Contagious margin calls: How COVID-19 threatened global stock market liquidity

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Abstract

The COVID-19 pandemic has caused some of the largest — and fastest — market dislocations in modern history. Contemporaneous with the significant fall in equity market values is the evaporation of market liquidity. We show that transactions costs increase sharply in a coordinated fashion across global markets, with depth drying up almost overnight. We show the increase in margin requirements of over 300% results in the withdrawal of global liquidity suppliers, driving a pro-cyclical downwards liquidity spiral. These effects are concentrated in securities most exposed to electronic liquidity provides, consistent with the binding nature of increased capital constraints.

Keywords: COVID-19; Margin requirements; Stock market liquidity, liquidity spiral
JEL classifications: G01; G12; G14; G15;

Highlights

- COVID-19 pandemic increases equity market margins by more than 300% almost overnight.
- Binding margins lead market makers to withdraw from equity markets.
- Market maker withdrawal precipitates downward liquidity spiral, reducing depth and increasing transactions costs.
- Negative liquidity impacts most pronounced for stocks most exposed to HFT market makers.

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Introduction

> *"We can't bid on anything that adds to the balance sheet right now."*
>
> — Justin Baer, "The Day Coronavirus Nearly Broke the Financial Markets"
> *Wall Street Journal*, May 20, 2020

This quote from Vikram Rao — head bond trader of Capital Group — with respect to the purchase of U.S. Treasury bonds during the height of the COVID-19 pandemic exposes one of the major issues faced by global equity market makers — a downward liquidity spiral exacerbated by the significant increase in margin requirements the world over. An announcement from one of the only listed global equity market makers, Virtu Financial, echoed a similar sentiment:

> *"Given the sustained levels of extraordinary volatility in the current macro environment ... we consider it prudent to opportunistically supplement our borrowing capacity."*
>
> — Virtu Financial Press Release, March 20, 2020

Indeed, Virtu required a temporary addition of $450 million USD in "additional broker dealer capital" to continue their global market making operations. Their announcement came nine days after the World Health Organization (WHO) declared COVID-19 to be a global pandemic. An announcement which itself triggered global equities and futures markets to begin a pro-cyclical process of increasing margin requirements for all traders at the same time as extreme volatility washed through financial markets.

Recent theory models postulate the potential for a negative liquidity spiral when there is a sharp drop in traders' funding liquidity. Brunnermeier and Pedersen (2009) documents that the increased trading margins required by exchanges to minimize counterparty default risk between participants increases funding liquidity risk. This in turn causes reductions in market liquidity, resulting in a pro-cyclical negative liquidity spiral. However, there are few empirical tests of these predictions, as large changes to margin requirements do not frequently occur.

The COVID-19 pandemic caused some of the largest dislocations in market history: Equity market values fell by 30-40% globally, and the withdrawal of liquidity supply correlated with an increase of 200-300% in margin requirements across global exchanges. Moreover, some exchanges, such as the London Stock Exchange (LSE) experienced much larger increases in margins relative to other exchanges, such as the Chicago Mercantile Exchange (CME).

We exploit these margin differentials between U.K. and U.S. markets to test theory predicting that an increase in capital requirements results in a reduction in market liquidity. Using ETFs that track the S&P500 index traded on the LSE and NYSE, we examine whether market liquidity deteriorates due to an increase in margin using a difference-in-difference framework.

Next, we generalize our finding to a global setting. Specifically, we investigate changes in the liquidity of index and non-index stocks following margin spikes for a large cross-section of global equity markets. We argue that high frequency trading (HFT) market makers are more reliant on leverage to provide liquidity and thus, their behavior is more sensitive to margin requirements than traditional investors. Further, HFT market makers are more likely to be present in index stocks, relative to non-index stocks, which have lower HFT participation (Foley et al., 2021). As HFT market makers withdraw their activity due to margin constraints, we expect this withdrawal of liquidity to be most pronounced in the index stocks in which they are most active. Last, to confirm our assertion that HFT market makers are more prevalent in index stocks, we investigate changes in the order-to-trade ratio, which we use as a proxy for HFT activity in global equities.

Our results strongly support theoretical predictions that an increase in capital requirements leads to a decline in equity market liquidity. We document three main findings. First, for our analysis on the S&P500 ETFs listed on LSE and NYSE, we show that market liquidity deteriorates more in the U.K., which experienced a larger increase in margin, than in the U.S., where margins remained relatively static. Further, we find a reversal when the margin differential declines. Specifically, while U.K. margins increased precipitously when U.S. margins were relatively static, the U.S. subsequently experienced a large jump in margin requirements, narrowing the margin differential. Corresponding to this subsequent jump in U.S. margins, we show that NYSE market liquidity deteriorates relative to that of the LSE.

Second, consistent with the notion that increases in margin requirements have a larger impact on stocks where a higher proportion of liquidity is provided by electronic market markers, we report a larger deterioration in liquidity for index stocks as compared to non-index stocks. This result is also consistent with the theoretical model developed by Cespa and Foucalt (2014), where liquidity contagion from the index derivatives has a muted impact on non-index stocks. Finally, we show that electronic market makers withdrew liquidity more from index stocks, than non-index stocks, when exchange margin requirements suddenly increased.

Overall, our results show that the higher margin requirements increases funding liquidity risk, leading to a sharp reduction in equity market liquidity. This margin-induced shock to funding liquidity impacted the available market liquidity exactly at the time equity market price levels were falling, due to the unprecedented global risk COVID-19 posed to company cash flows. Our findings suggest that the reduction in liquidity exacerbates the pre-existing funding liquidity risk, forcing traders (and specifically high-frequency market makers) to de-leverage their positions precisely at the point in time when prices were declining, further depressing prices, consistent with the theoretical findings of Morris and Shin (2004). Given other "value" traders face similar funding constraints (as noted by Shleifer and Vishny (1992)), this further amplifies the margin loss-spiral, as these traders seek to offload securities at fire-sale prices, resulting in the rapid reduction in both market liquidity and prices observed in March 2020.

The significance of the capital constraints faced by existing Electronic Liquidity Providers (ELPs) has become particularly important in a world where the majority of liquidity is provided by only a handful of firms — such as Citadel and Virtu. When these firms represent the majority of liquidity provision not only *within* a market, but also *across* markets, the pro-cyclicality of their available committed capital represents a systemic risk which should no longer be ignored.

Indeed, in many countries, regulatory "crisis capital" is made available to banks *exactly* in order to protect markets from such pro-cyclical margin-loss spirals. These have been shown to increase total welfare of both borrowers and lenders (Benes and Kumhof, 2015) by reducing loan losses and attenuating the extent to which banks reduce their lending during crises (Jokivuolle et al., 2015). Given the concentration of global equity market liquidity provision, perhaps a similar facility could be instituted by global regulators to prevent future calamities from impacting equity markets in such a coordinated fashion.

The remainder of the paper is structured as follows. Section 1 reviews related literature. Section 2 provides a brief overview of the COVID-19 pandemic, and its impact on global equity markets. Section 3 describes the data used. Section 4 describes the evolution of liquidity during the COVID-19 crisis. Section 5 discusses margins and their impact on liquidity provision, Section 6 provides our econometric analysis of the COVID-19 crisis, while Section 7 concludes.

1 Related Literature

Theoretical models identify shocks to market liquidity following price declines in a variety of ways. Collateral-based models rely on market makers to absorb these temporary buy-sell imbalances. However, market makers with finite funding levels obtain financing by posting margins, utilizing the underlying securities they hold as collateral. When stock prices fall rapidly, intermediaries hit their funding limits and are forced to liquidate. This "liquidity spiral" is documented by Brunnermeier and Pedersen (2009), and supported by the work of Weill (2007). Pro-cyclical increases in margin in response to volatility limit the ability of participants to provide liquidity, particularly when such constraints become binding. Similar models are proposed with funding constrained arbitrageurs as liquidity providers (Gromb and Vayanos, 2002) or with short-term traders unable to take on inventory due to funding constraints (Morris and Shin, 2004). In a model proposed by Gârleanu and Pedersen (2011), the impact of binding margin requirements becomes "priced", resulting in discounts on high-margin assets.

This pro-cyclicality has been studied extensively in the area of banking in response to the 2008 Financial Crisis (GFC), both theoretically (Repullo and Suarez, 2013; Hugonnier and Morellec, 2017) and empirically (Behn et al., 2016; Berger et al., 2016).

