied by a

[17] See Matt Phillips, 'Accenture's Flash Crash: What's an 'Intermarket Sweep Order'', *The Wall Street Journal*, May 7, 2010, https://blogs.wsj.com/marketbeat/2010/05/07/accentures-flash-crash-whats-an-intermarket-sweep-order/.
[18] We find similar patterns for other trading activity measures.

significant increase in all six trading activity measures ($\Delta P_1 > 0$). The difference-in-differences result (i.e., $\Delta P_1 - \Delta P_2$) in Panel B shows that the increase in trading activities for the NYSE stocks is larger than that for the Nasdaq stocks. For instance, COVID-19 is associated with an additional increase of 462 in the number of ISO trades, a further increase of $5.54 million in the ISO dollar trading volume, an additional increase of 275 in the number of odd-lot trades, and an additional increase of $1.162 million in the odd-lot dollar trading volume for the NYSE stocks relative to the Nasdaq stocks.

Panel A in Table 6 provides the results of regression model (1) when we use the trading activity as the dependent variable. The estimates of β_1 are positive and significant in all regression models, indicating that the positive effect of COVID-19 on trading activities for the NYSE stocks is greater than that for the Nasdaq stocks. One possible explanation for this finding is that the NYSE trading floor helped increase trading during the COVID period before its closure (i.e., the pre-NTF period). We showed earlier that COVID-19 increased pricing efficiency on the NYSE and Nasdaq, and the increase is larger for the NYSE stocks. Because share prices become informationally efficient through the trading of informed investors, the greater positive effect of COVID-19 on pricing efficiency for the NYSE stocks could be explained, at least in part, by the greater positive impact of COVID-19 on ISO trading and odd-lot trading for the NYSE stocks.

5.2. Effects of the closure of the NYSE trading floor on trading activities

Panel A in Table 5 shows that the closure of the NYSE trading floor is accompanied by a significant decrease ($\Delta C_1 < 0$) in all six trading activity measures for the NYSE stocks. The results for the Nasdaq stocks are qualitatively similar to those for the NYSE stocks. The difference-in-differences result (i.e., $\Delta C_1 - \Delta C_2$) in Panel B shows that the decrease in trading activities for the NYSE stocks is greater than the decline in trading activities for the Nasdaq stocks. For instance, the closure of the NYSE trading floor is associated with an additional decrease of 708 in the number of ISO trades, a further reduction of $3.13 million in the ISO dollar trading volume, an additional reduction of 351 in the number of odd-lot trades, and an additional decrease of $2.034 million in the odd-lot dollar trading volume for the NYSE stocks, relative to the Nasdaq stocks.

Panel B in Table 6 provides the results of regression model (2) when we use the trading activity as the dependent variable. We find that the estimates of β_1 (i.e., –867.9, –8.611, –697.7, –3.204, –347.8, and –1.991) are negative and significant in all six regression models and similar in sizes to the corresponding difference-in-differences result (i.e., $\Delta C_1 - \Delta C_2$) in Panel B of Table 5, indicating that the closure of the NYSE trading floor is associated with a decrease in trading for the NYSE stocks after controlling for any market-wide change in trading. To the extent that intermarket sweep orders and odd-lot orders are used by better-informed traders, the decrease in pricing efficiency for the NYSE stocks associated with the closure of the NYSE's trading floor shown in the previous section could be explained by a concurrent reduction in ISO trading and odd-lot trading.

5.3. Effects of the reopening of the NYSE trading floor on trading activities

Panel A in Table 5 shows that the reopening of the NYSE trading floor is accompanied by a significant increase ($\Delta R_1 > 0$) in all six trading activity measures for the NYSE stocks. The results for the Nasdaq stocks are qualitatively similar to those for the NYSE stocks (i.e., $\Delta R_2 > 0$). The difference-in-differences result (i.e., $\Delta R_1 - \Delta R_2$) in Panel B shows that the increase in trading activities for the NYSE stocks is greater than the increase in trading activities for the Nasdaq stocks.

Panel C in Table 6 shows the results of regression model (3) for each trading activity variable. The results show that the estimates of β_1 are positive and significant in all regression models, and their magnitudes are comparable to the corresponding difference-in-differences values provided in Panel B of Table 5. These results indicate that the restoration of the NYSE trading floor is associated with an increase in trading for the NYSE stocks. The increase in pricing efficiency for the NYSE stocks resulted from the reopening of the NYSE's trading floor shown in the previous section could be explained by a concurrent increase in ISO trading and odd-lot trading. The estimates of β_2 are negative and significant in all six regression models, indicating that the NYSE stocks have lower trading activities than the Nasdaq stocks during the NTF period.

6. Changes in liquidity, pricing efficiency, and trading between the pre-COVID and other periods

In the previous sections, we compare our variables of interest (i.e., liquidity, pricing efficiency, and trading) between the pre-NTF period and the NTF period to assess the effects of the closure of the NYSE trading floor on these variables. Similarly, we compare these variables between the NTF period and the post-NTF period to assess the effects of the reopening of the NYSE trading floor. This section compares these variables between the pre-COVID period and each of the three subsequent periods (i.e., pre-NTF, NTF, and post-NTF) to assess changes in these variables relative to their values before the pandemic. In particular, comparing these variables between the pre-COVID period and the post-NTF period would inform us whether the effects of the pandemic on these variables are partially or fully reversed after the NYSE reopened its trading floor. For this, we estimate the following regression model using the matched NYSE and Nasdaq stocks in the pre-COVID, pre-NTF, NTF, and post-NTF periods:

$$\begin{aligned} \mathrm{VAR}_{i,t} = {} & \beta_0 + \beta_1 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_2 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{NTF}} + \beta_3 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{Post-NTF}} + \beta_4 \mathrm{NYSE} \\ & + \beta_5 \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_6 \mathrm{D}^{\mathrm{NTF}} + \beta_7 \mathrm{D}^{\mathrm{Post-NTF}} + \beta_8 \mathrm{PRICE}_{i,t} + \beta_9 \mathrm{VOLUME}_{i,t} \\ & + \beta_{10} \mathrm{RET}_{i,t} + \beta_{11} \mathrm{VOLA}_{i,t} + \beta_{12} \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \end{aligned} \tag{4}$$

where all variables are the same as previously defined. Panel A in Table 7 shows the results for liquidity variables, Panel B shows the results for pricing efficiency variables, and Panel C shows the results for trading activity variables. To save space, we omit the results for the control variables in Table 7.

6.1. Results for liquidity variables

The difference in liquidity between the pre-NTF period and the pre-COVID period measures the effect of COVID-19 on liquidity. Hence, in regression model (4), the coefficient (β_5) on $\mathrm{D}^{\mathrm{Pre-NTF}}$ measures the effect of COVID-19 on liquidity for the Nasdaq stocks. Likewise, the coefficient (β_1) on NYSE x $\mathrm{D}^{\mathrm{Pre-NTF}}$ measures the differential effect of COVID-19 for the NYSE stocks relative to the Nasdaq stocks. As expected, the estimates of β_1 and β_5 in Panel A of Table 7 are similar to the estimates of β_1 and β_3 in Panel A of Table 2.

The coefficients (β_2) on NYSE x D^{NTF} in Panel A of Table 7 are positive and significant in the regression models of the spreads and price impacts, and negative and significant in the regression model of the depth.[19] These results indicate that the closure of the NYSE trading floor is associated with a decrease in liquidity (relative to its pre-pandemic level) for the NYSE stocks after controlling for market-wide changes in liquidity due to COVID-19 and other reasons.

The coefficients (β_3) on NYSE x $D^{Post-NTF}$ in Panel A of Table 7 are not significantly different from zero in all regression models. Similarly, the coefficients (β_7) on $D^{Post-NTF}$ are not significantly different from zero in all regression models. Note that β_3 (β_7) measures the difference in liquidity between the post-NTF period and the pre-COVID period for the NYSE (Nasdaq) stocks. Hence, these results indicate that the effect of COVID-19 on liquidity is completely reversed after the NYSE trading floor is fully restored.

6.2. Results for pricing efficiency variables

As expected, the estimates of β_1 and β_5 in Panel B of Table 7 are similar to the estimates of β_1 and β_3 in Panel A of Table 4. The coefficients (β_2) on NYSE x D^{NTF} in Panel B of Table 7 are positive and significant in all regression models, indicating that the closure of the NYSE trading floor is associated with a decrease in pricing efficiency (relative to its pre-pandemic level) for the NYSE stocks after controlling for the market-wide change in pricing efficiency. The coefficients (β_7) on $D^{Post-NTF}$ in Panel B of Table 7 are not significantly different from zero, indicating no difference in pricing efficiency on Nasdaq between the post-NTF period and the pre-COVID period. Similarly, the coefficients (β_3) on NYSE x $D^{Post-NTF}$ are not significantly different from zero in all regression models, indicating no difference in pricing efficiency on the NYSE between the post-NTF period and the pre-COVID period. These results suggest that the effect of COVID-19 on pricing efficiency is fully reversed after the reopening of the NYSE trading floor.

[19] The estimates of β_2 in regression model (4) are not directly comparable to the estimates of β_1 in regression model (2) because β_2 measures the difference in liquidity between the pre-COVID period and the NTF period, while β_1 measures the difference in liquidity between the pre-NTF period and the NTF period.

6.3. Results for trading activity variables

As expected, the estimates of β_1 and β_5 in Panel C of Table 7 are similar to the estimates of β_1 and β_3 in Panel A of Table 6. The coefficients (β_2) on NYSE x D^{NTF} in Panel C of Table 7 are all negative and significant, indicating that the closure of the NYSE trading floor is associated with a decrease in trading activities (relative to their pre-pandemic level) for the NYSE stocks. The coefficients (β_7) on $D^{Post-NTF}$ and the coefficients (β_3) on NYSE x $D^{Post-NTF}$ in Panel C of Table 7 are insignificant in all regression models, indicating that the reopening of the NYSE trading floor fully reversed the effect of COVID-19 on trading activities.

7. Liquidity and informed trading as pricing efficiency channels

We showed earlier that COVID-19 is accompanied by a significant increase in pricing efficiency. We also find a decrease in pricing efficiency when the NYSE closed its trading floor, and an increase in pricing efficiency when the NYSE reopened its trading floor. We suggested that these changes in pricing efficiency could be explained by concurrent changes in liquidity and informed trading based on the findings of prior research that pricing efficiency increases with both liquidity (Chordia, Roll, and Subrahmanyam, 2008) and informed trading (Kyle, 1985; Easley, Kiefer, and O'Hara, 1997). In this section, we explore whether liquidity and informed trading are indeed channels through which COVID-19 and the closure and reopening of the NYSE trading floor led to changes in pricing efficiency. Specifically, we conduct the two-stage least squares (2SLS) regression analysis using each of these three events as an instrumental variable. For space consideration, we report the results using each of the five variance ratios (VR_1 through VR_5) as an inverse measure of pricing efficiency, the effective spread (ESP) or price impact (PIMPACT) as an inverse measure of liquidity, and the intermarket sweep order dollar volume (DVISO) or the total odd-lot dollar volume (DVODDLOT) as a measure of informed trading.

7.1. COVID-19 and the pricing efficiency channels of liquidity and informed trading

We first estimate the following first-stage regression model using the matched NYSE and Nasdaq stocks in the pre-COVID and pre-NTF periods:

$$\mathrm{LIQUIDITY}_{i,t} \text{ or } \mathrm{TRADING}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \tag{5}$$

where LIQUIDITY is either the effective spread (ESP) or price impact (PIMPACT), TRADING is either the intermarket sweep order dollar volume (DVISO) or the odd-lot dollar volume (DVODDLOT), and all other variables are the same as previously defined. We then estimate the following second-stage regression model:

$$\mathrm{VR}_{i,t} = \beta_0 + \beta_{1L} \widehat{\mathrm{LIQUIDITY}}_{i,t} + \beta_{1T} \widehat{\mathrm{TRADING}}_{i,t} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \tag{6}$$

where VR is one of the five variance ratios and $\widehat{\mathrm{LIQUIDITY}}$ ($\widehat{\mathrm{TRADING}}$) is the predicted value of LIQUIDITY (TRADING) from the first-stage regression model (5).[20]

Panel A in Table 8 reports the estimates of β_{1L} and β_{1T} from the second-stage regression model (6) using each of the five variance ratios as the dependent variable.[21] The left half of the panel shows the results when we measure liquidity by the effective spread (ESP) and the right half shows the results when we measure liquidity by price impact (PIMPACT). Within each half, we show the results when we measure informed trading by DVISO and DVODDLOT, respectively. The results show that the coefficients (β_{1L}) on

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[20] Dippel et al. (2020) show that the same instrumental variable can be used for two endogenous variables if one of those endogenous variables is on the path between the treatment and outcome variables. In the context of the present study, it is reasonable to assume that liquidity affects pricing efficiency through its impact on (i.e., by expediting) informed trading (Chordia, Roll, and Subrahmanyam, 2008).

[21] To save space, we report only the estimates of β_{1L} and β_{1T}. The results of other variables are available from the authors upon request. The results of each first-stage regression are the same as those reported in Panel A of Table 2 and Table 6, satisfying the relevance condition. Unlike the relevance condition, the exclusion condition cannot be tested because the regression error term is unobservable. To the extent that COVID-19 affects pricing efficiency only through liquidity and informed trading, we expect COVID-19 to meet the exclusion condition. The significant β_1 coefficients on NYSE x $\mathrm{D}^{\mathrm{Pre-NTF}}$ in Panel A of Table 4 do not imply the violation of the exclusion condition if the relation between variance ratios and the interaction variable is spurious. For instance, the relation between variance ratios and the interaction variable may actually capture the relation between variance ratios and the effective spread because the effective spread and the interaction variable are correlated according to the first-stage regression results.

$\widehat{\text{LIQUIDITY}}_{i,t}$ are positive and significant and the coefficients (β_{1T}) on $\widehat{\text{TRADING}}_{i,t}$ are negative and significant in all regressions, regardless of whether we measure liquidity by ESP or PIMPACT and informed trading by DVISO or DVODDLOT. Because variance ratios are an inverse measure of pricing efficiency and both ESP and PIMPACT are an inverse measure of liquidity, the positive β_{1L} coefficients indicate that pricing efficiency increases with liquidity. Because DVISO and DVODDLOT are a direct measure of informed trading, the negative β_{1T} coefficients indicate that pricing efficiency increases with informed trading.[22] Overall, these results support the idea that COVID-19 led to an increase in pricing efficiency through the channels of liquidity and informed trading.

7.2. The NYSE trading floor closure and the pricing efficiency channels of liquidity and informed trading

We estimate regression models (5) and (6) using the matched NYSE and Nasdaq stocks in the pre-NTF and NTF periods after replacing NYSE x $D^{Pre-NTF}$ in regression model (5) with NYSE x D^{NTF} and $D^{Pre-NTF}$ in regression models (5) and (6) with D^{NTF}. Panel B in Table 8 reports the estimates of β_{1L} and β_{1T} from the second-stage regression model (6) using each of the five variance ratios as the dependent variable. The results show that the coefficients (β_{1L}) on $\widehat{\text{LIQUIDITY}}_{i,t}$ are positive and significant and the coefficients (β_{1T}) on $\widehat{\text{TRADING}}_{i,t}$ are negative and significant in all regressions. Overall, these results support the idea that the closure of the NYSE trading floor led to a decrease in pricing efficiency through the channels of liquidity and informed trading.

7.3. The NYSE trading floor reopening and the pricing efficiency channels of liquidity and informed trading

We estimate regression models (5) and (6) using the matched NYSE and Nasdaq stocks in the NTF and post-NTF periods after we replace NYSE x $D^{Pre-NTF}$ in regression model (5) with NYSE x $D^{Post-NTF}$ and $D^{Pre-NTF}$ in regression models (5) and (6) with $D^{Post-NTF}$. Panel C in Table 8 reports the estimates of β_{1L} and

[22] This result is consistent with the finding of prior research. Sung, Johnson, and McDonald (2016) find that informed trading is associated with an increase in pricing efficiency. Bennett, Stulz, and Wang (2020) use both PIN and price nonsynchronicity as measures of pricing efficiency based on the observation "when there is more informed trading in a stock, new information is more likely to be incorporated into that stock's price, which improves the stock's price informativeness."

β_{1T} from the second-stage regression model (6). Again, the results show that the coefficients (β_{1L}) on $\widehat{\text{LIQUIDITY}}_{i,t}$ are positive and significant and the coefficients (β_{1T}) on $\widehat{\text{TRADING}}_{i,t}$ are negative and significant in all regressions, suggesting that the reopening of the NYSE trading floor led to an increase in pricing efficiency through the channels of liquidity and informed trading.

8. Summary and concluding remarks

The COVID-19 pandemic brought significant disruptions to financial markets across the globe. Market volatility exploded, stock prices plummeted, and liquidity evaporated during the initial months of the pandemic. The NYSE closed its trading floor to protect floor brokers and market makers from the pandemic and subsequently reopened it as the initial shock of the pandemic subsided and health risks associated with floor operations became manageable. In this paper, we explore how the initial shock of the pandemic, the suspension of the NYSE trading floor, and its subsequent restoration have influenced liquidity, pricing efficiency, and trading activities on the NYSE and Nasdaq.

We find that the initial shock of COVID-19 led to a significant decrease in liquidity and an increase in pricing efficiency and trading activities on both the NYSE and Nasdaq before the closure of the NYSE trading floor. The decrease in liquidity is smaller, and the increase in pricing efficiency and trading activities are larger for the NYSE stocks relative to the Nasdaq stocks. The larger increase in pricing efficiency on the NYSE can be attributed at least in part to both the smaller decrease in liquidity and the larger increase in trading activities for the NYSE stocks. These results could be explained by the positive role of the trading floor in improving liquidity and pricing efficiency and expediting trading activities. That is, the NYSE trading floor mitigated the negative effect of COVID-19 on liquidity while helped improve pricing efficiency and expedite trading activities.

The closure of the NYSE trading floor is followed by a larger decrease in liquidity, pricing efficiency, and trading activities on the NYSE relative to Nasdaq. The decrease in pricing efficiency can be related, at least in part, to the concurrent decline in liquidity and trading activities. The reopening of the NYSE trading floor is followed by a larger increase in liquidity, pricing efficiency, and trading activities on the NYSE relative to Nasdaq, reflecting the value of the trading floor in improving liquidity and pricing efficiency and expediting trading activities. We show that the reopening of the trading floor fully restored liquidity and pricing efficiency to their pre-pandemic levels, suggesting that the pandemic does not appear to have a permanent effect on these market quality metrics.

Whether trading floor and human involvement add value to asset exchange markets in the age of ultra-high-technologies and automated trading has long been debated among market participants, regulators, and scholars. Our study sheds additional light on this debate by providing coherent and convincing evidence that trading floor and human involvement improve liquidity and pricing efficiency. We provide this evidence by looking at how liquidity providers and other market participants responded to the unexpected arrival of the COVID-19 pandemic, the closure of the NYSE trading floor, and the subsequent reopening of the trading floor.

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Table 1

Comparisons of liquidity variables in the pre-COVID, pre-NTF, NTF, and post-NTF periods

We define January 22, 2020 to February 21, 2020 as the pre-COVID period, February 22, 2020 to March 22, 2020 as the pre-NTF period, March 23, 2020 to May 25, 2020 as the NTF period, and May 26, 2020 to June 25, 2020 as the post-NTF period, where NTF stands for **n**o **t**rading **f**loor. For each period, we compute the mean value of each variable for our matched NYSE and Nasdaq sample stocks. We use the following variables as our empirical proxies for liquidity: quoted spread (QSP), effective spread (ESP), value-weighted effective spread (ESP_VW), realized spread (RSP), value-weighted realized spread (RSP_VW), price impact (PIMPACT), value-weighted price impact (PIMPACT_VW), quoted depth (DEPTH), price impact coefficient with intercept (LAMBDA_1), and price impact coefficient without intercept (LAMBDA_2). Panel A shows the mean values of each variable in the pre-COVID, pre-NTF, NTF, and post-NTF periods for the matched NYSE and Nasdaq sample stocks. Panel A also shows the differences in mean values between the pre-NTF and pre-COVID periods (i.e., Pre-NTF – Pre-COVID = ΔP1 for the NYSE stocks and ΔP2 for the Nasdaq stocks), between the NTF and pre-NTF periods (i.e., NTF – Pre-NTF = ΔC1 for the NYSE stocks and ΔC2 for the Nasdaq stocks), and between the Post-NTF and NTF periods (i.e., Post-NTF – NTF = ΔR1 for the NYSE stocks and ΔR2 for the Nasdaq stocks). Panel B shows the difference-in-difference values, i.e., $\Delta P_1 - \Delta P_2$ [(Pre-NTF – Pre-COVID)$_{NYSE}$ – (Pre-NTF – Pre-COVID)$_{Nasdaq}$], $\Delta C_1 - \Delta C_2$ [(NTF – Pre-NTF)$_{NYSE}$ – (NTF – Pre-NTF)$_{Nasdaq}$], and $\Delta R_1 - \Delta R_2$ [(Post-NTF – NTF)$_{NYSE}$ – (Post-NTF – NTF)$_{Nasdaq}$], where the subscripts NYSE and Nasdaq represent NYSE and Nasdaq stocks. Numbers in parentheses are t-statistics. ** = significant at the one percent level.

Panel A: Comparisons of liquidity variables in the pre-COVID, pre-NTF, NTF, and post-NTF periods

	NYSE stocks							Nasdaq stocks						
Variable	Pre-COVID	Pre-NTF	NTF	Post-NTF	Pre-NTF – Pre-COVID (ΔP_1)	NTF – Pre-NTF (ΔC_1)	Post-NTF – NTF (ΔR_1)	Pre-COVID	Pre-NTF	NTF	Post-NTF	Pre-NTF – Pre-COVID (ΔP_2)	NTF – Pre-NTF (ΔC_2)	Post-NTF – NTF (ΔR_2)
QSP (%)	0.4848	0.6091	0.6663	0.4837	0.1243**	0.0572**	–0.1826**	0.4856	0.6407	0.6566	0.4863	0.1551**	0.0159**	–0.1703**
					(14.35)	(12.52)	(–23.64)					(17.39)	(8.61)	(–20.56)
ESP (%)	0.2534	0.3296	0.4059	0.2511	0.0762**	0.0763**	–0.1548**	0.2537	0.3481	0.3623	0.2509	0.0944**	0.0142**	–0.1114**
					(21.84)	(19.66)	(–35.26)					(27.63)	(9.34)	(–23.25)
ESP_VW (%)	0.3252	0.4401	0.5064	0.3247	0.1149**	0.0663**	–0.1817**	0.3260	0.4518	0.4668	0.3251	0.1258**	0.0150**	–0.1417**
					(20.16)	(18.74)	(–33.52)					(29.35)	(8.97)	(–25.79)
RSP (%)	0.1010	0.1114	0.1661	0.1024	0.0104**	0.0547**	–0.0637**	0.1033	0.1217	0.1296	0.1029	0.0184**	0.0079**	–0.0267**
					(9.46)	(20.01)	(–24.99)					(13.89)	(7.83)	(–11.64)
RSP_VW (%)	0.1033	0.1293	0.1786	0.1038	0.0260**	0.0493**	–0.0748**	0.1047	0.1364	0.1450	0.1041	0.0317**	0.0086**	–0.0409**
					(14.84)	(18.85)	(–26.84)					(18.93)	(8.55)	(–17.76)
PIMPACT (%)	0.1514	0.2192	0.2398	0.1487	0.0658**	0.0216**	–0.0911**	0.1504	0.2264	0.2327	0.1480	0.0760**	0.0063**	–0.0847**
					(24.67)	(14.23)	(–36.73)					(32.82)	(8.78)	(–24.72)
PIMPACT_VW (%)	0.2219	0.3108	0.3278	0.2209	0.0889**	0.0170**	–0.1069**	0.2213	0.3154	0.3218	0.2210	0.0941**	0.0064**	–0.1008**
					(27.23)	(13.76)	(–39.41)					(33.15)	(7.96)	(–26.03)
DEPTH ($ in thousands)	38.49	31.37	24.18	38.23	–7.124**	–7.190**	14.05**	38.33	29.32	27.69	38.12	–9.010**	–1.630**	10.43**
					(–9.48)	(–11.69)	(16.07)					(–11.91)	(–7.29)	(9.57)
LAMBDA _1 x 10^6	3.772	5.076	6.325	3.808	1.262**	1.291**	–2.517**	3.682	5.144	5.640	3.734	1.462**	0.4960**	–1.906**
					(12.64)	(11.82)	(–12.88)					(14.86)	(7.73)	(–8.87)
LAMBDA_2 x 10^6	3.960	5.307	6.529	4.003	1.296**	1.273**	–2.526**	3.898	5.281	5.795	3.932	1.383**	0.5140**	–1.863**
					(13.02)	(11.35)	(–13.83)					(13.84)	(8.05)	(–7.92)

Table 1 (continued)
Comparisons of liquidity variables in the pre-COVID, pre-NTF, NTF, and post-NTF periods

Panel B: Difference-in-differences			
Variable	(Pre-NTF – Pre-COVID)$_{NYSE}$ – (Pre-NTF – Pre-COVID)$_{Nasdaq}$ = $\Delta P_1 - \Delta P_2$	(NTF – Pre-NTF)$_{NYSE}$ – (NTF – Pre-NTF)$_{Nasdaq}$ = $\Delta C_1 - \Delta C_2$	(Post-NTF – NTF)$_{NYSE}$ – (Post-NTF – NTF)$_{Nasdaq}$ = $\Delta R_1 - \Delta R_2$
QSP (%)	–0.0308**	0.0413**	–0.0123**
	(–13.53)	(14.21)	(–10.06)
ESP (%)	–0.0182**	0.0621**	–0.0434**
	(–10.44)	(16.84)	(–14.97)
ESP_VW (%)	–0.0109**	0.0513**	–0.0400**
	(–9.26)	(15.95)	(–15.62)
RSP (%)	–0.0080**	0.0468**	–0.0370**
	(–8.85)	(14.28)	(–12.85)
RSP_VW (%)	–0.0057**	0.0407**	–0.0339**
	(–7.98)	(14.32)	(–13.07)
PIMPACT (%)	–0.0102**	0.0153**	–0.0064**
	(–15.94)	(15.82)	(–7.87)
PIMPACT_VW (%)	–0.0052**	0.0106**	–0.0061**
	(–8.36)	(14.76)	(–7.59)
DEPTH ($ in thousands)	1.886**	–5.560**	3.620**
	(9.36)	(–13.59)	(10.83)
LAMBDA_1 x 10^6	–0.1996**	0.7950**	–0.6110**
	(–8.53)	(12.97)	(–10.71)
LAMBDA_2 x 10^6	–0.0867**	0.7590**	–0.6637**
	(–6.74)	(11.98)	(–11.07)

Table 2
Regression results for liquidity measures using pre-COVID, pre-NTF, NTF, and post-NTF periods

Panel A provides the estimation results of the following regression model using the matched NYSE and Nasdaq stocks in the pre-COVID and pre-NTF periods:

$$\mathrm{VAR}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \quad \text{(a)}$$

where subscripts i and t denote stock i and time t, VAR denotes each liquidity variable, NYSE is a dummy variable equal to one for the NYSE stocks and zero for the Nasdaq stocks, $\mathrm{D}^{\mathrm{Pre-NTF}}$ is a dummy variable equal to one for the pre-NTF period and zero for the pre-COVID period. PRICE is the stock price, VOLUME denotes the trading volume, RET is the stock return, VOLA is the return volatility, VIX is the CBOE's volatility index, λ_i denotes the firm fixed effects which capture the effect of time-invariant firm attributes on VAR, θ_t denotes the time fixed effects which control for the effect of firm-invariant (common or economy-wide) temporal changes in VAR, and ε denotes the error term. Panel B provides the estimation results of the following regression model using the matched NYSE and Nasdaq stocks in the pre-NTF and NTF periods:

$$\mathrm{VAR}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \quad \text{(b)}$$

where $\mathrm{D}^{\mathrm{NTF}}$ is a dummy variable equal to one for the NTF period and zero for the pre-NTF period. Panel C reports the estimation results of the following regression model using the matched NYSE and Nasdaq stocks in the NTF and post-NTF periods:

$$\mathrm{VAR}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{Post-NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{Post-NTF}} + \beta_3 \mathrm{PRICE}_{i,t} + \beta_4 \mathrm{VOLUME}_{i,t} + \beta_5 \mathrm{RET}_{i,t} + \beta_6 \mathrm{VOLA}_{i,t} + \beta_7 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \quad \text{(c)}$$

where $\mathrm{D}^{\mathrm{Post-NTF}}$ is a dummy variable equal to one for the post-NTF period and zero for the NTF period. We use clustered standard errors by firm in the regressions. We define January 22, 2020 to February 21, 2020 as the pre-COVID period, February 22, 2020 to March 22, 2020 as the pre-NTF period, March 23, 2020 to May 25, 2020 as the NTF period, and May 26, 2020 to June 25, 2020 as the post-NTF period. We use the following variables (VAR) as our empirical proxies for liquidity: quoted spread (QSP), effective spread (ESP), value-weighted effective spread (ESP_VW), realized spread (RSP), value-weighted realized spread (RSP_VW), price impact (PIMPACT), value-weighted price impact (PIMPACT_VW), quoted depth (DEPTH), price impact coefficient with intercept (LAMBDA_1), and price impact coefficient without intercept (LAMBDA_2). Numbers in parentheses are t-statistics. ** = significant at the one percent level. * = significant at the five percent level.