Empirically, studies of the margin requirements for equity market makers have been hindered by the availability of such data. In some markets, the link between liquidity provision and margin constraints have been explicitly documented. In bond markets, Adrian et al. (2017) document larger reductions in liquidity after the GFC in bonds traded by firms with more leverage, indicating the binding nature of their margin requirements. Aramonte and Szerszeń (2020) uses a supervisory dataset to examine U.S. corporate bonds and credit default swaps to show that dealer profitability plays a significant role in secondary market liquidity. Daskalaki and Skiadopoulos (2016) examines the commodity futures markets and show that increased margins following the Dodd-Frank act increase transactions costs and reduce depth. Finally, Dudley and Nimalendran (2011) show that increases in the funding margins for futures markets increase the illiquidity and contagion risk of mutual hedge funds.

Empirical studies of equity trading have *alluded* to the the role binding margin constraints play in harming overall market liquidity but have not directly shown this relation. For example, Hameed et al. (2010) document reductions in liquidity around market declines, particularly at times when the funding markets are tight, likely to arise from capital constraints on market makers. Similarly, Comerton-Forde et al. (2010) show that the inventory levels and trading revenues of NYSE market makers were correlated with their propensity to supply liquidity. In a global study, Karolyi et al. (2012) find that commonality in liquidity is greater in countries with higher market volatility, and is also higher at points in time when volatility is greatest, consistent with the impact of binding funding liquidity constraints. Despite this consistent evidence from equity markets of the potential role margin plays in equity market liquidity provision, no study to date has been able to clearly identify this mechanism.

Our global findings for the equity markets align well with evidence from Duffie (2020) for U.S. Treasury markets, who shows that the inventory risk faced by dealers results in bid-ask spreads that increase to over 10 times their (relatively stable) pre-crisis levels. Similarly, the depth available dropped by over a factor of 10 for New-York, London and Tokyo based government securities. The larger magnitudes observed in these markets likely reflects the greater leverage (and lower historic volatility) utilized in these settings. Other recent papers, including Cheng et al. (2020), Fleming and Ruela (2020) and Bent et al. (2019), who show that increased margin requirements during the COVID-19 pandemic caused significant deterioration in overall measures of market liquidity in Treasury bond markets.

Our paper further complements an emerging literature examining the effects of COVID-19 on equity markets, though the majority of these early papers aims to understand the asset pricing implications of the pandemic.[1]

The literature specifically on the *working* of financial equity markets during the COVID-19 crisis is more limited. Some examples include Brogaard et al. (2020), which shows that the suspension of trading by physical market makers on the trading floor at the NYSE causes deteriorations in overall market quality. Ibikunle and Rzayev (2020) looks at venue selection in the time of COVID-19, showing that impatient traders prefer the execution certainty provided by lit markets and avoid trading in dark venues.

2 The COVID-19 crisis

COVID-19 is a novel form of the coronavirus associated with previous (more limited) pandemics such as SARS and MERS. Of importance for our study is the staggered spread of the virus around the world. Starting in China in December 2019, COVID-19 initially appeared as if it was a localized issue, which would not spread to countries outside of China. Unfortunately, the potential for this virus to spread prior to the development of symptoms resulted in COVID-19 eventually reaching most countries on the planet. This gradual spread, and ensuing public panic and social shutdown have been incredibly costly, in both humanitarian and economic terms.

The unprecedented response of governments, halting global travel and in many cases shuttering all but the most essential businesses, has come with huge economic costs. These costs were rapidly reflected in stock prices, with most global indices dropping significantly as the scale of the domestic disruption became evident. Figure 1 shows the speed of the global spread of COVID-19 around the world: some countries (such as Italy) recorded 100 cases during mid-February, while others such as Australia did not register 100 cases until mid-March.

[1] See, for example, papers by Hansen (2020), Ellul et al. (2020), Baker et al. (2020), Ramelli and Wagner (2020), Ashraf (2020), and Gormsen and Koijen (2020).

3 Data and sample selection

3.1 Sample selection

In order to evaluate the variation in COVID-19 impacts, our analysis considers the major equity markets in North America, Europe, Scandinavia, and Australia. Table 1 documents the countries and index stocks which constitute our sample. This set of countries yields not only a broad cross-section of the developed world, but also provides variation in the societal response to the crisis, as well as variation in the absolute scale of the outbreak. Figure 2 illustrates the disruption to global stock markets, illustrating how the markets we consider have fallen from their price levels on February 1, 2020 (normalized to 100).

3.2 Data

The data for this study is sourced from the Refinitiv database.[2] The data contain millisecond timestamped records of both quotes and trades. For each stock, we calculate intra-day quoted spread, effective spread, realized spread and price impact. The latter two use a 10 second delay in the calculations, in order to capture the returns to high-frequency market makers, consistent with the work of Conrad and Wahal (2020). We also calculate depth as the sum of trading interest available (in currency) at the best bid and ask prices.[3] We only consider the trading activity during the continuous trading session at the main (listing) exchange.[4] To increase the cross-sectional variation in the stocks analyzed, we also gather data for trading outside of the main indices for selected exchanges. For the LSE we use data for the firms in the FTSE250 index. For the exchanges in Australia, Canada, Norway and Sweden we use data for all reasonably liquid non-index stocks listed on these exchanges, which we define as stocks above the median market capitalization among the non-index shares, conditional on having more than 100 trades per day.

Liquidity measures for U.S. stocks are taken from the summary measures calculated by Sunil Wahal.[5] This data provides daily estimates of quoted, effective and realized spreads, as well as price impact.

We also investigate the liquidity of an S&P 500 ETF, "SPY" (traded on the NYSE) which also trades on the London Stock Exchange (LSE) with the ticker "CSPX.L". Data on the trades and quotes for these ETFs is collected from Refinitiv. We calculate the same

[2]Earlier known as Thomson Reuters Tick History (TRTH).

[3]Detailed definitions of calculated measures are available in Section A1 of the Internet Appendix.

[4]We remove the first and last fifteen minutes of trading when calculating our liquidity measures to exclude the impact of the opening and closing auctions.

[5]The data is available at the W. P. Carey Business School at Arizona State University: Center for Investment Engineering. We are grateful to Sunil Wahal for providing this data to the research community.

liquidity measures as for the individual stocks, but computed as averages every trading hour.

qDaily margin requirements are collected from regulatory information available directly from the various exchanges.[6]

3.3 Descriptive statistics

Table 2 provides descriptive statistics for the stocks which constitute our sample. In order to illustrate a representative non-pandemic period, these tables provide averages over the period January 1 to February 15, 2020. Panel A presents statistics for the stocks which are constituents of the primary domestic index, as listed in Table 1, while Panel B provides descriptive statistics for the sample of relatively liquid non-index stocks. Of immediate interest is the similarity in quoted spreads across countries, and the significantly higher transaction costs in the non-index stocks when compared to their index-constituent counterparts.

4 Liquidity during the COVID-19 crisis

A key component of the health of any market is liquidity - how expensive it is to transact in the market, and the total available market depth, which measures the size with which one can immediately transact. Figure 3 illustrates the evolution of liquidity during the crisis. We document the changes across three key metrics: *Quoted spread* (the anticipated cost of liquidity provision), *Effective spread* (the cost of traded liquidity) and *Depth* (the value of shares quoted in the market).[7]

Panel A shows the quoted spread relative to the average during January, 2020. Quoted spreads measure the marginal cost charged by a liquidity provider for an additional unit of liquidity. What is immediately obvious is that spreads begin rising, particularly in the U.S., around the beginning of March. However, the WHO's declaration of a pandemic on March 11, 2020 spurs significant increases in this measure of transaction costs.[8] In U.S. markets, the quoted spread increases from around 200% of January levels in the beginning of March to upwards of 600% by the end of March. All other countries show a similar response, increasing between 200-400% from pre-COVID-19 levels. This sharp increase in quoted spreads indicates that liquidity providers were extremely cautious in

[6]See Section A2 in the Internet Appendix for further details.

[7]In Section A3 of the Internet Appendix we provide plots showing the corresponding evolution for individual markets.

[8]Consistent with the work of Donadelli et al. (2017) we use the WHO's announcement of a pandemic as a significant announcement which has been shown to impact stock returns.

their provision of liquidity once it became clear that COVID-19 would become a worldwide issue. By early May 2020 these costs had fallen to a more normal level, but still remain between 150-200% of their pre-pandemic levels.[9]

Panel B documents the evolution of effective spreads, representing the transaction cost of liquidity demanders when liquidity is consumed. Unlike the quoted spread, which measures the cost of an additional share, the effective spread measures the cost of liquidity in the size demanded - large market orders are likely to walk the book, increasing their actual cost. Rapid, correlated "fire sales" by market participants are likely to exhaust available market depth, increasing the transaction costs borne by market participants. Panel B shows effective spreads follow a similar evolution to quoted spreads, with the cost of demanding liquidity in the U.S. increasing the most, peaking at 600% of January levels by the end of March.