Panel A: Regression results using liquidity variables in the pre-COVID and pre-NTF periods (regression model (a))

Variable	QSP	ESP	ESP_VW	RSP	RSP_VW	PIMPACT	PIMPACT_VW	DEPTH	LAMBDA_1	LAMBDA_2
NYSE x $\mathrm{D}^{\mathrm{Pre-NTF}}$	–0.0296**	–0.0190**	–0.0112**	–0.0076**	–0.0061**	–0.0096**	–0.0058**	1.903**	–0.2018**	–0.0901**
	(–8.96)	(–7.74)	(–7.48)	(–8.58)	(–5.13)	(–6.87)	(–4.76)	(3.92)	(–3.74)	(–2.96)
NYSE	–0.0007	–0.0002	–0.0008	–0.0019	–0.0017	0.0025	0.0005	0.1586	0.0863	0.0591
	(–0.26)	(–0.13)	(–0.15)	(0.43)	(–0.27)	(0.41)	(0.16)	(0.77)	(1.60)	(1.22)
$\mathrm{D}^{\mathrm{Pre-NTF}}$	0.1560**	0.0950**	0.1266**	0.0177**	0.0309**	0.0751**	0.0935**	–8.883**	1.412**	1.357**
	(5.43)	(4.51)	(5.18)	(3.76)	(4.68)	(3.67)	(4.19)	(–3.59)	(3.11)	(2.88)
PRICE	–0.0365**	–0.0585**	–0.0754**	–0.0111**	–0.0148**	–0.0381**	–0.0567**	1.366**	–6.975**	–6.610**
	(–3.15)	(–7.95)	(–11.14)	(–3.49)	(–3.63)	(–10.45)	(–11.19)	(3.73)	(–27.33)	(–23.16)
VOLUME	–0.0824**	–0.0491**	–0.0541**	–0.0268**	–0.0168**	–0.0059**	–0.0102**	5.361**	–0.3208**	–0.3693**
	(–13.13)	(–11.90)	(–13.83)	(–9.91)	(–5.65)	(–3.68)	(–6.23)	(5.13)	(–3.29)	(–5.25)
RET	–0.0013**	–0.0003**	–0.0002**	–0.0001**	–0.0001**	–0.0005**	–0.0005**	0.0295**	–0.0148**	–0.0160**
	(–4.79)	(–3.46)	(–2.96)	(–3.53)	(–3.30)	(–6.70)	(–4.18)	(2.71)	(–2.93)	(–3.25)
VOLA	0.0102**	0.0114**	0.0123**	0.0036**	0.0040**	0.0060**	0.0081**	–0.0068**	0.0726**	0.0975**
	(26.41)	(25.74)	(24.90)	(21.60)	(22.34)	(16.86)	(17.86)	(–2.97)	(12.05)	(16.98)
VIX	0.2154**	0.1777**	0.1464**	0.0399**	0.0309**	0.0625**	0.1166**	–19.50**	5.501**	5.527**
	(3.12)	(4.53)	(3.87)	(3.53)	(3.20)	(3.92)	(4.35)	(–3.59)	(2.86)	(3.22)
Intercept	0.4879**	0.2492**	0.3241**	0.1027**	0.1041**	0.1497**	0.2199**	37.88**	3.614**	3.876**
	(7.50)	(3.25)	(4.61)	(2.94)	(2.89)	(3.81)	(3.17)	(3.84)	(3.06)	(3.32)
Adjusted R^2	0.67	0.82	0.69	0.58	0.32	0.56	0.45	0.82	0.36	0.37

Table 2 (continued)
Regression results for liquidity measures using pre-COVID, pre-NTF, NTF, and post-NTF periods

Panel B: Regression results using liquidity variables in the pre-NTF and NTF periods (regression model (b))

Variable	QSP	ESP	ESP_VW	RSP	RSP_VW	PIMPACT	PIMPACT_VW	DEPTH	LAMBDA_1	LAMBDA_2
NYSE x D^{NTF}	0.0409**	0.0617**	0.0508**	0.0461**	0.0416**	0.0148**	0.0112**	–5.524**	0.8103**	0.7611**
	(6.91)	(14.83)	(13.21)	(14.32)	(12.45)	(7.48)	(6.78)	(–6.13)	(4.81)	(4.67)
NYSE	–0.0322**	–0.0191**	–0.0113**	–0.0096**	–0.0079**	–0.0079**	–0.0052**	2.101**	–0.1204**	–0.0306*
	(–5.14)	(–4.87)	(–4.29)	(–5.97)	(–4.53)	(–5.46)	(–3.43)	(3.85)	(–2.69)	(–2.08)
D^{NTF}	0.0151**	0.0136**	0.0147**	0.0072**	0.0092**	0.0067**	0.0070**	–1.594**	0.5110**	0.5176**
	(4.42)	(3.72)	(3.58)	(3.41)	(3.88)	(3.76)	(3.92)	(–3.34)	(3.64)	(2.89)
PRICE	–0.0370**	–0.0381**	–0.0478**	–0.0068**	–0.0132**	–0.0449**	–0.0801**	1.518**	–6.653**	–6.518**
	(–3.15)	(–9.87)	(–10.54)	(–3.17)	(–9.03)	(–14.17)	(–19.72)	(5.76)	(–30.25)	(–29.62)
VOLUME	–0.0702**	–0.0087**	–0.0069**	–0.0148**	–0.0144**	–0.0061**	–0.0148**	6.305**	–0.2986**	–0.2305**
	(–10.87)	(–5.02)	(–4.74)	(–8.07)	(–4.81)	(–3.51)	(–4.89)	(29.57)	(–3.46)	(–2.95)
RET	–0.0005**	–0.0006**	–0.0004**	–0.0001**	–0.0002**	–0.0006**	–0.0002**	0.0334**	–0.0131**	–0.0176**
	(–3.76)	(–3.64)	(–3.82)	(–3.72)	(–3.50)	(–4.72)	(–3.31)	(4.61)	(–3.32)	(–3.54)
VOLA	0.0131**	0.0109**	0.0098**	0.0036**	0.0038**	0.0066**	0.0072**	–0.0071**	0.0741**	0.0931**
	(31.88)	(25.23)	(23.52)	(21.24)	(22.15)	(17.84)	(19.71)	(–2.91)	(14.23)	(16.24)
VIX	0.4052**	0.0856**	0.0674**	0.0411**	0.0427**	0.1557**	0.1202**	–20.38**	6.783**	4.942**
	(5.43)	(4.96)	(3.16)	(3.63)	(3.68)	(4.68)	(3.81)	(–4.06)	(2.97)	(2.86)
Intercept	0.6394**	0.3475**	0.4496**	0.1209**	0.1371**	0.2258**	0.3147**	29.27**	5.097**	5.225**
	(7.43)	(3.87)	(4.12)	(3.14)	(3.82)	(3.27)	(3.35)	(3.56)	(2.88)	(3.18)
Adjusted R^2	0.74	0.80	0.72	0.61	0.34	0.57	0.48	0.75	0.37	0.38

Panel C: Regression results using liquidity variables in the NTF and post-NTF periods (regression model (c))

Variable	QSP	ESP	ESP_VW	RSP	RSP_VW	PIMPACT	PIMPACT_VW	DEPTH	LAMBDA_1	LAMBDA_2
NYSE x $D^{Post\text{-}NTF}$	–0.0130**	–0.0429**	–0.0413**	–0.0362**	–0.0327**	–0.0070**	–0.0068**	3.702**	–0.6170**	–0.6710**
	(–6.91)	(–13.89)	(–12.95)	(–14.18)	(–10.79)	(–7.96)	(–6.14)	(5.90)	(–6.89)	(–7.87)
NYSE	0.0105**	0.0423**	0.0430**	0.0373**	0.0342**	0.0076**	0.0065**	–3.473**	0.6933**	0.7532**
	(3.82)	(4.47)	(4.87)	(3.66)	(4.63)	(4.97)	(4.33)	(–4.61)	(3.58)	(3.37)
$D^{Post\text{-}NTF}$	–0.1688**	–0.1106**	–0.1387**	–0.0278**	–0.0417**	–0.0819**	–0.0987**	9.987**	–2.017**	–1.836**
	(–4.21)	(–3.27)	(–3.70)	(–3.55)	(–3.86)	(–4.21)	(–4.38)	(4.77)	(–3.79)	(–3.47)
PRICE	–0.0080**	–0.0521**	–0.1075**	–0.0063**	–0.0319**	–0.0473**	–0.0741**	1.342**	–4.235**	–4.084**
	(–3.53)	(–18.26)	(–24.16)	(–4.71)	(–7.65)	(–17.76)	(–14.60)	(4.86)	(–19.92)	(–18.23)
VOLUME	–0.0835**	–0.0152**	–0.0077**	–0.0187**	–0.0088**	–0.0051**	–0.0098**	5.384**	–0.4040**	–0.3537**
	(–15.81)	(–9.73)	(–3.68)	(–10.54)	(–3.42)	(–3.37)	(–4.56)	(26.54)	(–3.71)	(–3.62)
RET	–0.0008**	–0.0007**	–0.0005**	–0.0014**	–0.0017**	–0.0022**	–0.0015**	0.0393**	–0.0039**	–0.0041**
	(–3.12)	(–4.82)	(–3.14)	(–12.76)	(–12.76)	(–5.43)	(–4.34)	(3.02)	(–3.47)	(–3.54)
VOLA	0.0114**	0.0100**	0.0118**	0.0041**	0.0035**	0.0066**	0.0068**	–0.0027**	0.0220**	0.0412**
	(23.43)	(19.84)	(20.81)	(16.53)	(15.86)	(17.10)	(17.47)	(–3.97)	(4.24)	(8.21)
VIX	0.1087**	0.0874**	0.0804**	0.0186**	0.0128**	0.0063*	0.0120**	–1.723**	2.058*	3.159**
	(3.09)	(3.13)	(3.02)	(2.78)	(2.71)	(2.52)	(2.98)	(–2.90)	(2.49)	(3.21)
Intercept	0.6553**	0.3598**	0.4659**	0.1289**	0.1444**	0.2319**	0.3201**	28.11**	5.598**	5.837**
	(3.76)	(3.11)	(3.67)	(2.90)	(4.10)	(2.89)	(3.43)	(4.27)	(3.36)	(3.88)
Adjusted R^2	0.75	0.84	0.75	0.64	0.37	0.57	0.46	0.83	0.38	0.40

Table 3

Comparisons of pricing efficiency measures in the pre-COVID, pre-NTF, NTF, and post-NTF periods

We define January 22, 2020 to February 21, 2020 as the pre-COVID period, February 22, 2020 to March 22, 2020 as the pre-NTF period, March 23, 2020 to May 25, 2020 as the NTF period, and May 26, 2020 to June 25, 2020 as the post-NTF period, where NTF stands for **n**o **t**rading **f**loor. For each period, we compute the mean value of each variable for our matched NYSE and Nasdaq sample stocks. We use multiple versions of variance ratio (VR) as empirical proxies for pricing efficiency: variance ratios based on 15-second / 3 x 5-second (VR_1), 1-minute / 4 x 15-second (VR_2), 5-minute / 5 x 1-minute (VR_3), 15-minute / 3 x 5-minute (VR_4), and 30-minute / 2 x 15-minute (VR_5). Panel A shows the mean values of each variable in the pre-COVID, pre-NTF, NTF, and post-NTF periods for the matched NYSE and Nasdaq sample stocks. Panel A also shows the differences in mean values between the pre-NTF and pre-COVID periods (i.e., Pre-NTF – Pre-COVID = ΔP1 for the NYSE stocks and ΔP2 for the Nasdaq stocks), between the NTF and pre-NTF periods (i.e., NTF – Pre-NTF = ΔC1 for the NYSE stocks and ΔC2 for the Nasdaq stocks), and between the Post-NTF and NTF periods (i.e., Post-NTF – NTF = ΔR1 for the NYSE stocks and ΔR2 for the Nasdaq stocks). Panel B shows the difference-in-difference values, i.e., $\Delta P_1 - \Delta P_2$ [(Pre-NTF – Pre-COVID)$_{NYSE}$ – (Pre-NTF – Pre-COVID)$_{Nasdaq}$], $\Delta C_1 - \Delta C_2$ [(NTF – Pre-NTF)$_{NYSE}$ – (NTF – Pre-NTF)$_{Nasdaq}$], and $\Delta R_1 - \Delta R_2$ [(Post-NTF – NTF)$_{NYSE}$ – (Post-NTF – NTF)$_{Nasdaq}$], where the subscripts NYSE and Nasdaq represent NYSE and Nasdaq stocks. Numbers in parentheses are t-statistics. ** = significant at the one percent level.

Panel A: Comparisons of pricing efficiency measures in the pre-COVID, pre-NTF, NTF, and post-NTF periods

	NYSE stocks							Nasdaq stocks						
Variable	Pre-COVID	Pre-NTF	NTF	Post-NTF	Pre-NTF – Pre-COVID (ΔP_1)	NTF – Pre-NTF (ΔC_1)	Post-NTF – NTF (ΔR_1)	Pre-COVID	Pre-NTF	NTF	Post-NTF	Pre-NTF – Pre-COVID (ΔP_2)	NTF – Pre-NTF (ΔC_2)	Post-NTF – NTF (ΔR_2)
VR_1	0.3788	0.3483	0.4115	0.3787	–0.0305**	0.0628**	–0.0324**	0.3816	0.3598	0.4071	0.3836	–0.0218**	0.0473**	–0.0235**
					(–27.58)	(46.27)	(–32.21)					(–17.15)	(31.77)	(–26.32)
VR_2	0.3349	0.3159	0.3719	0.3341	–0.0190**	0.0560**	–0.0378**	0.3351	0.3264	0.3604	0.3343	–0.0087**	0.0340**	–0.0261**
					(–15.46)	(35.61)	(–33.47)					(–9.79)	(19.81)	(–23.74)
VR_3	0.3154	0.2991	0.3320	0.3149	–0.0163**	0.0329**	–0.0171**	0.3153	0.3090	0.3255	0.3160	–0.0063**	0.0165**	–0.0095**
					(–15.34)	(22.78)	(–20.88)					(–8.96)	(12.76)	(–9.91)
VR_4	0.2981	0.2784	0.3092	0.2965	–0.0197**	0.0308**	–0.0127**	0.2965	0.2835	0.3015	0.2952	–0.0130**	0.0180**	–0.0063**
					(–15.86)	(19.42)	(–16.33)					(–12.47)	(12.92)	(–7.74)
VR_5	0.2838	0.2646	0.2971	0.2834	–0.0192**	0.0325**	–0.0137**	0.2834	0.2750	0.2886	0.2821	–0.0084**	0.0134**	–0.0065**
					(–16.87)	(20.86)	(–17.64)					(–10.53)	(10.98)	(–7.96)

Table 3 (continued)
Comparisons of pricing efficiency measures in the pre-COVID, pre-NTF, NTF, and post-NTF periods

Panel B: Difference-in-differences			
Variable	(Pre-NTF – Pre-COVID)$_{NYSE}$ – (Pre-NTF – Pre-COVID)$_{Nasdaq}$ = $\Delta P_1 - \Delta P_2$	(NTF – Pre-NTF)$_{NYSE}$ – (NTF – Pre-NTF)$_{Nasdaq}$ = $\Delta C_1 - \Delta C_2$	(Post-NTF – NTF)$_{NYSE}$ – (Post-NTF – NTF)$_{Nasdaq}$ = $\Delta R_1 - \Delta R_2$
VR_1	–0.0087**	0.0155**	–0.0089**
	(–10.38)	(12.04)	(–10.19)
VR_2	–0.0103**	0.0220**	–0.0117**
	(–10.73)	(15.19)	(–14.81)
VR_3	–0.0100**	0.0164**	–0.0076**
	(–10.56)	(12.13)	(–9.35)
VR_4	–0.0067**	0.0128**	–0.0064**
	(–8.67)	(11.27)	(–8.34)
VR_5	–0.0108**	0.0189**	–0.0072**
	(–9.86)	(14.92)	(–9.13)

Table 4

Regression results for pricing efficiency measures using pre-COVID, pre-NTF, NTF, and post-NTF periods

Panel A provides the estimation results of the following regression model using the matched NYSE and Nasdaq stocks in the pre-COVID and pre-NTF periods:

$$\mathrm{VAR}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \quad \text{(a)}$$

where subscripts i and t denote stock i and time t, VAR denotes each pricing efficiency variable, NYSE is a dummy variable equal to one for the NYSE stocks and zero for the Nasdaq stocks, $\mathrm{D}^{\mathrm{Pre-NTF}}$ is a dummy variable equal to one for the pre-NTF period and zero for the pre-COVID period. PRICE is the stock price, VOLUME denotes the trading volume, RET is the stock return, VOLA is the return volatility, VIX is the CBOE's volatility index, λ_i denotes the firm fixed effects which capture the effect of time-invariant firm attributes on VAR, θ_t denotes the time fixed effects which control for the effect of firm-invariant (common or economy-wide) temporal changes in VAR, and ε denotes the error term. Panel B reports the estimation results of the following regression model using the matched NYSE and Nasdaq stocks in the pre-NTF and NTF periods:

$$\mathrm{VAR}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \quad \text{(b)}$$

where $\mathrm{D}^{\mathrm{NTF}}$ is a dummy variable equal to one for the NTF period and zero for the pre-NTF period. Panel C provides the estimation results of the following regression model using the matched NYSE and Nasdaq stocks in the NTF and post-NTF periods:

$$\mathrm{VAR}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{Post-NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{Post-NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \quad \text{(c)}$$

where $\mathrm{D}^{\mathrm{Post-NTF}}$ is a dummy variable equal to one for the post-NTF period and zero for the NTF period. We use clustered standard errors by firm in the regressions. We use January 22, 2020 to February 21, 2020 as the pre-COVID period, February 22, 2020 to March 22, 2020 as the pre-NTF period, March 23, 2020 to May 25, 2020 as the NTF period, and May 26, 2020 to June 25, 2020 as the post-NTF period. We use multiple versions of variance ratio (VR) as our empirical proxies for pricing efficiency variables (VAR): variance ratios based on 15-second / 3 x 5-second (VR_1), 1-minute / 4 x 15-second (VR_2), 5-minute / 5 x 1-minute (VR_3), 15-minute / 3 x 5-minute (VR_4), and 30-minute / 2 x 15-minute (VR_5). Numbers in parentheses are t-statistics. ** = significant at the one percent level. * = significant at the five percent level.

Panel A: Regression results using pricing efficiency measures in the pre-COVID and pre-NTF periods (regression model (a))

Variable	VR_1	VR_2	VR_3	VR_4	VR_5
NYSE x $\mathrm{D}^{\mathrm{Pre-NTF}}$	–0.0084**	–0.0109**	–0.0113**	–0.0071**	–0.0115**
	(–5.32)	(–6.86)	(–5.97)	(–4.05)	(–4.84)
NYSE	–0.0021	–0.0001	–0.0001	0.0011	0.0003
	(–0.85)	(–0.08)	(–0.06)	(0.15)	(0.10)
$\mathrm{D}^{\mathrm{Pre-NTF}}$	–0.0209**	–0.0081**	–0.0059**	–0.0122**	–0.0089**
	(–3.65)	(–3.16)	(–2.83)	(–3.24)	(–2.81)
PRICE	0.0178**	0.0154**	0.0050**	0.0032**	0.0040**
	(10.29)	(6.97)	(4.93)	(3.74)	(3.87)
VOLUME	–0.0333**	–0.0186**	–0.0098**	–0.0061**	–0.0087**
	(–20.97)	(–8.43)	(–6.24)	(–4.57)	(–4.81)
RET	0.0001**	0.0003**	0.0005**	0.0002**	0.0001**
	(3.09)	(6.39)	(6.26)	(4.09)	(3.01)
VOLA	0.0015**	0.0014**	0.0008**	0.0005**	0.0004**
	(21.33)	(20.34)	(5.60)	(5.47)	(3.86)
VIX	–0.1061**	–0.0757**	–0.0536**	–0.0499**	–0.0466**
	(–3.28)	(–3.04)	(–2.88)	(–2.91)	(–2.73)
Intercept	0.3797**	0.3334**	0.3149**	0.2953**	0.2792**
	(4.85)	(4.20)	(4.36)	(4.03)	(3.86)
Adjusted R^2	0.82	0.74	0.45	0.18	0.12

Table 4 (continued)
Regression results for pricing efficiency measures using pre-COVID, pre-NTF, NTF, and post-NTF periods

Panel B: Regression results using pricing efficiency measures in the pre-NTF and NTF periods (regression model (b))					
Variable	VR_1	VR_2	VR_3	VR_4	VR_5
NYSE x D^{NTF}	0.0162**	0.0211**	0.0170**	0.0133**	0.0178**
	(9.49)	(11.35)	(6.24)	(5.26)	(5.81)
NYSE	–0.0121**	–0.0112**	–0.0108**	–0.0056**	–0.0094**
	(–4.03)	(–3.98)	(–4.05)	(–3.07)	(–3.78)
D^{NTF}	0.0466**	0.0333**	0.0159**	0.0174**	0.0129**
	(4.71)	(4.67)	(3.86)	(4.01)	(4.26)
PRICE	0.0130**	0.0152**	0.0055**	0.0114**	0.0113**
	(11.97)	(10.32)	(5.51)	(4.62)	(3.91)
VOLUME	–0.0428**	–0.0310**	–0.0121**	–0.0143**	–0.0115**
	(–29.66)	(–27.65)	(–7.11)	(–7.54)	(–5.51)
RET	0.0002**	0.0002**	0.0001**	0.0001**	0.0001**
	(3.51)	(4.41)	(3.34)	(3.62)	(2.92)
VOLA	0.0015**	0.0016**	0.0020**	0.0013**	0.0005**
	(23.42)	(21.81)	(23.86)	(15.84)	(4.70)
VIX	–0.1305**	–0.5402**	–0.3215**	–0.5530**	–0.7991**
	(–4.57)	(–9.25)	(–4.23)	(–5.88)	(–7.46)
Intercept	0.3612**	0.3249**	0.2983**	0.2826**	0.2738**
	(7.41)	(8.14)	(5.12)	(6.16)	(5.41)
Adjusted R^2	0.82	0.74	0.43	0.20	0.15

Panel C: Regression results using pricing efficiency measures in the NTF and post-NTF periods (regression model (c))					
Variable	VR_1	VR_2	VR_3	VR_4	VR_5
NYSE x $D^{Post\text{-}NTF}$	–0.0094**	–0.0123**	–0.0082**	–0.0070**	–0.0078**
	(–6.73)	(–7.34)	(–5.78)	(–5.39)	(–5.65)
NYSE	0.0045**	0.0123**	0.0061**	0.0082**	0.0090**
	(2.95)	(3.81)	(3.58)	(3.64)	(3.76)
$D^{Post\text{-}NTF}$	–0.0228**	–0.0254**	–0.0104**	–0.0069**	–0.0071**
	(–3.82)	(–4.17)	(–3.10)	(–2.74)	(–2.85)
PRICE	0.0090**	0.0061**	0.0016**	0.0021**	0.0015**
	(5.84)	(4.46)	(3.86)	(3.08)	(3.21)
VOLUME	–0.0455**	–0.0338**	–0.0030**	–0.0110**	–0.0091**
	(–20.06)	(–19.66)	(–6.02)	(–3.57)	(–3.95)
RET	0.0004**	0.0002**	0.0001**	0.0002**	0.0001**
	(3.88)	(3.52)	(2.87)	(3.24)	(2.97)
VOLA	0.0014**	0.0017**	0.0020**	0.0009**	0.0002**
	(31.57)	(32.41)	(33.41)	(13.68)	(4.18)
VIX	–0.0130**	–0.0065**	–0.0053**	–0.0022*	0.0041**
	(–3.45)	(–2.99)	(–2.81)	(–2.49)	(–2.79)
Intercept	0.4042**	0.3581**	0.3246**	0.3049**	0.2895**
	(3.68)	(3.43)	(3.30)	(2.94)	(2.85)
Adjusted R^2	0.83	0.78	0.47	0.19	0.17

Table 5

Comparisons of trading activity measures in the pre-COVID, pre-NTF, NTF, and post-NTF periods

We define January 22, 2020 to February 21, 2020 as the pre-COVID period, February 22, 2020 to March 22, 2020 as the pre-NTF period, March 23, 2020 to May 25, 2020 as the NTF period, and May 26, 2020 to June 25, 2020 as the post-NTF period, where NTF stands for **n**o **t**rading **f**loor. For each period, we compute the mean value of each variable for our matched NYSE and Nasdaq sample stocks. We use the following variables as our empirical proxies for trading activities: number of trades (NTRADE), total dollar volume (DVOL), number of intermarket sweep order trades (NISO), total intermarket sweep order dollar volume (DVISO), number of odd-lot trades (NODDLOT), and total odd-lot dollar volume (DVODDLOT. Panel A shows the mean values of each variable in the pre-COVID, pre-NTF, NTF, and post-NTF periods for the matched NYSE and Nasdaq sample stocks. Panel A also shows the differences in mean values between the pre-NTF and pre-COVID periods (i.e., Pre-NTF – Pre-COVID = ΔP1 for the NYSE stocks and ΔP2 for the Nasdaq stocks), between the NTF and pre-NTF periods (i.e., NTF – Pre-NTF = ΔC1 for the NYSE stocks and ΔC2 for the Nasdaq stocks), and between the Post-NTF and NTF periods (i.e., Post-NTF – NTF = ΔR1 for the NYSE stocks and ΔR2 for the Nasdaq stocks). Panel B shows the difference-in-difference values, i.e., $\Delta P_1 - \Delta P_2$ [(Pre-NTF – Pre-COVID)$_{NYSE}$ – (Pre-NTF – Pre-COVID)$_{Nasdaq}$], $\Delta C_1 - \Delta C_2$ [(NTF – Pre-NTF)$_{NYSE}$ – (NTF – Pre-NTF)$_{Nasdaq}$], and $\Delta R_1 - \Delta R_2$ [(Post-NTF – NTF)$_{NYSE}$ – (Post-NTF – NTF)$_{Nasdaq}$], where the subscripts NYSE and Nasdaq represent NYSE and Nasdaq stocks. Numbers in parentheses are t-statistics. ** = significant at the one percent level.

Panel A: Comparisons of trading activity measures in the pre-COVID, pre-NTF, NTF, and post-NTF periods

	NYSE stocks							Nasdaq stocks						
Variable	Pre-COVID	Pre-NTF	NTF	Post-NTF	Pre-NTF – Pre-COVID (ΔP_1)	NTF – Pre-NTF (ΔC_1)	Post-NTF – NTF (ΔR_1)	Pre-COVID	Pre-NTF	NTF	Post-NTF	Pre-NTF – Pre-COVID (ΔP_2)	NTF – Pre-NTF (ΔC_2)	Post-NTF – NTF (ΔR_2)
NTRADE	10,018	12,264	9,550	10,045	2,246**	–2,714**	495**	10,012	11,665	9,833	10,069	1,653**	–1,832**	236**
					(16.72)	(–18.67)	(13.61)					(11.96)	(–13.13)	(6.12)
DVOL ($ in millions)	70.97	83.78	60.83	71.19	12.81**	–22.95**	10.36**	68.08	75.35	60.99	68.55	7.270**	–14.36**	7.560**
					(13.34)	(–16.81)	(14.52)					(9.82)	(–9.57)	(8.47)
NISO	2,983	4,342	2,415	3,006	1,359**	–1,927**	591**	2,957	3.854	2,635	2,944	897**	–1219**	309**
					(24.72)	(–31.58)	(16.38)					(12.34)	(–16.87)	(11.21)
DVISO ($ in millions)	12.86	16.72	10.68	12.99	3.861**	–6.040**	2.310**	12.83	14.65	11.74	12.93	1,816**	–2.910**	1.190**
					(18.41)	(–17.45)	(15.47)					(11.32)	(–9.26)	(7.28)
NODDLOT	3,246	4,027	2,788	3,273	781**	–1,239**	485**	3,231	3,737	2,849	3,261	506**	–888**	412**
					(17.79)	(–21.04)	(14.05)					(10.65)	(–12.56)	(8.65)
DVODDLOT ($ in millions)	8.14	10.99	6.135	8.177	2.853**	–4.859**	2,042**	8.081	9.772	6.947	8.123	1.691**	–2.825**	1.176**
					(15.70)	(–19.26)	(18.74)					(8.93)	(–11.83)	(7.39)

Table 5 (continued)
Comparisons of trading activity measures in the pre-COVID, pre-NTF, NTF, and post-NTF periods

Panel B: Difference-in-differences			
Variable	(Pre-NTF – Pre-COVID)$_{NYSE}$ – (Pre-NTF – Pre-COVID)$_{Nasdaq}$ = $\Delta P_1 - \Delta P_2$	(NTF – Pre-NTF)$_{NYSE}$ – (NTF – Pre-NTF)$_{Nasdaq}$ = $\Delta C_1 - \Delta C_2$	(Post-NTF – NTF)$_{NYSE}$ – (Post-NTF – NTF)$_{Nasdaq}$ = $\Delta R_1 - \Delta R_2$
NTRADE	593**	–882**	259**
	(9.15)	(–10.46)	(9.46)
DVOL ($ in millions)	5.540**	–8.590**	2.800**
	(7.94)	(–12.64)	(8.62)
NISO	462**	–708**	282**
	(12.71)	(–13.54)	(8.21)
DVISO ($ in millions)	2.045**	–3.130**	1.120**
	(14.43)	(–14.24)	(10.75)
NODDLOT	275**	–351**	73**
	(8.51)	(–10.68)	(6.23)
DVODDLOT ($ in millions)	1.162**	–2.034**	0.8660**
	(14.73)	(–15.38)	(12.77)

Table 6

Regression results for trading activity measures using pre-COVID, pre-NTF, NTF, and post-NTF periods

Panel A provides the estimation results of the following regression model using the matched NYSE and Nasdaq stocks in the pre-COVID and pre-NTF periods:

$$\mathrm{VAR}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE\ x\ D}^{\mathrm{Pre-NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \quad (a)$$

where subscripts i and t denote stock i and time t, VAR denotes each trading activity variable, NYSE is a dummy variable equal to one for the NYSE stocks and zero for the Nasdaq stocks, $D^{Pre-NTF}$ is a dummy variable equal to one for the pre-NTF period and zero for the pre-COVID period. PRICE is the stock price, VOLUME denotes the trading volume, RET is the stock return, VOLA is the return volatility, VIX is the CBOE's volatility index, λ_i denotes the firm fixed effects which capture the effect of time-invariant firm attributes on VAR, θ_t denotes the time fixed effects which control for the effect of firm-invariant (common or economy-wide) temporal changes in VAR, and ε denotes the error term. Panel B reports the estimation results of the following regression model using the matched NYSE and Nasdaq stocks in the pre-NTF and NTF periods:

$$\mathrm{VAR}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE\ x\ D}^{\mathrm{NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \quad (b)$$

where D^{NTF} is a dummy variable equal to one for the NTF period and zero for the pre-NTF period. Panel C provides the estimation results of the following regression model using the matched NYSE and Nasdaq stocks in the NTF and post-NTF periods:

$$\mathrm{VAR}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE\ x\ D}^{\mathrm{Post-NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{Post-NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \quad (c)$$

where $D^{Post-NTF}$ is a dummy variable equal to one for the post-NTF period and zero for the NTF period. We use clustered standard errors by firm in the regressions. We use January 22, 2020 to February 21, 2020 as the pre-COVID period, February 22, 2020 to March 22, 2020 as the pre-NTF period, March 23, 2020 to May 25, 2020 as the NTF period, and May 26, 2020 to June 25, 2020 as the post-NTF period. We use the following variables (VAR) as our empirical proxies for trading activity variables: number of trades (NTRADE), total dollar volume (DVOL), number of intermarket sweep order trades (NISO), total intermarket sweep order dollar volume (DVISO), number of odd-lot trades (NODDLOT), and total odd-lot dollar volume (DVODDLOT). We exclude the control variable VOLUME from the NTRADE and DVOL regressions. Numbers in parentheses are t-statistics. ** = significant at the one percent level. * = significant at the five percent level.