Panel C shows how liquidity providing activity changed across our sample of exchanges. Quoted depth provides an opportunity for market participants to execute their orders, with more depth representing an ability to trade more at the best prices. The pandemic announcement by the WHO results in a sharp and severe decrease in the amount of liquidity provided. While such a reduction could be associated with the increased price volatility generated by COVID-19, it appears that the pandemic announcement precipitates a rapid reduction in quoted liquidity. If such an announcement was accompanied by an increase in the margin required for liquidity providers by exchanges, we would expect to see such a significant, and globally correlated, reduction in liquidity provision.

Overall, our initial results indicate that while the volatility and fear associated with SSeaSethe unfolding pandemic had begun to have an impact on liquidity in global equity markets, it seems the WHO pandemic declaration resulted in rapid deterioration of all of our relevant measures. Given the pandemic impacted different countries at different rates, it is intriguing to see such consistent behavior globally in such a small time frame.

One feature of the models proposed by Morris and Shin (2004) and Brunnermeier and Pedersen (2009) is that volatile markets may result in increased capital margin requirements. These increased margins may constrain the ability of market makers, arbitrageurs and speculators to provide liquidity exactly when it is needed. This constraint can result in reduced depth, further increasing volatility, resulting in a negative "liquidity spiral" or "liquidity black hole". The COVID-19 pandemic provides a fertile field to test these theoretical arguments in an equity-market setting.

[9]This relatively quick return to pre-crisis levels of spreads is a difference between the COVID-19 crisis and the 2008 Financial Crisis. In Section A5 of the Internet Appendix we show a comparison of the liquidity during these two events.

5 Margins

Margins refer to the amount of money implicitly borrowed from a broker or exchange. It is the difference between the total value of a traded financial instrument, and the amount of funds deposited by the trader. These margins serve as a collateral deposit and serve to minimize credit risk.

Specifically, exchanges typically define both an initial margin (IM) and maintenance margin (MM). IM is the collateral required as a proportion of the total traded value in order to open a new leveraged position. MM is the minimum collateral a trader must retain in order to maintain their open position. For example, a $100 buy order may require an IM of 5% (or $5). Appreciation in the bought asset, say to $110, results in an increase in the margin account of $10. However, reductions in price will be deducted from the margin account. For a MM of 2.5%, the trader's position is automatically closed if the price falls below $97.5 (leaving only the minimum 2.5% margin).

Electronic liquidity providers and high-frequency traders operate necessarily across incredibly small time horizons[10] and participate extensively in both equities and futures markets.[11] Indeed, futures markets are often used as a venue in which to hedge price risk for underlying equities positions held by such traders.

While numerous studies have documented that ELP market makers prefer to end the day "flat"[12] — that is without any inventory — this does not render margin requirements irrelevant. Exchanges compute an individual trader's maximum *intraday* position limit with reference to their available margin balance. This is necessary, particularly during times of volatility, to prevent traders taking infinitely large positions. As such, ELPs who tend to have numerous open orders at any one point, are likely to be significantly impacted by rapid increases in margin, requiring them to either reduce their order's exposure or increase their margin balance. The impact of increased margin on market quality has been shown in other contexts, including commodity futures markets (Daskalaki and Skiadopoulos, 2016) and hedge fund liquidity (Dudley and Nimalendran, 2011).

To understand the impact of the crisis on the margin levels faced by traders, Figure 4 shows required margin levels for futures on national equity indices, trading across six major exchanges. Futures margins are publicly disseminated due to their importance in managing the collateral requirements of the underlying contracts. [13] Futures margins over the main indices are also likely to be heavily correlated with the required margins for

[10]See, for example, Bartlett and McCrary (2019), and Aquilina et al. (2016).

[11]See e.g. Hasbrouck and Saar (2013), Goldstein et al. (2020) and Shkilko and Sokolov (2020).

[12]See, for example, Hagströmer and Nordén (2013); Brogaard et al. (2015) and Van Kervel and Menkveld (2019).

[13]Section A2 of the Internet Appendix documents the publicly available sources of futures margins relied upon for this study.

equity exchange participants, particularly due to their relevance in hedging equity market exposure.

Finally, the margin requirements were reasonably constant throughout January and February 2020, but spiked on March 11, 2020, the day of the WHO's pandemic announcement, increasing to around 120% of January levels. These margins rapidly increased for all exchanges, reaching over 300% of pre-COVID-19 levels in the case of Canada. Anecdotally, this caused significant constraints on liquidity providers. Indeed, in a press release on the March 20, 2020, Virtu Financial — a large, listed, global liquidity supplier — announced that they would be raising an additional $450 million USD of capital to "augment our liquidity provisioning services globally." Given the extensive participation of Virtu in global financial markets, such liquidity constraints could cripple the ability of such firms to supply liquidity when it is most needed in financial markets.[14] In the following sections, we investigate the impact of the increases in these margin requirements on global liquidity provision.

6 Empirical Results

This section contains the main results. We first examine a case of the same security traded across two markets with differing margin requirements in order to directly measure the effect of margin on market liquidity. Second, we investigate trading in some of the world's major equities market, and argue that margins primarily affect the stocks in a given market's major index. Using a difference-in-difference analysis, we show that the liquidity of stocks outside a market's main index is less affected by margin increases than stocks inside the index.

6.1 Liquidity of the S&P 500 market

We start by looking at one of the world's largest single markets, that of derivatives based on the S&P 500 index, which include futures contracts, options contracts and exchange traded funds. In the U.S., the derivatives contracts trade at the Chicago Mercantile Exchange, while the ETF trades at the New York Stock Exchange (NYSE). These markets are strongly linked through arbitrage activities. Recent evidence suggests that price discovery is actually concentrated in the ETF.[15] We investigate the best known ETF tracking the S&P500, SPY, which is traded at the NYSE. The same ETF is traded at the London

[14] Press Release Virtu Announces 450 Million of Additional Broker Dealer Borrowing Capacity and Preliminary Quarter to Date Results.

[15] See e.g. Buckle et al. (2018), Chen et al. (2016), Chen et al. (2018) and Wallace et al. (2019).

Stock Exchange (LSE) with the ticker CSPX.L. We investigate the liquidity differences between these two contracts, and link them to the timing of margin changes.

Brunnermeier and Pedersen (2009) suggest that an exogenous shock to capital requirements should lead to a decline in market liquidity. While all exchange margins increased around the time of the World Health Organization's declaration of a pandemic (Figure 1), some markets experienced larger increases in margins, relative to other exchanges. Exploiting this phenomenon, we use a difference-in-difference framework to isolate the effect of an idiosyncratic margin increase on market liquidity.

Figure 5 illustrates the differential increase in LSE and CME margins. Panel A shows a large jump in exchange margins on the LSE (red line), relative to CME margins (blue line) on March 11 (indicated with a vertical line). To illustrate the difference in margin changes more distinctly, Panel B shows the margin differential, which is the difference between the LSE and CME margins. This figure shows more clearly that the period when LSE margin is increasing substantially relative to the CME margin is March 11 to March 17. On March 18, following substantial increases in CME margins, the margin differential narrows. We will later use the period of substantial increase, March 11–17, as the post-period in a diff-in-diff estimation, to test the prediction from Brunnermeier and Pedersen (2009) that binding margin constraints should lead to deterioration in market liquidity.

Because the LSE margin increased earlier, and by more than the CME margin, we expect market liquidity to deteriorate more on the LSE than in the U.S. markets. Turning to the two ETF contracts, Figure 6 shows the evolution of the effective spread of the LSE (red markers) and NYSE ETFs (blue markers). We see a much larger increase in the effective spread for the LSE ETF, relative to the NYSE ETF, which is consistent with the theoretical prediction from Brunnermeier and Pedersen (2009) and Morris and Shin (2004).