Panel A: Regression results using trading activity measures in the pre-COVID and pre-NTF periods (regression model (a))

Variable	NTRADE	DVOL	NISO	DVISO	NODDLOT	DVODDLOT
NYSE x $D^{Pre-NTF}$	586.2**	5.561**	470.6**	2.039**	278.2**	1.170**
	(6.96)	(5.33)	(4.94)	(5.38)	(4.19)	(4.82)
NYSE	5.881	2.574	24.93	0.0192	14.94	0.0588
	(0.53)	(1.39)	(0.66)	(0.43)	(0.74)	(0.57)
$D^{Pre-NTF}$	1638**	6.951**	886.6**	1.793**	498.5**	1.636**
	(3.51)	(3.89)	(4.20)	(3.34)	(4.31)	(3.47)
PRICE	537.6**	13.14**	–1493**	–1.375**	–454.2**	–0.9064**
	(5.43)	(15.68)	(–10.39)	(–4.27)	(–11.96)	(–9.54)
VOLUME			4737**	19.67**	6799**	13.89**
			(19.35)	(18.84)	(25.59)	(20.02)
RET	–16.91**	–0.1274**	–6.446**	–0.0116**	–1.298**	–0.0118**
	(–3.75)	(–3.40)	(–6.63)	(–2.93)	(–2.77)	(–2.85)
VOLA	–32.18**	0.1541**	–11.87**	0.0153**	2.543**	0.0079*
	(–11.89)	(5.95)	(–13.79)	(3.06)	(2.97)	(2.41)
VIX	2367**	85.19**	3386**	0.9338**	3711**	0.1735*
	(3.38)	(3.67)	(3.40)	(2.80)	(3.26)	(2.48)
Intercept	9997**	67.80**	2933**	12.76**	3213**	7.934**
	(4.16)	(4.26)	(2.91)	(3.09)	(3.67)	(3.14)
Adjusted R^2	0.83	0.90	0.87	0.87	0.90	0.92

Table 6 (continued)
Regression results for trading activity measures using pre-COVID, pre-NTF, NTF, and post-NTF periods

Panel B: Regression results using trading activity measures in the pre-NTF and NTF periods (regression model (b))						
Variable	NTRADE	DVOL	NISO	DVISO	NODDLOT	DVODDLOT
NYSE x D^{NTF}	–867.9**	–8.611**	–697.7**	–3.204**	–347.8**	–1.991**
	(–13.88)	(–14.64)	(–12.43)	(–6.38)	(–5.80)	(–5.14)
NYSE	612.6**	8.711**	479.2**	1.985**	295.4**	1.198**
	(4.72)	(4.16)	(5.67)	(4.09)	(3.88)	(4.58)
D^{NTF}	–1791**	–14.68**	–1188**	–3.152**	–871.6**	–2.785**
	(–4.37)	(–4.16)	(–5.21)	(–4.43)	(–4.95)	(–2.87)
PRICE	532.9**	16.86**	–1675**	–2.054**	–489.7**	–0.9002**
	(6.54)	(19.24)	(–22.94)	(–11.87)	(–15.36)	(–11.75)
VOLUME			5352**	25.77**	6323**	10.93**
			(24.53)	(22.65)	(21.54)	(18.94)
RET	–18.12**	–0.1805**	–8.812**	–0.0190**	–1.472**	–0.0157**
	(–4.14)	(–4.22)	(–5.27)	(–3.66)	(–4.25)	(–2.81)
VOLA	–55.36**	0.1241**	–13.42**	0.0141**	3.733**	0.1016**
	(–20.78)	(5.75)	(–17.70)	(3.17)	(3.65)	(2.92)
VIX	15616**	190.7**	4404**	0.8901**	4162**	0.1561**
	(5.04)	(6.82)	(3.95)	(3.12)	(4.11)	(2.73)
Intercept	11621**	76.60**	3911**	14.47**	3783**	9.694**
	(4.61)	(3.42)	(3.27)	(3.26)	(3.14)	(2.92)
Adjusted R^2	0.84	0.87	0.86	0.85	0.88	0.89

Panel B: Regression results using trading activity measures in the NTF and post-NTF periods (regression model (c))						
Variable	NTRADE	DVOL	NISO	DVISO	NODDLOT	DVODDLOT
NYSE x $D^{Post\text{-}NTF}$	263.8**	2.754**	287.7**	1.139**	75.22**	0.8581**
	(5.17)	(5.85)	(7.89)	(4.93)	(3.97)	(4.59)
NYSE	–280.1**	–0.1813*	–216.6**	–0.9892**	–64.66**	–0.7867**
	(–4.06)	(–2.39)	(–4.31)	(–4.23)	(–3.95)	(–3.48)
$D^{Post\text{-}NTF}$	232.5**	7.383**	289.9**	1.223**	419.5**	1.213**
	(3.24)	(4.81)	(4.73)	(3.71)	(4.63)	(3.67)
PRICE	1532**	18.85**	–898.5**	–1.776**	–381.7**	–0.7624**
	(10.58)	(15.52)	(–12.36)	(–11.80)	(–12.89)	(–3.86)
VOLUME			5493**	29.38**	6596**	11.06**
			(28.62)	(29.86)	(22.87)	(21.85)
RET	–10.91**	–0.0916*	–6.781**	–0.0324**	–0.1221*	–0.0284**
	(–3.57)	(–2.52)	(–3.92)	(–6.31)	(–2.50)	(–5.31)
VOLA	–44.23**	–0.0553**	–10.87**	0.0170**	2.362**	0.0071**
	(–13.75)	(–3.37)	(–14.26)	(3.56)	(2.89)	(3.12)
VIX	668.6**	2.518**	297.3**	0.2122*	325.2**	0.0663**
	(3.42)	(3.02)	(2.89)	(2.54)	(3.91)	(2.77)
Intercept	9791**	58.62**	2597**	11.51**	2788**	6.786**
	(4.16)	(2.86)	(3.15)	(3.27)	(3.79)	(3.70)
Adjusted R^2	0.88	0.87	0.89	0.86	0.89	0.90

Table 7
Changes in liquidity, pricing efficiency, and trading between the pre-COVID and other periods

This table provides the estimation results of the following regression model using the matched NYSE and Nasdaq stocks in the pre-COVID, pre-NTF, NTF, and post NTF periods:

$$\mathrm{VAR}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_2 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{NTF}} + \beta_3 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{Post-NTF}} + \beta_4 \mathrm{NYSE}_i + \beta_5 \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_6 \mathrm{D}^{\mathrm{NTF}} + \beta_7 \mathrm{D}^{\mathrm{Post-NTF}} + \beta_8 \mathrm{PRICE}_{i,t} + \beta_9 \mathrm{VOLUME}_{i,t} + \beta_{10} \mathrm{RET}_{i,t} + \beta_{11} \mathrm{VOLA}_{i,t} + \beta_{12} \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{I,t};$$

where subscripts i and t denote stock i and time t, VAR denotes each liquidity variable, NYSE is a dummy variable equal to one for the NYSE stocks and zero for the Nasdaq stocks, $D^{Pre-NTF}$ is a dummy variable equal to one for the pre-NTF period and zero otherwise, D^{NTF} is a dummy variable equal to one for the NTF period and zero otherwise, $D^{Post-NTF}$ is a dummy variable equal to one for the post-NTF period and zero otherwise. PRICE is the stock price, VOLUME denotes the trading volume, RET is the stock return, VOLA is the return volatility, VIX is the CBOE Volatility Index, λ_i denotes the firm fixed effects which capture the effect of time-invariant firm attributes on VAR, θ_t denotes the time fixed effects which control for the effect of firm-invariant (common or economy-wide) temporal changes in VAR, and ε denotes the error term. We use clustered standard errors by firm in the regressions. We use January 22, 2020 to February 21, 2020 as the pre-COVID period, February 22, 2020 to March 22, 2020 as the pre-NTF period, March 23, 2020 to May 25, 2020 as the NTF period, and May 26, 2020 to June 25, 2020 as the post-NTF period. We use the following variables (VAR) as our empirical proxies for liquidity: quoted spread (QSP), effective spread (ESP), value-weighted effective spread (ESP_VW), realized spread (RSP), value-weighted realized spread (RSP_VW), price impact (PIMPACT), value-weighted price impact (PIMPACT_VW), quoted depth (DEPTH), price impact coefficient with intercept (LAMBDA_1), and price impact coefficient without intercept (LAMBDA_2). We use multiple versions of variance ratio (VR) as our empirical proxies for pricing efficiency measures (VAR): variance ratios based on 15-second / 3 x 5-second (VR_1), 1-minute / 4 x 15-second (VR_2), 5-minute / 5 x 1-minute (VR_3), 15-minute / 3 x 5-minute (VR_4), and 30-minute / 2 x 15-minute (VR_5). We use the following variables (VAR) as our empirical proxies for trading activity variables: number of trades (NTRADE), total dollar volume (DVOL), number of intermarket sweep order trades (NISO), total intermarket sweep order dollar volume (DVISO), number of odd-lot trades (NODDLOT), and total odd-lot dollar volume (DVODDLOT). We exclude the control variable VOLUME from the NTRADE and DVOL regressions. To save space, we omit the results for the control variables. Numbers in parentheses are t-statistics. ** = significant at the one percent level.

Panel A: Regression results for liquidity variables

Variable	QSP	ESP	ESP_VW	RSP	RSP_VW	PIMPACT	PIMPACT_VW	DEPTH	LAMBDA_1	LAMBDA_2
NYSE x $D^{Pre-NTF}$	–0.0301**	–0.0188**	–0.0114**	–0.0077**	–0.0060**	–0.0098**	–0.0055**	1.907**	–0.2012**	–0.0896**
	(–4.71)	(–8.35)	(–6.63)	(–6.43)	(–4.97)	(–5.21)	(–4.33)	(5.25)	(–3.37)	(–2.82)
NYSE x D^{NTF}	0.0110**	0.0444**	0.0410**	0.0376**	0.0342**	0.0056**	0.0058**	–3.599**	0.6238**	0.6511**
	(3.14)	(9.21)	(8.34)	(9.52)	(9.15)	(3.94)	(4.14)	(–4.57)	(4.31)	(3.67)
NYSE x $D^{Post-NTF}$	–0.0014	0.0002	0.0005	0.0013	0.0008	–0.0010	–0.0009	–0.0485	–0.0120	0.0085
	(–0.40)	(0.23)	(0.38)	(0.43)	(0.36)	(–0.54)	(–0.61)	(–0.21)	(–0.18)	(0.46)
NYSE	–0.0003	–0.0002	–0.0006	–0.0020	–0.0017	0.0016	0.0005	0.1588	0.0783	0.0572
	(–0.24)	(–0.31)	(–0.49)	(–0.65)	(–0.51)	(0.66)	(0.38)	(0.53)	(0.54)	(0.39)
$D^{Pre-NTF}$	0.1548**	0.0951**	0.1263**	0.0191**	0.0311**	0.0751**	0.0932**	–8.886**	1.535**	1.425**
	(4.67)	(4.36)	(4.51)	(3.87)	(5.13)	(4.78)	(4.89)	(–4.43)	(2.92)	(2.75)
D^{NTF}	0.1689**	0.1073**	0.1415**	0.0270**	0.0391**	0.0819**	0.0996**	–10.26**	2.238**	2.026**
	(3.96)	(4.87)	(4.35)	(3.29)	(3.90)	(4.35)	(3.42)	(–4.98)	(3.74)	(3.45)
$D^{Post-NTF}$	0.0005	–0.0024	–0.0011	–0.0002	–0.0005	–0.0020	–0.0001	–0.1722	0.0471	0.0283
	(0.42)	(–0.48)	(–0.29)	(–0.17)	(–0.18)	(–0.51)	(–0.11)	(–0.60)	(0.41)	(0.27)
Adjusted R^2	0.73	0.82	0.71	0.58	0.36	0.56	0.44	0.79	0.36	0.37

Table 7 (continued)
Changes in liquidity, pricing efficiency, and trading between the pre-COVID and other periods

Panel B: Regression results for pricing efficiency variables

Variable	VR_1	VR_2	VR_3	VR_4	VR_5
NYSE x $D^{Pre\text{-}NTF}$	–0.0089**	–0.0111**	–0.0109**	–0.0072**	–0.0113**
	(–6.58)	(–6.97)	(–5.72)	(–4.73)	(–5.97)
NYSE x D^{NTF}	0.0073**	0.0125**	0.0070**	0.0065**	0.0086**
	(5.42)	(6.43)	(4.87)	(4.27)	(4.58)
NYSE x $D^{Post\text{-}NTF}$	–0.0016	–0.0001	–0.0009	–0.0001	0.0006
	(–1.17)	(–0.10)	(–0.53)	(–0.15)	(0.43)
NYSE	–0.0023	–0.0003	0.0001	0.0019	0.0007
	(–1.41)	(–0.26)	(0.17)	(0.58)	(0.46)
$D^{Pre\text{-}NTF}$	–0.0212**	–0.0084**	–0.0061**	–0.0126**	–0.0086**
	(–4.66)	(–3.34)	(–3.26)	(–4.12)	(–3.78)
D^{NTF}	0.0248**	0.0248**	0.0261**	0.0055**	0.0057**
	(3.98)	(3.80)	(4.39)	(2.90)	(3.37)
$D^{Post\text{-}NTF}$	–0.0005	–0.0009	0.0005	–0.0010	–0.0015
	(–0.35)	(–0.49)	(0.46)	(–0.65)	(–0.71)
Adjusted R^2	0.83	0.75	0.47	0.15	0.11

Panel C: Regression results for trading activity variables

Variable	NTRADE	DVOL	NISO	DVISO	NODDLOT	DVODDLOT
NYSE x $D^{Pre\text{-}NTF}$	587.6**	5.554**	465.5**	2.087**	–279.9**	1.168**
	(5.95)	(5.73)	(6.11)	(7.24)	(–6.38)	(5.96)
NYSE x D^{NTF}	–302.3**	–2.911**	–256.7**	–1.135**	–84.31**	–0.9136**
	(–5.27)	(–3.99)	(–4.59)	(–5.01)	(–2.70)	(–4.80)
NYSE x $D^{Post\text{-}NTF}$	–25.29	–0.1923**	31.40	0.0423	–3.542	–0.0050
	(–0.46)	(–0.36)	(0.48)	(0.12)	(0.15)	(0.22)
NYSE	5.782	2.381	22.43	0.0337	14.82	0.0613
	(0.32)	(1.57)	(0.51)	(0.16)	(0.47)	(0.45)
$D^{Pre\text{-}NTF}$	1644**	7.151**	888.9**	1.803**	501.7**	1.672**
	(4.73)	(3.65)	(5.02)	(3.72)	(4.81)	(4.31)
D^{NTF}	–202.7**	–7.668**	–331.7**	–1.179**	–374.3**	–1.096**
	(2.84)	(3.26)	(4.28)	(–3.47)	(–4.05)	(–3.76)
$D^{Post\text{-}NTF}$	49.13	0.4354	–15.31**	0.1251	28.16	0.0362
	(0.81)	(0.57)	(0.21)	(0.27)	(0.64)	(0.30)
Adjusted R^2	0.84	0.88	0.90	0.89	0.88	0.91

Table 8

Liquidity and informed trading as pricing efficiency channels: The two-stage least squares (2SLS) regression analysis using COVID-19, the NYSE trading floor closure, and the NYSE trading floor reopening as instruments

To examine whether COVID-19 led to an increase in pricing efficiency through the channels of liquidity and informed trading, we estimate the following first-stage regression model using the matched NYSE and Nasdaq stocks in the pre-COVID and pre-NTF periods:

$$\mathrm{LIQUIDITY}_{i,t} \text{ or } \mathrm{TRADING}_{i,t} = \beta_0 + \beta_1 \mathrm{NYSE} \times \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} + \beta_6 \mathrm{RET}_{I,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \quad \text{(a)}$$

where LIQUIDITY is either the effective spread (ESP) or price impact (PIMPACT), TRADING is either the intermarket sweep order dollar volume (DVISO) or the odd-lot dollar volume (DVODDLOT), and all other variables are the same as previously defined. We then estimate the following second-stage regression model:

$$\mathrm{VR}_{i,t} = \beta_0 + \beta_{1L} \widehat{\mathrm{LIQUIDITY}}_{i,t} + \beta_{1T} \widehat{\mathrm{TRADING}}_{i,t} + \beta_2 \mathrm{NYSE} + \beta_3 \mathrm{D}^{\mathrm{Pre-NTF}} + \beta_4 \mathrm{PRICE}_{i,t} + \beta_5 \mathrm{VOLUME}_{i,t} + \beta_6 \mathrm{RET}_{i,t} + \beta_7 \mathrm{VOLA}_{i,t} + \beta_8 \mathrm{VIX}_t + \lambda_i + \theta_t + \varepsilon_{i,t}; \quad \text{(b)}$$

where VR is one of the five variance ratios and $\widehat{\mathrm{LIQUIDITY}}$ ($\widehat{\mathrm{TRADING}}$) is the predicted value of LIQUIDITY (TRADING) from the first-stage regression model (a). Panel A reports the estimates of β_{1L} and β_{1T} from the second-stage regression model (b) using each of the five variance ratios as the dependent variable. The left half of the panel shows the results when we measure liquidity by the effective spread (ESP) and the right half shows the results when we measure liquidity by price impact (PIMPACT). Within each half, we show the results when we measure informed trading by DVISO and DVODDLOT, respectively. To examine whether the closure of the NYSE trading floor led to a decrease in pricing efficiency through the channels of liquidity and informed trading, we estimate regression models (a) and (b) using the matched NYSE and Nasdaq stocks in the pre-NTF and NTF periods after we replace NYSE x $\mathrm{D}^{\mathrm{Pre-NTF}}$ in regression model (a) with NYSE x $\mathrm{D}^{\mathrm{NTF}}$ and $\mathrm{D}^{\mathrm{Pre-NTF}}$ in regression models (a) and (b) with $\mathrm{D}^{\mathrm{NTF}}$. Panel B reports the estimates of β_{1L} and β_{1T} from the second-stage regression model (b) using each of the five variance ratios as the dependent variable. To examine whether the reopening of the NYSE trading floor led to an increase in pricing efficiency through the channels of liquidity and informed trading, we estimate regression models (a) and (b) using the matched NYSE and Nasdaq stocks in the NTF and post-NTF periods after replacing NYSE x $\mathrm{D}^{\mathrm{Pre-NTF}}$ in regression model (a) with NYSE x $\mathrm{D}^{\mathrm{Post-NTF}}$ and $\mathrm{D}^{\mathrm{Pre-NTF}}$ in regression models (a) and (b) with $\mathrm{D}^{\mathrm{Post-NTF}}$. Panel C reports the estimates of β_{1L} and β_{1T} from the second-stage regression model (b). We use clustered standard errors by firm in the regressions. We use January 22, 2020 to February 21, 2020 as the pre-COVID period, February 22, 2020 to March 22, 2020 as the pre-NTF period, March 23, 2020 to May 25, 2020 as the NTF period, and May 26, 2020 to June 25, 2020 as the post-NTF period. Numbers in parentheses are t-statistics. ** = significant at the one percent level.

Panel A: Results for β_{1L} and β_{1T} from the second-stage regression model (b) using the pre–COVID and pre–NTF periods

Dep. var.	Results for ESP (β_{1L}) and DVISO or DVODDLOT (β_{1T})				Results for PIMPACT (β_{1L}) and DVISO or DVODDLOT (β_{1T})			
	ESP	0.3185**	ESP	0.3177**	PIMPACT	0.4709**	PIMPACT	0.4726**
		(10.58)		(10.49)		(9.54)		(10.05)
VR_1	DVISO	–0.0107**	DVODDLOT	–0.0148**	DVISO	–0.0092**	DVODDLOT	–0.0124**
		(–9.89)		(–10.17)		(–9.38)		(–9.13)
	Adj. R^2	0.84	Adj. R^2	0.83	Adj. R^2	0.86	Adj. R^2	0.85
	ESP	0.3064**	ESP	0.3056**	PIMPACT	0.4592**	PIMPACT	0.4609**
		(9.37)		(9.61)		(8.91)		(9.18)
VR_2	DVISO	–0.0093**	DVODDLOT	–0.0115**	DVISO	–0.0080**	DVODDLOT	–0.0108**
		(–8.88)		(–8.10)		(–8.72)		(–7.96)
	Adj. R^2	0.76	Adj. R^2	0.77	Adj. R^2	0.74	Adj. R^2	0.75
	ESP	0.2713**	ESP	0.2694**	PIMPACT	0.4320**	PIMPACT	0.4345**
		(7.52)		(7.50)		(8.76)		(8.68)
VR_3	DVISO	–0.0079**	DVODDLOT	–0.0091**	DVISO	–0.0071**	DVODDLOT	–0.0096**
		(–8.62)		(–8.68)		(–7.76)		(–6.85)
	Adj. R^2	0.56	Adj. R^2	0.56	Adj. R^2	0.58	Adj. R^2	0.57
	ESP	0.1221**	ESP	0.1299**	PIMPACT	0.2589**	PIMPACT	0.2568**
		(4.95)		(4.86)		(5.59)		(5.93)
VR_4	DVISO	–0.0047**	DVISO	–0.0064**	DVISO	–0.0059**	DVODDLOT	–0.0081**
		(–5.11)		(–5.24)		(–6.09)		(–5.72)
	Adj. R^2	0.42	Adj. R^2	0.41	Adj. R^2	0.44	Adj. R^2	0.43
	ESP	0.0080**	ESP	0.0075**	PIMPACT	0.1119**	PIMPACT	0.1125**
		(4.87)		(4.62)		(3.71)		(3.81)
VR_5	DVISO	–0.0035**	DVODDLOT	–0.0049**	DVISO	–0.0037**	DVODDLOT	–0.0073**
		(–4.43)		(–3.74)		(–4.26)		(–4.58)
	Adj. R^2	0.24	Adj. R^2	0.23	Adj. R^2	0.26	Adj. R^2	0.26

Table 8 (continued)

Liquidity and informed trading as pricing efficiency channels: The two-stage least squares (2SLS) regression analysis using COVID-19, the NYSE trading floor closure, and the NYSE trading floor reopening as instruments

Panel B: Results for β_{1L} and β_{1T} from the second-stage regression model (b) using the pre–NTF and NTF periods								
Dep. var.	Results for ESP (β_{1L}) and DVISO or DVODDLOT (β_{1T})				Results for PIMPACT (β_{1L}) and DVISO or DVODDLOT (β_{1T})			
	ESP	0.3108**	ESP	0.3119**	PIMPACT	0.4818**	PIMPACT	0.4787**
		(9.22)		(9.43)		(10.49)		(10.84)
VR_1	DVISO	–0.0094**	DVODDLOT	–0.0126**	DVISO	–0.0097**	DVODDLOT	–0.0138**
		(–10.84)		(–9.52)		(–9.97)		(–10.16)
	Adj. R^2	0.83	Adj. R^2	0.82	Adj. R^2	0.85	Adj. R^2	0.84
	ESP	0.2980**	ESP	0.2979**	PIMPACT	0.4405**	PIMPACT	0.4354**
		(8.10)		(8.25)		(9.72)		(9.60)
VR_2	DVISO	–0.0085**	DVODDLOT	–0.0104**	DVISO	–0.0077**	DVODDLOT	–0.0119**
		(–9.78)		(–8.85)		(–8.59)		(–9.32)
	Adj. R^2	0.75	Adj. R^2	0.76	Adj. R^2	0.72	Adj. R^2	0.71
	ESP	0.2757**	ESP	0.2795**	PIMPACT	0.4236**	PIMPACT	0.4206**
		(7.81)		(7.84)		(9.37)		(9.30)
VR_3	DVISO	–0.0074**	DVODDLOT	–0.0086**	DVISO	–0.0066**	DVODDLOT	–0.0108**
		(–8.91)		(–7.64)		(–7.71)		(–8.65)
	Adj. R^2	0.53	Adj. R^2	0.54	Adj. R^2	0.56	Adj. R^2	0.56
	ESP	0.1237**	ESP	0.1265**	PIMPACT	0.2316**	PIMPACT	0.2472**
		(5.28)		(5.73)		(6.31)		(6.78)
VR_4	DVISO	–0.0042**	DVISO	–0.0065**	DVISO	–0.0051**	DVODDLOT	–0.0084**
		(–6.57)		(–6.94)		(–5.45)		(–5.76)
	Adj. R^2	0.39	Adj. R^2	0.40	Adj. R^2	0.37	Adj. R^2	0.36
	ESP	0.0072**	ESP	0.0069**	PIMPACT	0.1103**	PIMPACT	0.1097**
		(4.70)		(3.96)		(3.92)		(4.32)
VR_5	DVISO	–0.0031**	DVODDLOT	–0.0056**	DVISO	–0.0033**	DVODDLOT	–0.0070**
		(–5.30)		(–4.63)		(–5.40)		(–4.76)
	Adj. R^2	0.20	Adj. R^2	0.21	Adj. R^2	0.23	Adj. R^2	0.22
Panel C: Results for β_{1L} and β_{1T} from the second-stage regression model (b) using the NTF and post–NTF periods								
Dep. var.	Results for ESP (β_{1L}) and DVISO or DVODDLOT (β_{1T})				Results for PIMPACT (β_{1L}) and DVISO or DVODDLOT (β_{1T})			
	ESP	0.3091**	ESP	0.3062**	PIMPACT	0.5190**	PIMPACT	0.5160**
		(8.91)		(8.55)		(11.35)		(11.44)
VR_1	DVISO	–0.0087**	DVODDLOT	–0.0112**	DVISO	–0.0088**	DVODDLOT	–0.0121**
		(–8.83)		(–10.00)		(–9.68)		(–9.29)
	Adj. R^2	0.85	Adj. R^2	0.84	Adj. R^2	0.87	Adj. R^2	0.86
	ESP	0.2812**	ESP	0.2772**	PIMPACT	0.4799**	PIMPACT	0.4805**
		(7.39)		(8.05)		(9.07)		(9.41)
VR_2	DVISO	–0.0070**	DVODDLOT	–0.0095**	DVISO	–0.0066**	DVODDLOT	–0.0105**
		(–7.42)		(–8.30)		(–7.60)		(–8.23)
	Adj. R^2	0.78	Adj. R^2	0.79	Adj. R^2	0.76	Adj. R^2	0.77
	ESP	0.2759**	ESP	0.2798**	PIMPACT	0.4413**	PIMPACT	0.4383**
		(7.80)		(7.67)		(8.67)		(8.88)
VR_3	DVISO	–0.0067**	DVODDLOT	–0.0081**	DVISO	–0.0059**	DVODDLOT	–0.0090**
		(–8.57)		(–9.72)		(–6.27)		(–7.94)
	Adj. R^2	0.58	Adj. R^2	0.58	Adj. R^2	0.55	Adj. R^2	0.54
	ESP	0.1331**	ESP	0.1371**	PIMPACT	0.2788**	PIMPACT	0.2826**
		(5.03)		(5.12)		(5.94)		(6.02)
VR_4	DVISO	–0.0044**	DVISO	–0.0056**	DVISO	–0.0048**	DVODDLOT	–0.0077**
		(–5.36)		(–4.81)		(–4.37)		(–4.93)
	Adj. R^2	0.40	Adj. R^2	0.39	Adj. R^2	0.42	Adj. R^2	0.41
	ESP	0.0087**	ESP	0.0084**	PIMPACT	0.1245**	PIMPACT	0.1241**
		(4.31)		(4.87)		(3.64)		(3.55)
VR_5	DVISO	–0.0038**	DVODDLOT	–0.0045**	DVISO	–0.0029**	DVODDLOT	–0.0062**
		(–4.02)		(–3.80)		(–3.87)		(–4.26)
	Adj. R^2	0.22	Adj. R^2	0.23	Adj. R^2	0.24	Adj. R^2	0.24

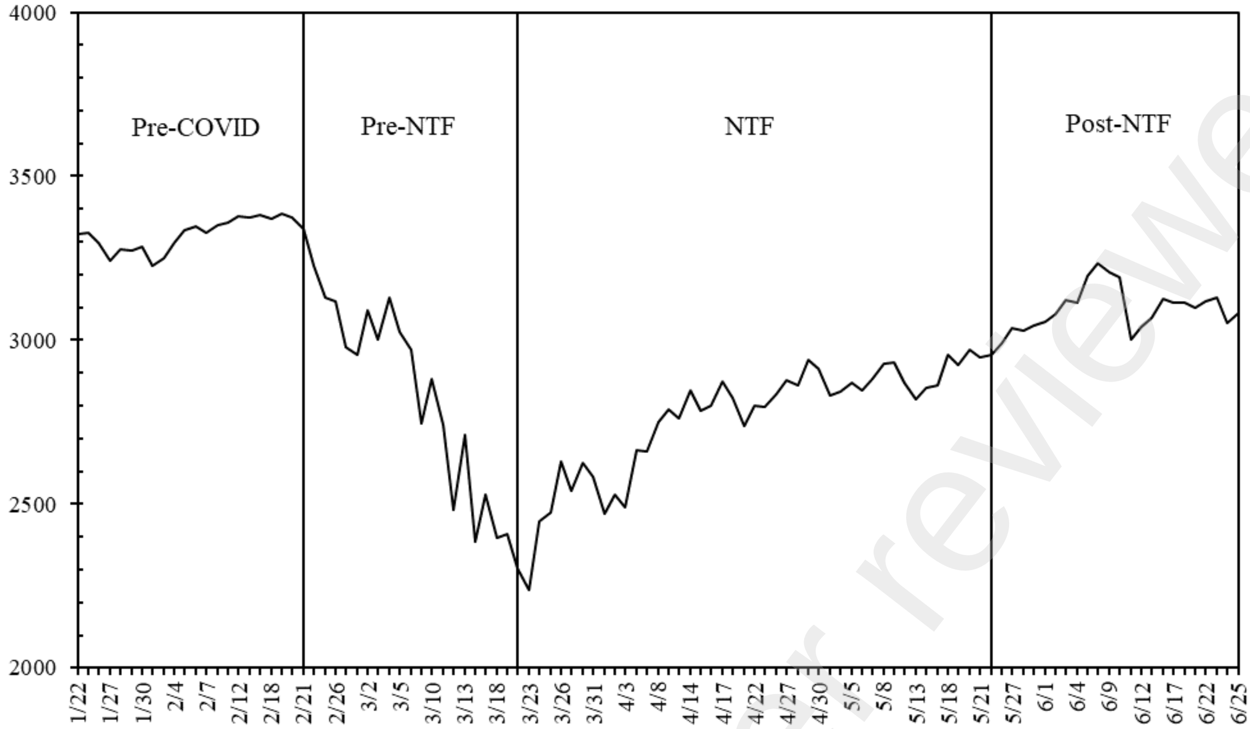

Figure 1: S&P 500 Index in the pre-COVID, pre-NTF, NTF, and post-NTF periods. The figure shows the values of the S&P 500 index in the pre-COVID (January 22 to February 21), pre-NTF (February 22 to March 22), NTF (March 23 to May 25) and post-NTF (May 26 to June 25) periods, where NTF stands for no trading floor.