To formalize these observations, we perform a difference-in-difference estimation. We use a pre-period covering the interval February 5 to February 11, 2020, as Figure 5 shows there is no material deviations in the margin differential over this period. Our post-period covers the period March 11 to March 17, 2020, which corresponds to the jump in margin differential described earlier. These two periods are indicated in Figure 5. Specifically, we run the following difference-in-difference regression model:

$$
\begin{aligned}
Liquidity_{i,t} &= \alpha_0 + \beta_1 LSE_{i,t} + \beta_2 Margin\ increase_t \\
&\quad + \beta_3 LSE_{i,t} \times Margin\ increase_t + \varepsilon_{i,t} \qquad (1)
\end{aligned}
$$

where $Liquidity_{i,t}$ is one of the following liquidity variables: Quoted spread, Effective spread, Realized spread or Price impact. Each liquidity variable is measured as an average over hourly intervals. $LSE_{i,t}$ is an indicator variable equal to 1 if the ETF trades in the UK and 0 otherwise. $Margin\ increase_t$ is an indicator variable equal to 1 for the post-period from March 11 to March 17, 2020 and 0 for the pre-period from February 5 to February 11, 2020. The interaction term $LSE_{i,t} \times Margin\ increase_t$ isolates the effect of the margin increase on stock liquidity.

We report the results from the difference-in-difference regression models in Table 3. Consistent with the theoretical predictions of Brunnermeier and Pedersen (2009) and Morris and Shin (2004), the regressions confirm a decrease in liquidity in the LSE ETF after the jump in the LSE margin, relative to the US margin. The positive and significant coefficients on the *LSE*×*Margin increase* interaction variable show an increase in measures of transactions costs (quoted, effective and realized spreads), along with an increase in the price impact of trades on the LSE, which experienced the larger jump in margin. These empirical results are consistent with the findings of increased margins causing deteriorations in market quality found by Daskalaki and Skiadopoulos (2016) in commodity futures markets and Aramonte and Szerszeń (2020) in the CDS and bond markets.

6.1.1 Narrowing of margin difference

While the LSE experiences a larger jump in margins immediately after the WHO's declaration of a pandemic on March 11 2020, one week later, on March 18 2020, the U.S. margin subsequently jumps, and the difference between the U.K. and U.S. margins stabilize (Figure 5, Panel A). This subsequent adjustment in U.S. margins thus results in a reversal of the margin differential (Figure 5, Panel B).

Our second test exploits this reversal in the margin differential: because there is a decrease in the margin differential between the exchanges, based on the prediction of Gârleanu and Pedersen (2011), the elimination of the liquidity "basis" should cause the market quality difference between the U.K. and U.S. markets to narrow.

Table 4 shows the results of the difference-in-difference regression for the March 18, 2020 event. The pre-period is for March 16 to March 17, 2020 and the post-period is for March 18 to March 19, 2020.[16]

In line with our predictions, we observe negative and highly significant coefficients on the interaction term (*LSE*×*Margin narrowing*) for quoted, effective and realized spreads.

[16]Section A4 of the Internet Appendix provides Figure A.17 showing the placing of the pre- and post-periods. We rely on short pre-and post- periods to ensure we have an event window that is not contaminated by the frequent changes in exchange margins around this interval.

6.1.2 Robustness

To provide more confidence that the observed changes in market quality are driven by the relative changes in margin requirements, we investigate the robustness of these estimates through a falsification test: repeating the difference-in-difference analyses using data from March 2019, the year before the COVID-19 shock. The results of the falsification test are provided in Section A4 of the Internet Appendix. For all the significant variables in Table 3, the corresponding placebo test has statistically insignificant coefficient estimates of a much smaller magnitude than the estimates during the COVID-19 pandemic.

Taken together, our evidence provides strong empirical support for the prediction that an exogenous increase in margins leads to a decrease in market liquidity as proposed by Brunnermeier and Pedersen (2009) and Gârleanu and Pedersen (2011). This result is further supported by a reduction in the margin differential on March 18, 2020. Our main result is also robust to a falsification test in a period when there was no material difference between the U.K. and U.S. margins.

6.2 Global analysis

In the previous section, we show strong evidence that market quality declines more for the LSE ETF, which experienced larger increases in margin requirements, relative to the NYSE ETF. One limitation of this experiment is that we focus on a single cross-listed security. In this section, we generalize our main finding to a larger cross-section of listed equities. Because we do not observe large differentials in margin increases for all stock exchanges around the world, we focus on factors that are likely to affect some stocks more than others. Specifically, we argue that an increase in margin requirements is likely to disproportionately affect HFT market making firms, relative to traditional investors, due to their heavy reliance on leverage to provide liquidity. Extensive empirical literature has documented that HFT market makers prefer to end the day "flat", that is, without any inventory (See e.g. Hagströmer and Nordén (2013); Brogaard et al. (2015) and Van Kervel and Menkveld (2019)). This aversion is likely due to such inventory increasing holding costs - both in terms of risk and margin capital costs. As such, the increase in margin requirements is more likely to adversely affect the liquidity of stocks with high HFT participation, as compared to stocks with low HFT participation.

We conduct a difference-in-difference test using the increases in margin requirements on March 11, 2020 for identification. To capture this intuition, we create two subsamples. The first subsample contains stocks with the highest level of HFT participation (stocks within the primary country index, as documented in Table 1), while the second subsample contains stocks with low HFT participation. For our sample of low HFT stocks, we select the most liquid stocks outside the primary index. To be included in the sample of low HFT stocks, we require the stock to have at least 100 daily trades and to be above the median market capitalization of non-index stocks. Using this design, we estimate the following difference-in-difference regression:

$$\begin{aligned} Liquidity_{i,t} \; = \; & \alpha_0 + \beta_1 High\ margin_t + \beta_2 Index\ constituent_i \\ & + \beta_3 High\ margin \times Index\ constituent_{i,t} \\ & + \beta_4 Volume_{i,t} + \beta_5 Index\ return_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{2}$$

where $Liquidity_{i,t}$ is one of the following liquidity variables (Quoted spread, Effective spread, Realized spread, Price impact) in stock i on day t as described previously. *High margin* is an indicator variable equal to 1 for the period after the WHO declares the COVID-19 outbreak a pandemic, and 0 otherwise. *Index constituent* is an indicator variable equal to 1 if the stock belongs to a major stock market index as listed in Table 1.

The results in Table 5 support our main result that increased margin requirements contribute to the reduction in stock liquidity. Specifically, we find that the interaction term *High margin* × *Index constituent* is positive and significant for quoted, effective and realized spreads, indicating that the increase in spreads for index stocks is larger than the increase for non-index stocks after margin requirements increased. These results confirm the conjecture of Hameed et al. (2010) that the reduction in liquidity around market declines is indeed driven by margin constraints imposed on market makers. Our empirical evidence for the market quality impacts of margin on equity markets is also consistent with emerging results on COVID-19's impact in corporate bonds (O'Hara and Zhou, 2020) and government bonds (Duffie, 2020) in which inventory risk drove significant increases in transaction costs.

6.3 HFT behavior

In the previous sections, we show that market liquidity declines when stock exchange margins increase. Here, we analyze the channel by which this reduction in market liquidity occurs. If the results are driven by the constraints increased margin places on high-frequency market makers, we expect a reduction (or withdrawal) of their activity. Such a reduction in activity should be associated with a reduced order to trade ratio, as high frequency quote updates become less necessary. As such, we assess whether the increase in margin requirements is correlated with a decrease in HFT participation. Due to the large number of countries investigated and the lack of available trader identifiers, following Hendershott et al. (2011), Hagströmer and Nordén (2013) and Jørgensen et al. (2018), we use the order to trade ratio (OTR) to proxy for the overall level of HFT activity. For each stock and trading day, we calculate the order to trade ratio (*OTR*) as the sum of the number of asks and bid updates at the top of book, divided by the number of trades.

Following the empirical design from Section 6.2, we use a difference-in-difference regression framework to test whether HFT activity falls more for index stocks, which are likely to have higher HFT participation, versus non-index stocks. For this analysis, we replace the dependent variable in (2) with *OTR* and report the results in Table 6. Importantly, we find that the interaction term *High margin* × *Index constituent* is negative and significant, indicating that *OTR* falls more for index stocks, relative to non-index stocks, following the significant increase in exchange margins. These results support the finding that index stocks, which have higher HFT participation, experience a larger fall in HFT activity, relative to non-index stocks with lower HFT participation after the increase in margin requirements. Based on the results from Tables 5 and 6, our findings are consistent with the hypothesis that the primary channel by which escalating margins during times of crises negatively impact market liquidity is through the costs of high-frequency market makers providing liquidity to the market, resulting in a margin-loss spiral.

7 Discussion and Conclusion

Recent theory models suggest that exchange margin requirements could become destabilizing and procyclical, leading to liquidity spirals. Studies including Morris and Shin (2004) and Brunnermeier and Pedersen (2009) propose that when traders face funding liquidity constraints, they become reluctant to take on positions, which in turn, lowers overall market liquidity. The reductions in market liquidity increases the risk of trading, which further increases margins, resulting in a negative liquidity spiral. However empirical tests of these predictions in equity markets are rare, as changes in margin requirements sufficiently large so as to impact trader behavior are not frequently observed.