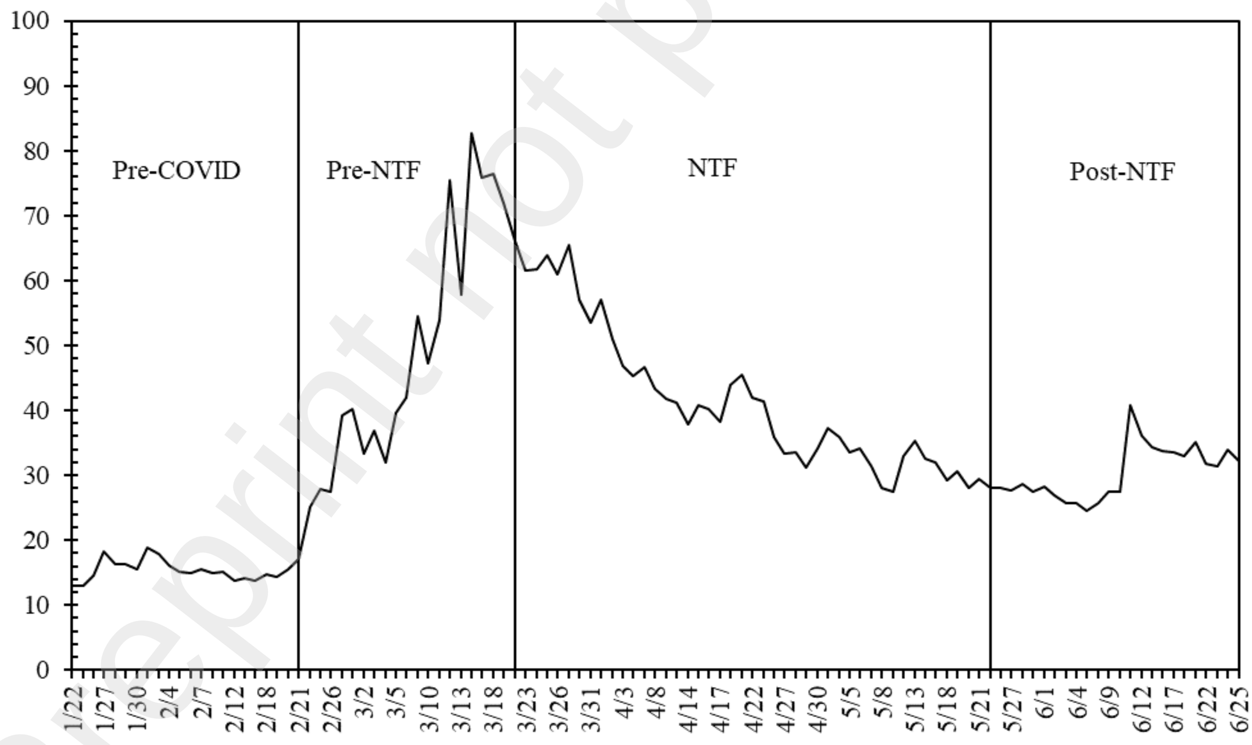

Figure 2: CBOE Volatility Index (VIX) in the pre-COVID, pre-NTF, NTF, and post-NTF periods. The figure shows the values of the VIX index in the pre-COVID (January 22 to February 21), pre-NTF (February 22 to March 22), NTF (March 23 to May 25) and post-NTF (May 26 to June 25) periods, where NTF stands for no trading floor.

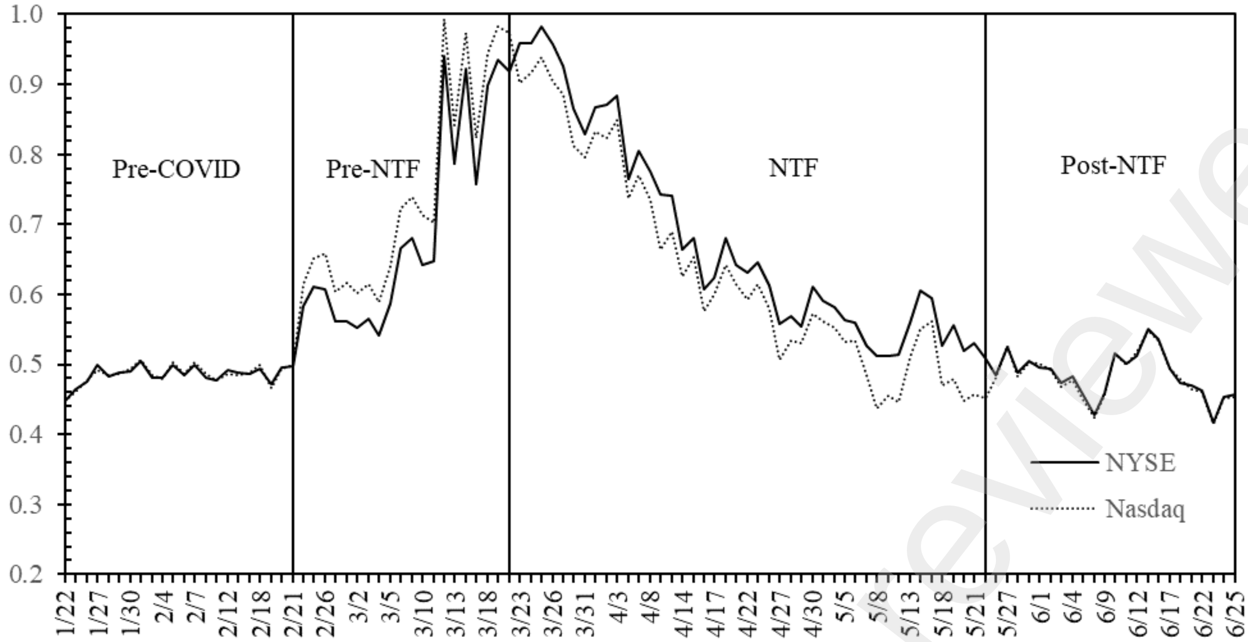

Figure 3: Quoted spreads (QSP) for NYSE and Nasdaq stocks in the pre-COVID, pre-NTF, NTF, and post-NTF periods.The figure shows the values of quoted spread for NYSE and Nasdaq stocks in the pre-COVID (January 22, 2020 to February 21, 2020), pre-NTF (February 22, 2020 to March 22, 2020), NTF (March 23, 2020 to May 22,2020) and post-NTF (May 26, 2020 to June 25, 2020) periods.

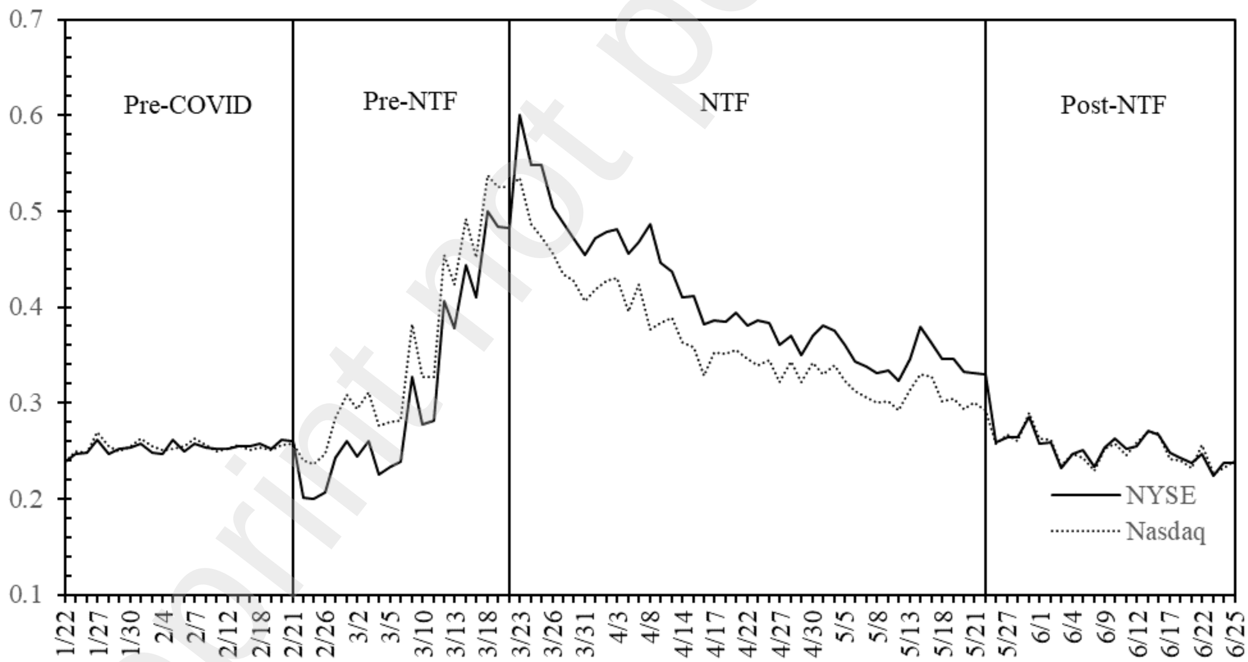

Figure 4: Effective spreads (ESP) for NYSE and Nasdaq stocks in the pre-COVID, pre-NTF, NTF, and post-NTF periods. The figure shows the values of effective spread for NYSE and Nasdaq stocks in the pre-COVID (January 22, 2020 to February 21, 2020), pre-NTF (February 22, 2020 to March 22, 2020), NTF (March 23, 2020 to May 22,2020) and post-NTF (May 26, 2020 to June 25, 2020) periods.

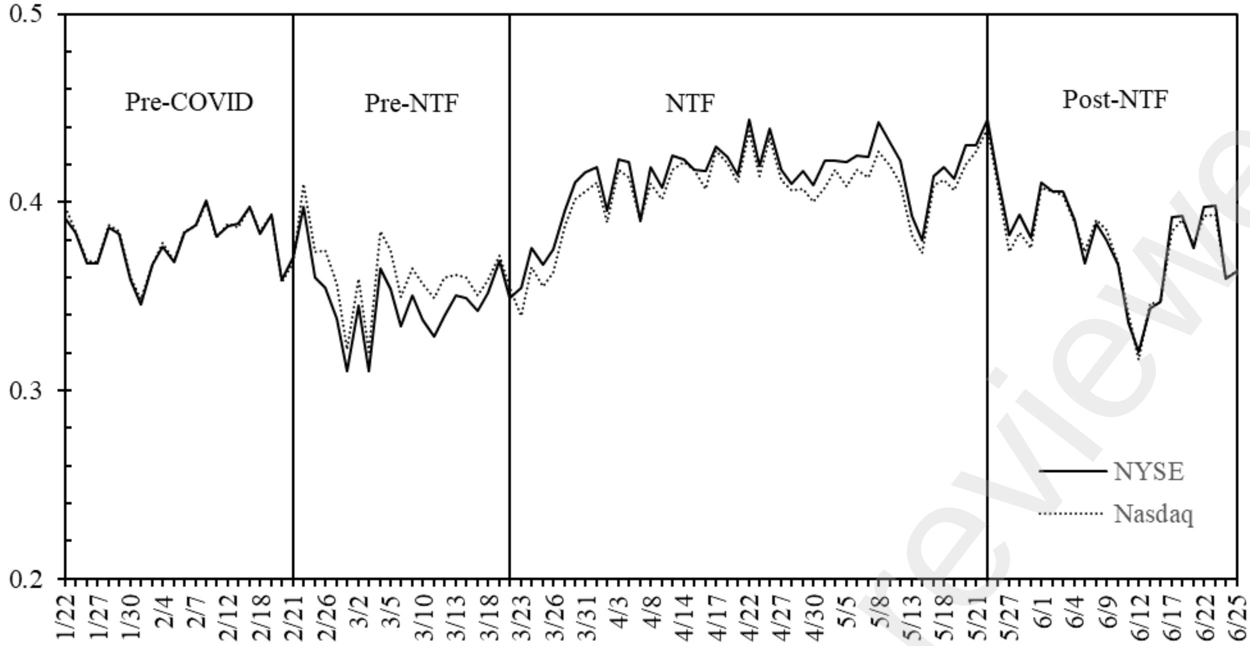

Figure 5: Variance ratios (VR_1) for NYSE and Nasdaq stocks in the pre-COVID, pre-NTF, NTF, and post-NTF periods.The figure shows the values of variance ratio for NYSE and Nasdaq stocks in the pre-COVID (January 22, 2020 to February 21, 2020), pre-NTF (February 22, 2020 to March 22, 2020), NTF (March 23, 2020 to May 22,2020) and post-NTF (May 26, 2020 to June 25, 2020) periods.

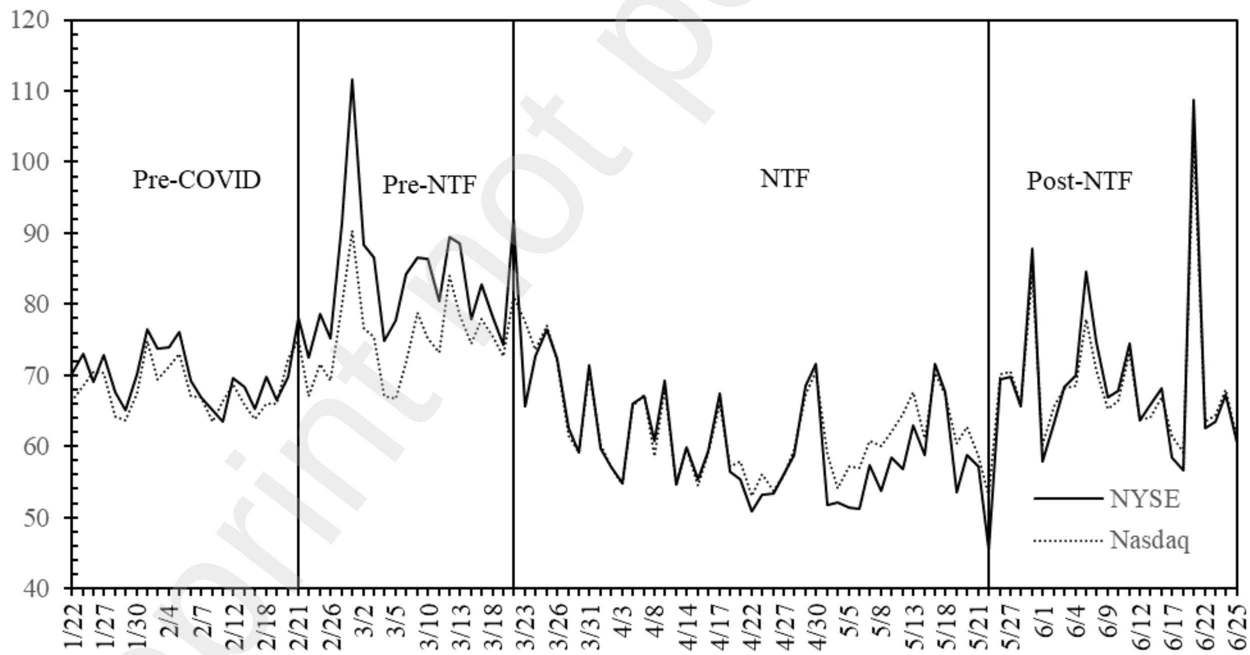

Figure 6: Dollar volume (DVOL) for NYSE and Nasdaq stocks in the pre-COVID, pre-NTF, NTF, and post-NTF periods.The figure shows the values of dollar volume for NYSE and Nasdaq stocks in the pre-COVID (January 22, 2020 to February 21, 2020), pre-NTF (February 22, 2020 to March 22, 2020), NTF (March 23, 2020 to May 22,2020) and post-NTF (May 26, 2020 to June 25, 2020) periods.

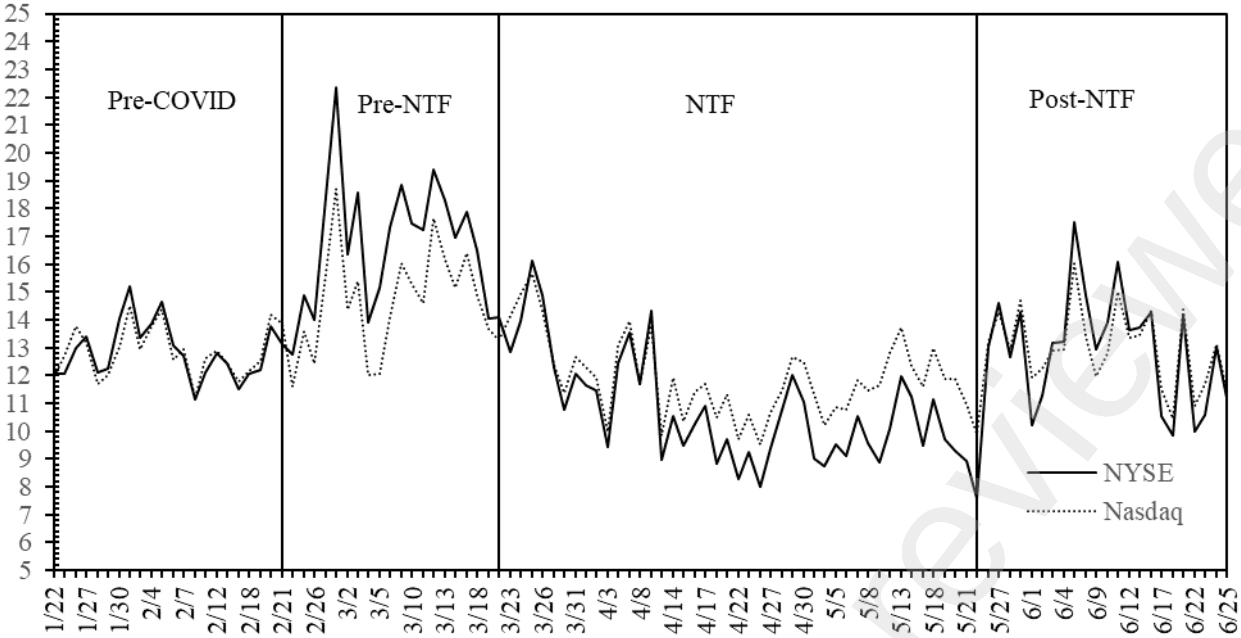

Figure 7: ISO volume (DVISO) for NYSE and Nasdaq stocks in the pre-COVID, pre-NTF, NTF, and post-NTF periods.The figure shows the values of ISO dollar volume for NYSE and Nasdaq stocks in the pre-COVID (January 22, 2020 to February 21, 2020), pre-NTF (February 22, 2020 to March 22, 2020), NTF (March 23, 2020 to May 22,2020) and post-NTF (May 26, 2020 to June 25, 2020) periods.

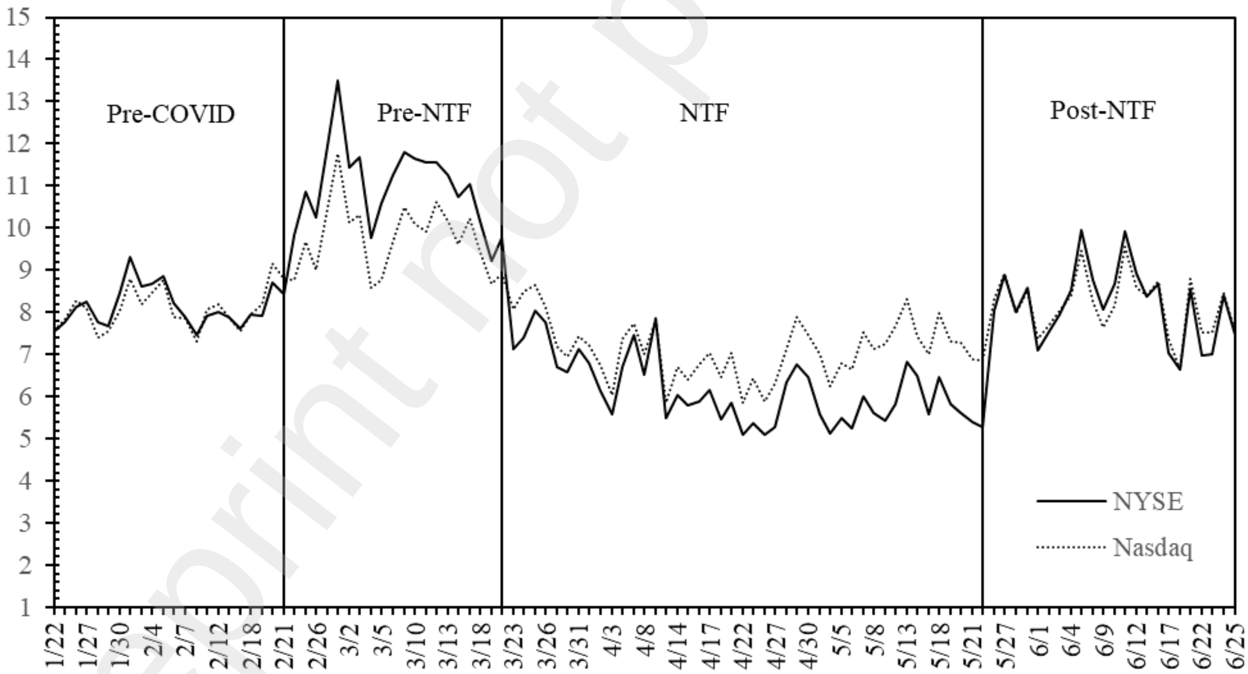

Figure 8: Odd lot volume (DVODDLOT) for NYSE and Nasdaq stocks in the pre-COVID, pre-NTF, NTF, and post-NTF periods.The figure shows the values of odd lot dollar volume for NYSE and Nasdaq stocks in the pre-COVID (January 22, 2020 to February 21, 2020), pre-NTF (February 22, 2020 to March 22, 2020), NTF (March 23, 2020 to May 22,2020) and post-NTF (May 26, 2020 to June 25, 2020) periods.

Appendix A

Variable Definitions

Nomenclature

P_k = price of trade k

SHR_k = size (in number of shares) of trade k

$Dvol_k$ = dollar volume of trade k = P_k x SHR_k

BUY_k = a buy order for trade k

$SELL_k$ = a sell order for trade k

B_k = bid price at the time of trade k or quote k

A_k = ask price at the time of trade k or quote k

M_k = bid-ask quote midpoint = $(B_k + A_k) / 2$ at the time of trade k or quote k

$BSIZE_k$ = quoted depth (size) at the bid price at the time of trade k or quote k

$ASIZE_k$ = quoted depth (size) at the ask price at the time of trade k or quote k

D_k = +1 if trade k is a buy and −1 if trade k is a sell

Variable	Definition
Time-Weighted Average Percentage Quoted Spread (QSP) of stock i on day t	$QSP_{i,t} = \sum_{k=1}^{N} w_k \left\{\frac{(A_k - B_k)}{M_k}\right\}$, where $w_k = \frac{\text{duration of quote k}}{\text{total duration of trading day t}}$, and N is the total number of quotes of stock i on day t
Simple Averaged Percentage Effective Spread (ESP) of stock i on day t	$ESP_{i,t} = \frac{1}{N}\sum_{k=1}^{N} \left\{\frac{2D_k(P_k - M_k)}{M_k}\right\}$, where N is the total number of trades of stock i on day t
Value-Weighted Percentage Effective Spread (ESP_VW) of stock i on day t	$ESP_{VW_{i,t}} = \sum_{k=1}^{N} w_k \left\{\frac{2D_k(P_k - M_k)}{M_k}\right\}$, where $w_k = \frac{P_k \text{ x } SHR_k}{\sum_{k=1}^{N} P_k \text{ x } SHR_k}$, and N is the total number of trades of stock i on day t
Simple Averaged Percent Realized Spread (RSP) of stock i on day t	$RSP_{i,t} = \frac{1}{N}\sum_{k=1}^{N} \left\{\frac{2D_k(P_k - M_{k+5})}{M_k}\right\}$, where M_{k+5} is the bid-ask quote midpoint five minutes after the k^{th} trade and N is the total number of trades of stock i on day t
Value-Weighted Percentage Realized Spread (RSP_VW) of stock i on day t	$RSP\_VW_{i,t} = \sum_{k=1}^{N} w_k \left\{\frac{2D_k(P_k - M_{k+5})}{M_k}\right\}$, where $w_k = \frac{P_k \text{ x } SHR_k}{\sum_{k=1}^{N} P_k \text{ x } SHR_k}$, M_{k+5} is the bid-ask quote midpoint five minutes after the k^{th} trade and N is the total number of trades of stock i on day t
Simple Averaged Percentage Price Impact (PIMPACT) of stock i on day t	$PIMPACT_{i,t} = \frac{1}{N}\sum_{k=1}^{N} \left\{\frac{2D_k(M_{k+5} - M_k)}{M_k}\right\}$, where M_{k+5} is the bid-ask quote midpoint five minutes after the k^{th} trade and N is the total number of trades of stock i on day t
Value-Weighted Percentage Price Impact (PIMPACT_VW) of stock i on day t	$PIMPACT\_VW_{i,t} = \sum_{k=1}^{N} w_k \left\{\frac{2D_k(M_{k+5} - M_k)}{M_k}\right\}$, where $w_k = \frac{P_k \text{ x } SHR_k}{\sum_{k=1}^{N} P_k \text{ x } SHR_k}$, M_{k+5} is the bid-ask quote midpoint five minutes after the k^{th} trade and N is the total number of trades of stock i on day t
Time-Weighted Quoted Depth (DEPTH) of stock i on day t	$DEPTH_{i,t} = \sum_{k=1}^{N} w_k(ASIZE_k + BSIZE_k)$, where $w_k = \frac{\text{duration of quote k}}{\text{total duration of trading day t}}$, and N is the total number of quotes of stock i on day t

Price impact coefficient (λ) with intercept (LAMBDA_1)	The regression coefficient (λ) of the following model: $\mathrm{Ln}\,\frac{M_{i,t}}{M_{i,t-300}} = \alpha + \lambda * \mathrm{SSqrtDVol} + \varepsilon$, where $\mathrm{SSqrtDVol} = \mathrm{Sgn}(\sum_{t-300}^{t} \mathrm{BuySHR} - \sum_{t-300}^{t} \mathrm{SellSHR})$ x $\sqrt{\lvert \sum_{t-300}^{t} \mathrm{BuySHR} - \sum_{t-300}^{t} \mathrm{SellSHR} \rvert}$, $M_{i,t} = \frac{B_{i,t}+A_{i,t}}{2}$ is the bid-ask midpoint of stock i at second t
Price impact coefficient (λ) without intercept (LAMBDA_2)	The regression coefficient (λ) of the following model: $\mathrm{Ln}\,\frac{M_{i,t}}{M_{i,t-300}} = \lambda * \mathrm{SSqrtDVol} + \varepsilon$, where $\mathrm{SSqrtDVol} = \mathrm{Sgn}(\sum_{t-300}^{t} \mathrm{BuySHR} - \sum_{t-300}^{t} \mathrm{SellSHR})$ x $\sqrt{\lvert \sum_{t-300}^{t} \mathrm{BuySHR} - \sum_{t-300}^{t} \mathrm{SellSHR} \rvert}$, $M_{i,t} = \frac{B_{i,t}+A_{i,t}}{2}$ is the bid-ask midpoint of stock i at second t
Variance ratio based on 15-second/3*5-second (VR_1)	$\mathrm{VR\_1} = \left\lvert \frac{\mathrm{VAR}(\mathrm{Ret}_{15t})}{3\,\mathrm{VAR}(\mathrm{Ret}_{5t})} - 1 \right\rvert$, where $\mathrm{VAR}(\mathrm{Ret}_{15t})$ is the variance of 15-second log returns
Variance ratio based on 1-min/4*15-second (VR_2)	$\mathrm{VR\_2} = \left\lvert \frac{\mathrm{VAR}(\mathrm{Ret}_{60t})}{4\,\mathrm{VAR}(\mathrm{Ret}_{15t})} - 1 \right\rvert$, where $\mathrm{VAR}(\mathrm{Ret}_{60t})$ is the variance of 1-minute log returns
Variance ratio based on 5-minute/5*1-minute (VR_3)	$\mathrm{VR\_3} = \left\lvert \frac{\mathrm{VAR}(\mathrm{Ret}_{300t})}{5\,\mathrm{VAR}(\mathrm{Ret}_{60t})} - 1 \right\rvert$, where $\mathrm{VAR}(\mathrm{Ret}_{300t})$ is the variance of 5-minute log returns
Variance ratio based on 15-minute/3*5-minute (VR_4)	$\mathrm{VR\_4} = \left\lvert \frac{\mathrm{VAR}(\mathrm{Ret}_{900t})}{3\,\mathrm{VAR}(\mathrm{Ret}_{300t})} - 1 \right\rvert$, where $\mathrm{VAR}(\mathrm{Ret}_{900t})$ is the variance of 15-minute log returns
Variance ratio based on 30-minute/2*15-minute (VR_5)	$\mathrm{VR\_5} = \left\lvert \frac{\mathrm{VAR}(\mathrm{Ret}_{1800t})}{2\,\mathrm{VAR}(\mathrm{Ret}_{900t})} - 1 \right\rvert$, where $\mathrm{VAR}(\mathrm{Ret}_{1800t})$ is the variance of 30-minute log returns
NTRADE	Number of trades
DVOL	Dollar trading volume
NISO	Number of intermarket sweep order trades
DVISO	Dollar value of intermarket sweep order trades
NODDLOT	Number of odd-lot trades
DVODDLOT	Dollar value of odd-lot trades
PRICE	Price of stock i on day t
RET	Return of stock i on day t
VOLUME	Dollar volume of stock i on day t = $\sum_{k=1}^{N} \mathrm{Price}_k$ x Share volume_k, where N is the total number of trades of stock i on day t
VOLA	Standard deviation of stock returns = $\frac{\sum_{\tau=1}^{t}(\mathrm{Ret}_{i,\tau} - \overline{\mathrm{Ret}_{i,\tau}})^2}{t-1}$