We show that the World Health Organization's declaration of the COVID-19 pandemic in 2020 is associated with a sharp and sudden increase in margin requirements for exchanges worldwide. Using this change in margin requirements across a variety of developed equity markets globally, we test the theoretical predictions of Brunnermeier and Pedersen (2009) and document three main findings.

First, we show causally that an increase in capital requirements leads to a decline in market liquidity. Using ETFs on the S&P500 index listed in the U.K. and U.S. markets, we show that market liquidity deteriorates more on the LSE, which experienced a large increase in margin, than on the NYSE.

Second, we demonstrate that stock liquidity decreases more for index stocks, which tend to have a higher proportion of liquidity provided by high frequency market makers, than for non-index stocks. Because of their higher portfolio turnovers and shorter holding periods, high frequency market makers are more reliant on margin as they hold leveraged portfolios. This findings is consistent with the notion that increases in margin requirements have a larger impact on the liquidity of stocks in which HFT are more active.

Third, we confirm that electronic liquidity providers withdrew more from index stocks, in which they are typically more prevalent. Specifically, we document that the order to trade ratio declined more for index stocks, relative to non-index stocks, when exchange margin requirements increased.

Our findings contribute to ongoing policy debates around systemic risk and the regulation of markets and their participants. First, the systemic risks of concentrating the liquidity provision functions, particularly in a global setting, among a handful of high-frequency firms is becoming more apparent. While the importance of collateral costs is becoming better understood through empirical work such as Benos et al. (2019), the increases in equity market margins observed during 2020 are some of the largest and fastest on record. The increased costs of regulatory collateral have seen significant rapid withdrawal of electronic liquidity providers, which has the potential to reignite the debates surrounding positive obligations for market makers. It is possible that market structure changes — such as imposing positive obligations on appointed designated market makers — could potentially mitigate the liquidity crisis observed during such turbulent times. We leave this interesting cross-market analysis to future researchers.

Further, our analysis begins to question whether regulatory capital reserves should be used to act as a counter-cyclical buffer to markets in times of stress. Such initiatives were undertaken subsequent to the 2008 Financial Crisis by global regulators in an attempt to solve these liquidity spirals. Such a buffer would provide support to market makers in times of crisis, allowing them to continue their critical role of liquidity provision exactly when it is required. He and Krishnamurthy (2013) proposes three potential governmental interventions to support liquidity providing intermediaries: reductions in borrowing costs; direct injections of equity capital; and the purchase of distressed assets. Weill (2007) further suggests direct central bank lending to market makers as a potential policy response. Our research will, hopefully, initiate the conversation about what equity market margin liquidity buffers would look like, how they could be implemented, and when they would be triggered.

Finally, we contribute to the extant literature in two key ways. First, we empirically test theories documenting the procyclical nature of margin requirements and the negative spirals they could generate for market participants (Brunnermeier and Pedersen, 2009; Repullo and Suarez, 2013; Hugonnier and Morellec, 2017). While Behn et al. (2016) and Berger et al. (2016) study the impacts of margin requirements during the 2008 Financial

Crisis in a banking context, we are the first to test these theories in equity markets. It is likely more research on margin (and crisis capital buffers) will be forthcoming in this area as the economic impacts of COVID-19 become better understood.

Second, we contribute to a growing literature seeking to understand and explain why the effects of the COVID-19 pandemic were so significant and swift for asset valuations and the overall trading environment. Market participants have come to expect the underlying market architecture, or "plumbing", to facilitate smooth and orderly trading of vast proportions within our financial institutions. Any failure of such systems, no matter how brief, must be examined and understood. Existing papers seeking to understand these dislocations include Duffie (2020) and Cheng et al. (2020) in U.S. Treasury assets, the utility of the NYSE trading floor (Brogaard et al., 2020) and the magnitude of asset price responses (Baker et al., 2020; Ramelli and Wagner, 2020). Our work provides a channel by which such dislocations can occur - namely changes in the margin required for liquidity suppliers.

The impacts of the current crisis have been rapidly felt in all sectors of the economy. However, our research shows that markets are recovering more rapidly than in previous crises. Whether this is due to the unprecedented levels of economic stimuli provided by central banks, which could help to overcome the funding liquidity risk, or by the short and sharp nature of COVID-19, only time will tell.

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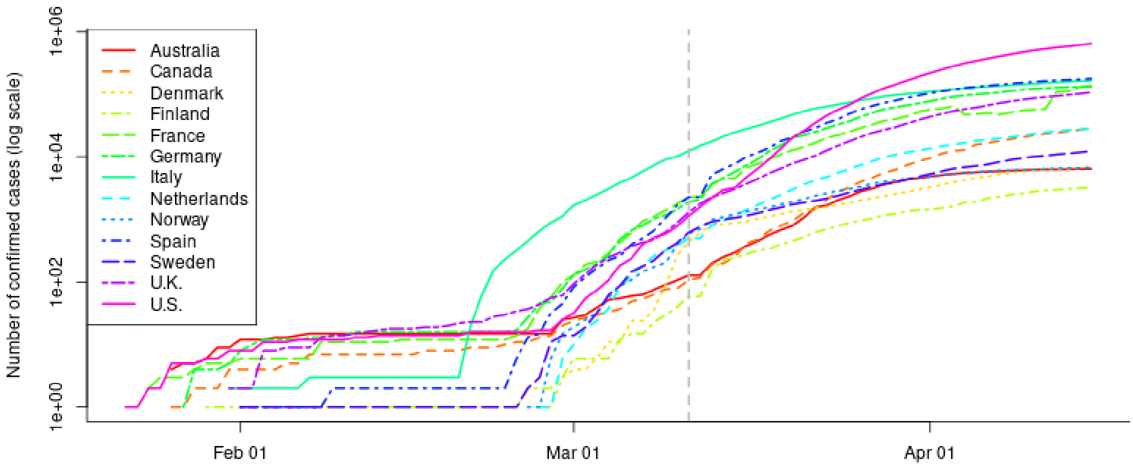
Figure 1: The evolution of COVID-19 cases

This figure illustrates the global evolution of COVID-19. Panels A and B show the total number of confirmed cases and deaths per country in log scale, respectively, for the countries listed in Table 1. The gray vertical line represents March 11, 2020, when the World Health Organization declared the COVID-19 outbreak a pandemic. Data Source: Johns Hopkins University COVID-19 data.

Panel A: Confirmed Cases



Panel B: Deaths related to COVID-19

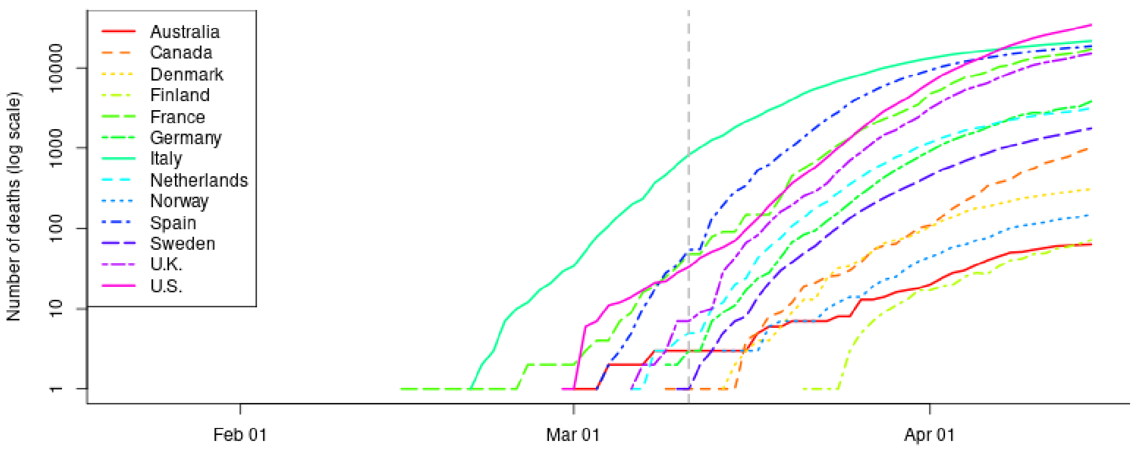


Figure 2: The evolution of stock market prices

This figure illustrates the change in stock market levels. For each market, we show the evolution of the indices listed in table 1. The plots are normalized to start at 100 by calculating the percentage level relative to the price level on February 1, 2020. The gray vertical line represents March 11, 2020, when the World Health Organization declared the COVID-19 outbreak a pandemic.

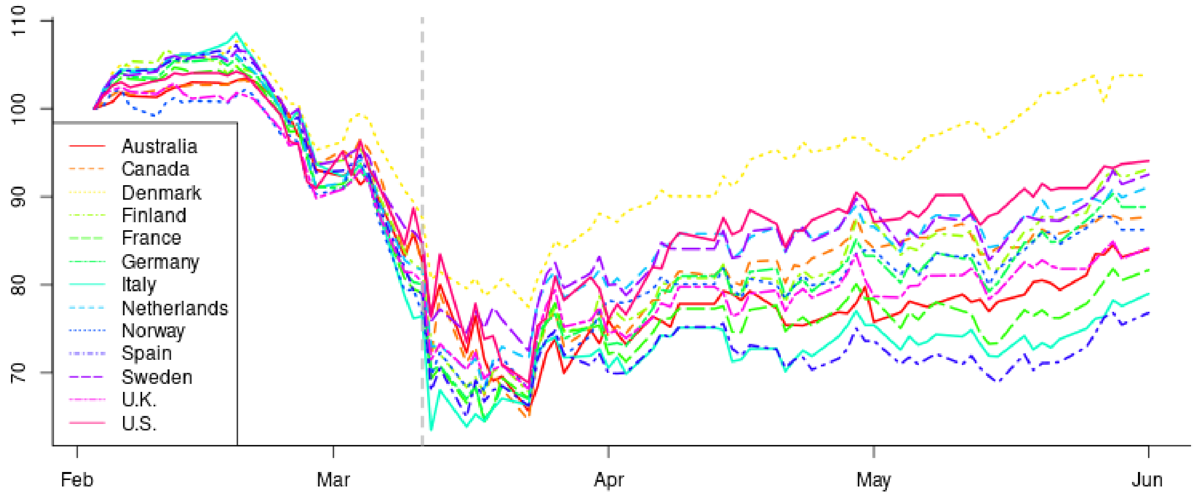
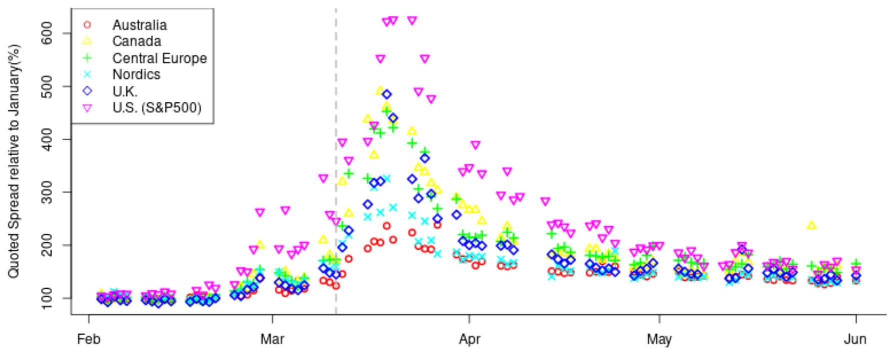


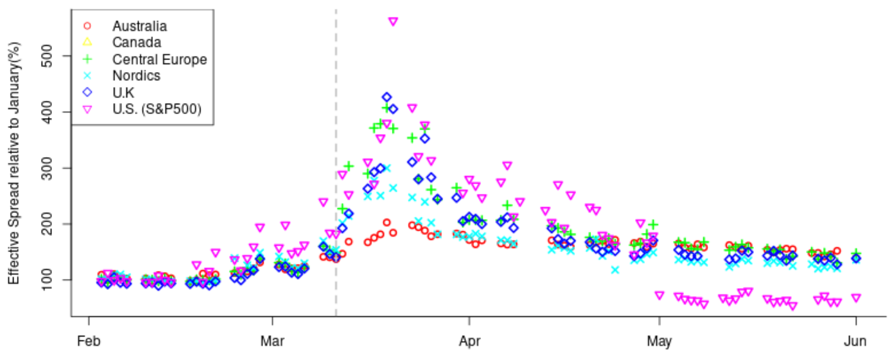
Figure 3: Liquidity evolution during the COVID-19 crisis

The figures illustrate the changes in liquidity during the COVID-19 crisis, starting in February 2020 and ending on June 19, 2020. At each date, the liquidity measures are presented as a percentage of their average in January 2020. *Quoted spread* is the difference between the best bid and ask, divided by the current midpoint. *Effective spread* is the difference between the traded price and the current midpoint, relative to the current midpoint. *Depth* is the (local currency) sum of trading interest at the best bid and ask quotes. The gray vertical line represents March 11, 2020, when the World Health Organization declared the COVID-19 outbreak a pandemic.

Panel A: Quoted spread



Panel B: Effective spread



Panel C: Depth

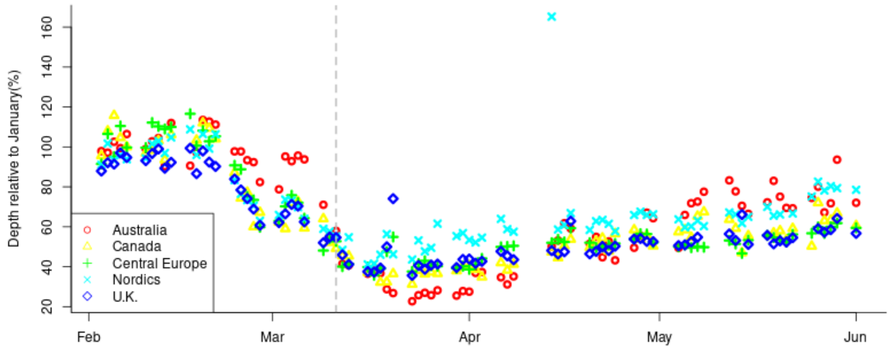


Figure 4: The evolution of global margin requirements

This figure shows the evolution in margin requirements. At each date, the margin requirement is presented as a percentage of the margin requirement in January 2020. Our data spans February 11 to April 11, 2020. The gray vertical line represents March 11, 2020, when the World Health Organization declared the COVID-19 outbreak a pandemic.

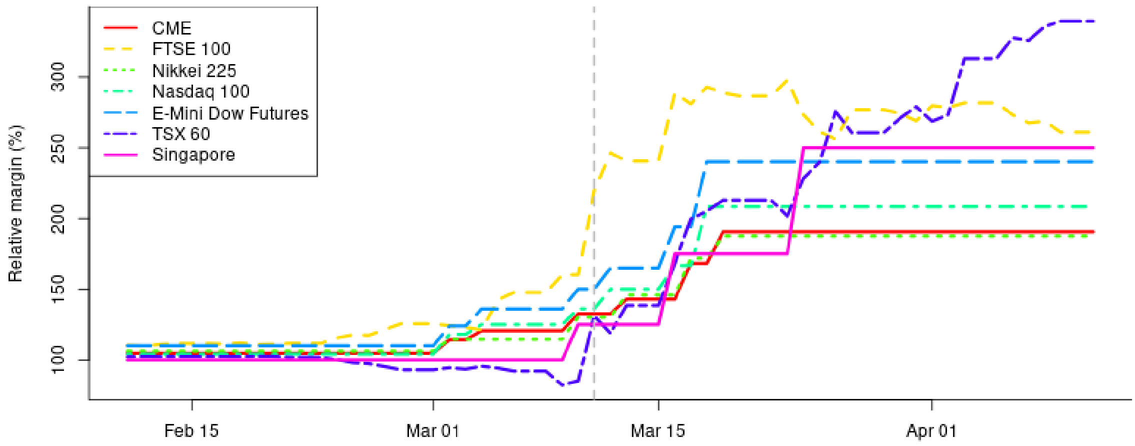
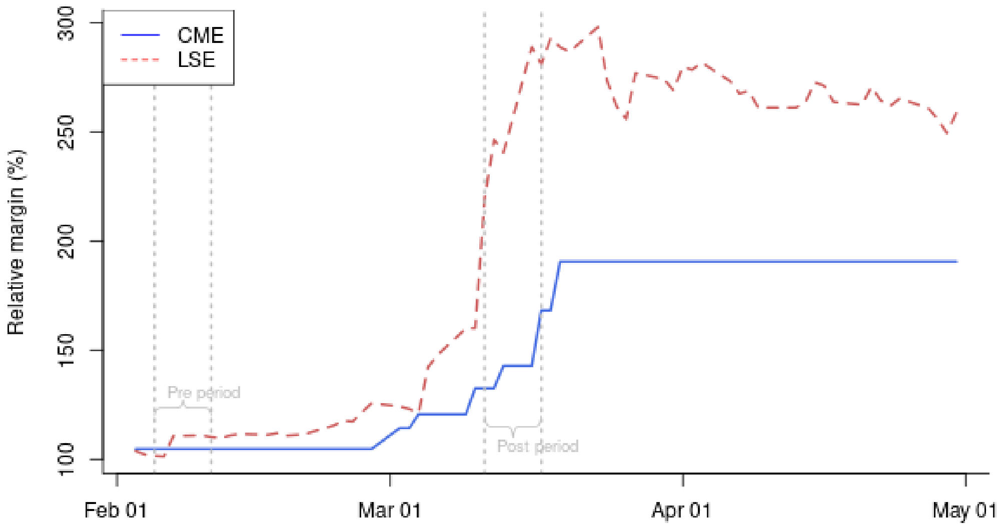


Figure 5: Relative margins for U.S. and U.K. exchanges

Panel A plots the time series evolution of margins at the CME (Blue line) and LSE (red dotted line). The margin is presented as a percentage of the margin requirement on February 1, 2020. The CME margin is for S&P 500 Futures Contracts. Panel B plots the *difference* between the two relative margins. The plots show the pre- (February 5 to February 11, 2020) and post- (March 11 to March 17, 2020) periods for our difference-in-difference analysis.

Panel A: Relative margins, CME and LSE.



Panel B: Difference between CME and LSE margins.

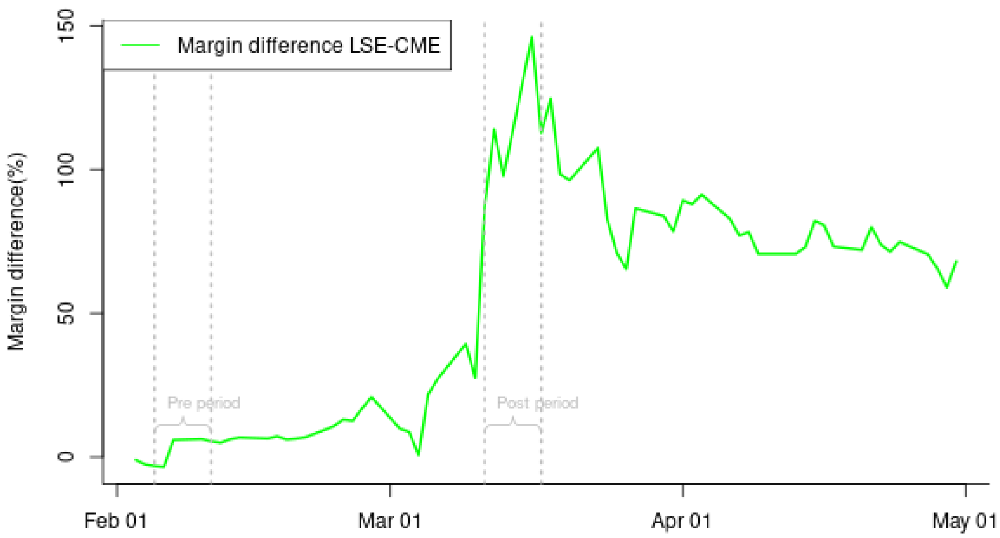


Figure 6: Effective spreads for S&P 500 ETFs, U.S. and U.K. exchanges

The figure plots the evolution of effective spreads for the S&P ETFs SPY (traded at NYSE) and CSPX.L (traded at LSE), at hourly intervals. The effective spread is the time-weighted average effective spread (in basis points) over an hour. The spreads are only plotted for times of the day when both markets are open. Towards the right axis (the green line) we show the difference between the relative margins at the LSE and CME (in percent). The plot shows the pre- (February 5 to February 11, 2020) and post- (March 11 to March 17, 2020) periods for our difference-in-difference analysis.

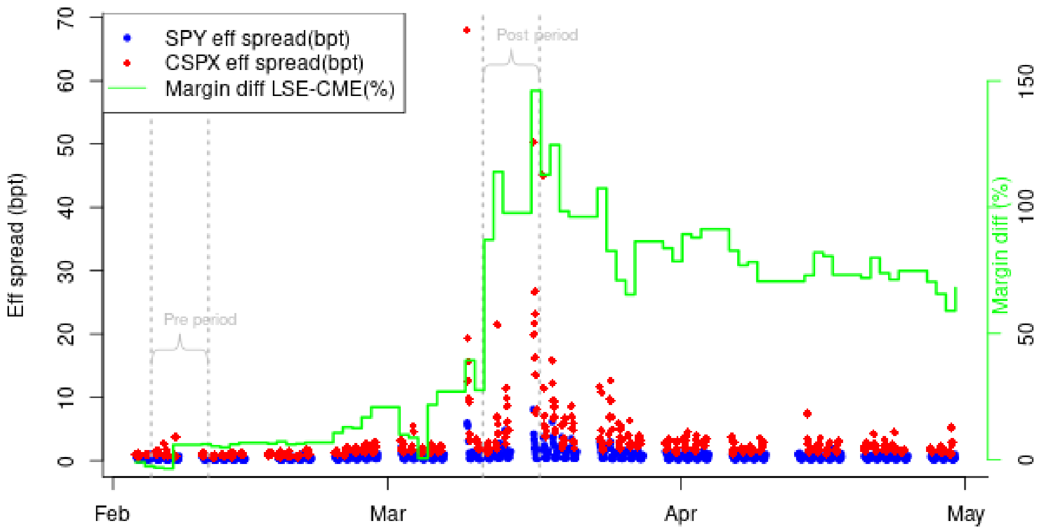


Table 1: Markets and Exchanges

Overview of the markets considered in the study.

Country	Index	No. Stocks in index
Australia	ASX	50
Canada	TSX	60
Denmark	Copenhagen	25
Finland	Helsinki	25
France	CAC	40
Italy	MIB	40
Germany	DAX	30
Netherlands	AMX	25
Norway	OBX	25
Spain	IBEX	35
Sweden	OMX	30
U.K.	FTSE	100
U.S.	S&P	500

Table 2: Descriptive Statistics

This table provides descriptive statistics for our liquidity variables for January 1 to February 15, 2020. *Quoted spread* is the difference between the best bid and ask, divided by the current midpoint. *Effective spread* is the difference between the traded price and the current midpoint, relative to the current midpoint. *Realized spread* and *Price impact* are calculated using a 10-second delay. *Depth* is the sum of trading interest at the best bid and ask quotes, translated into US dollars. *Realized volatility* is calculated from five-second returns. Note: The U.S. data is calculated by Sunil Wahal in a similar manner to what is done for the other markets, except for the Realized Spread and Price Impact. For the U.S. measures these are calculated against a 5 second delay, not 10 seconds. The U.S. data do not include depth and realized volatility. The statistics in panel A are for stocks in the main indices, as listed in Table 1. In panel B we describe the stocks we use outside of the main indices. For the UK, we use the constituents of the FTSE 250 as the sample. For the other four markets (Australia, Canada, Norway and Sweden), we only include stocks with market capitalization higher than the median company outside of the main index, and with more than 100 daily trades. In panel C we describe the liquidity of trading of the SPY ETF tracking the S&P 500 index traded at the NYSE (SPY) and LSE (CSPX.L). Descriptives for hourly estimates of the liquidity variables.

	Quoted spread (bp)	Effective spread (bp)	Realized spread (bp)	Price impact (bp)	Depth (thous USD)	Realized volatility (%)
Panel A: Index stocks						
Australia	10.5	3.6	2.6	1.0	267	0.20
Canada	5.2	2.3	-0.2	2.5	1	0.12
Denmark	6.9	3.4	-0.5	3.9	48	0.13
Finland	8.2	3.8	-0.3	4.1	42	0.14
France	3.9	1.4	0.6	0.8	114	0.10
Germany	3.4	1.4	-0.1	1.5	135	0.10
Italy	6.2	2.1	0.8	1.3	84	0.12
Netherlands	4.1	1.4	0.6	0.8	98	0.10
Norway	9.9	4.4	7.0	0.7	35	0.16
Spain	7.5	3.4	-0.1	3.5	63	0.13
Sweden	6.7	3.3	0.4	3.2	46	0.15
U.K.	6.2	2.5	-0.3	2.8	44	0.11
U.S.	5.4	4.7	1.8	2.8		
Panel B: Non-index stocks						
Australia	40.7	15.7	10.9	4.8	125	0.29
Canada	31.0	14.4	2.1	12.3	0	0.50
Norway	37.4	14.2	11.2	3.5	23	0.32
Sweden	18.5	8.9	2.4	6.7	34	0.20
UK	19.0	7.1	0.4	6.8	28	0.16
Panel C: ETFs						
SPY	0.8	0.3	0.2	0.2	10	
CSPX.L	4.0	0.9	0.4	0.6	386	

Table 3: Difference-in-difference regression for ETFs tracking the S&P500 index

This table reports the results for Difference-in-Difference regressions $\textit{Liquidity}_{i,t} = \alpha_0 + \beta_1 \textit{LSE}_{i,t} + \beta_2 \textit{Margin increase}_t + \beta_3 \textit{LSE}_{i,t} \times \textit{Margin increase}_t + \varepsilon_{i,t}$ on changes to liquidity measures around the COVID-19 pandemic for the CSPX.L (LSE ETF) and SPY (NYSE ETF), which are ETFs that track the performance of the S&P500, traded on the LSE and NYSE, respectively. The dependent variables are *Quoted spread*, *Effective spread*, *Realized spread* and *Price impact*, calculated over one hour intervals. Spreads are reported in basis points. Estimation only uses times of the day when both markets are open. *LSE* is an indicator variable equal to 1 if the ETF trades at the LSE, and 0 otherwise. *Margin increase* is an indicator variable equal to 1 for the period March 11 to March 17, 2020 and 0 for the period February 5 to February 11, 2020. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

Dependent variable:	Quoted spread	Effective spread	Realized spread	Price impact
LSE	1.92	0.63	0.07	0.48
	(1.80)	(0.77)	(0.77)	(0.36)
Margin increase	1.91	0.78	0.86	0.62*
	(1.80)	(0.77)	(0.77)	(0.36)
LSE x Margin increase	13.69***	5.73***	2.29**	2.73***
	(2.55)	(1.08)	(1.08)	(0.50)
Constant	1.01	0.39	0.28	0.20
	(1.28)	(0.54)	(0.54)	(0.25)
Observations	160	160	160	160
Adjusted R^2	0.43	0.41	0.11	0.47

Table 4: Difference-in-difference regression for LSE and NYSE ETFs (reversal on March 18, 2020)

This table reports the results for the difference-in-difference regression: $Liquidity_{i,t} = \alpha_0 + \beta_1 LSE_{i,t} + \beta_2 Margin\ narrowing_t + \beta_3 LSE_{i,t} \times Margin\ narrowing_t + \varepsilon_{i,t}$ on changes to liquidity measures for CSPX.L (LSE ETF) and SPY (NYSE ETF), which are ETFs that track the performance of the S&P500, traded on the LSE and NYSE, respectively. The dependent variables are *Quoted spread*, *Effective spread*, *Realized spread* and *Price impact*. Spreads and Price impact are reported in basis points. We only use the time of the day when both markets are open. *LSE* is an indicator variable equal to 1 for the LSE ETF (CSPX.L), and 0 for the NYSE ETF (SPY). *Margin narrowing* is an indicator variable equal to 1 for the period March 18 to March 19, 2020 and 0 for the period March 16 to March 17, 2020. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

Dependent variable:	Quoted spread	Effective spread	Realized spread	Price impact
LSE	25.50***	10.35***	6.78***	3.14***
	(2.77)	(1.11)	(1.20)	(0.38)
Margin narrowing	0.11	0.07	0.82	−0.34
	(2.36)	(0.95)	(1.02)	(0.32)
LSE × Margin narrowing	−11.18***	−5.94***	−5.84***	−0.39
	(3.92)	(1.57)	(1.69)	(0.54)
Constant	3.18*	1.27*	0.61	1.00***
	(1.67)	(0.67)	(0.72)	(0.23)
Observations	88	88	88	88
Adjusted R^2	0.56	0.55	0.27	0.58

Table 5: Difference-in-difference analysis for index and non-index stocks around the COVID-19 pandemic

This table reports the results for Difference-in-Difference regression $Liquidity_{i,T} = \alpha_0 + \beta_1 High\ margin_t + \beta_2 Index\ constituent_i + \beta_3 High\ margin \times Index\ constituent_{i,t} + \beta_4 Volume_{i,t} + \beta_5 Index\ return_{i,t} + \varepsilon_{i,t}$ on changes to liquidity measures around the COVID-19 pandemic for index and non-index stocks. Our sample period covers February 11, 2020 to April 11, 2020. The dependent variables are Quoted spread, Effective spread, Realized spread and Price impact. For each stock, the liquidity measure is normalized based on the average of January liquidity measures. *High margin* is an indicator variable equal to 1 for the period after the World Health Organization declares the COVID-19 outbreak a pandemic, and 0 otherwise. *Index constituent* is an indicator variable equal to 1 if the stock belongs in the main market index for the stock's listing market as outlined in Table 1. *Volume* is the natural logarithm of the daily number of shares traded in the stock. *Index return* is the percentage return for the main stock market index for the stock's listing market as outlined in Table 1. The estimation uses data for Australia, Canada, Norway, Sweden and UK. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

Dependent variable:	Quoted spread	Effective spread	Realized spread	Price impact
High margin	141.6***	125.4***	−437.2***	144.9***
	(1.4)	(1.2)	(142.6)	(4.9)
Index constituent	−3.8*	−1.4	−114.4	14.1**
	(2.0)	(1.7)	(220.1)	(7.0)
High margin × Index constituent	15.5***	14.3***	608.1**	−7.1
	(2.6)	(2.1)	(293.7)	(9.0)
Volume	3.3***	1.1***	160.6***	−16.0***
	(0.5)	(0.4)	(43.0)	(1.6)
Index return	−1.4***	−0.9***	5.2	−0.5
	(0.2)	(0.1)	(16.7)	(0.5)
Constant	67.8***	101.6***	−2,565.7***	388.6***
	(7.4)	(6.1)	(683.9)	(25.4)
Observations	39,790	39,816	19,002	39,816
Adjusted R^2	0.3	0.3	0.002	0.03

Table 6: Changes in Order To Trade Ratio around the COVID-19 pandemic

This table reports the results for Difference-in-Difference regression $OTR_{i,t} = \alpha_0 + \beta_1 High\ margin_t + \beta_2 Index\ constituent_i + \beta_3 High\ margin \times Index\ constituent_{i,t} + \beta_4 Volume_{i,T} + \beta_5 Index\ return_{i,t} + \varepsilon_{i,t}$, investigating determinants of changes to Order to Trade ratio (OTR) around the COVID-19 pandemic for index and non-index stocks. Our sample period covers February 11, 2020 to April 11, 2020. For each stock, the OTR is normalized based on the average of January OTRs. *High margin* is an indicator variable equal to 1 for the period after the World Health Organization declares the COVID-19 outbreak a pandemic, and 0 otherwise. *Index constituent* is an indicator variable equal to 1 if the stock belongs in the main market index for the stock's listing market as outlined in Table 1. *Volume* is the natural logarithm of the daily trading volume (converted to USD) in the stock. *Index return* is the percentage return for the main stock market index for the stock's listing market as outlined in Table 1. The estimation uses data for Australia, Canada, Norway, Sweden and UK. The first column collects data for all countries. The rest shows estimates for single countries. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

	Dependent variable: Order to Trade ratio					
Sample:	All	Australia	Canada	Norway	Sweden	U.K.
High margin	2.8***	−6.9***	−0.1	13.1***	−4.4***	25.6***
	(0.6)	(0.5)	(1.7)	(2.5)	(0.9)	(1.3)
Index constituent	9.7***	2.6***	0.8	8.5***	7.0***	26.5***
	(0.9)	(0.8)	(3.2)	(2.9)	(1.2)	(1.8)
High margin × Index constituent	−13.4***	−1.7	−12.6***	−9.6***	−4.9***	−39.1***
	(1.2)	(1.1)	(3.7)	(3.4)	(1.6)	(2.0)
Volume	−7.3***	−3.2***	−3.1***	−12.4***	−10.6***	−13.0***
	(0.2)	(0.1)	(0.6)	(1.0)	(0.3)	(0.5)
Index return	0.3***	0.05	0.5***	−0.6**	−0.2*	0.4***
	(0.1)	(0.1)	(0.2)	(0.3)	(0.1)	(0.1)
Constant	221.7***	149.8***	164.2***	303.6***	278.1***	305.5***
	(3.3)	(2.4)	(9.8)	(15.3)	(5.4)	(8.6)
Observations	39,816	9,932	10,973	1,866	7,327	9,718
Adjusted R^2	0.04	0.1	0.01	0.1	0.1	0.1