# Contagious margin calls: How COVID-19 threatened global stock market liquidity[⋆]

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**Abstract**

The outbreak of the COVID-19 pandemic caused some of the largest — and fastest — market dislocations in modern history. During the outbreak, liquidity quickly evaporated in a coordinated fashion across global markets. We show a sudden increase in margin requirements during the pandemic is correlated with the withdrawal of global liquidity providers. These effects are concentrated in securities most exposed to high frequency market makers, consistent with the binding nature of increased capital constraints.

## 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

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spiral exacerbated by the significant increase in margin requirements the world over. An announcement from 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: A pro-cyclical period of increasing margin requirements across global equities and futures 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. These rising margin requirements cause 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 occur infrequently.

The WHO's declaration of the COVID-19 pandemic in March 2020 is associated with some of the largest dislocations in market history. Equity market values fell by 30-40% globally, and the withdrawal of liquidity supply was correlated with a sharp increase in margin requirements for exchange traded equity products, in some instances by more than 300%. Moreover, some markets (such as the U.K.) experienced much larger increases in margins relative to other markets (such as the U.S.), resulting in a margin differential across exchanges.

In this study, we test theory predicting that an increase in capital requirements results in a reduction in market liquidity. Using a difference-in-difference framework, we exploit the change in margin differential between the U.K. and U.S. markets and examine the liquidity of ETFs that both track the S&P 500 index, but trade in the U.K. and U.S., respectively. Because both the U.K. and U.S. traded ETFs track the same underlying index, we effectively control for any common changes to liquidity in these ETFs due to changes in the fundamental value of the S&P 500. Thus, the U.K. and U.S. traded ETFs primarily differ only by the margin required to trade them on their respective exchange.

Next, we extend our analysis to a global setting and investigate changes in the liquidity of index and non-index stocks following the margin spike in March 2020 for a large cross-section of global equity markets. We argue that high frequency market makers (HFMM), who are heavily reliant on leverage for liquidity provision, are more sensitive to margin requirements than traditional investors, and thus, more likely to withdraw from the market following large increases in margin requirements. Further, HFMM are more likely to be present in index stocks, relative to non-index stocks, which have lower HFMM participation (see Brogaard, Hendershott and Riordan (2014) and Shkilko and Sokolov (2020)). Because of these factors, as margin requirements increase, we expect a larger decline in the liquidity of index stocks in which HFMM are more active, relative to non-index stocks. Last, using the order to trade ratio to proxy for HFMM activity in global equities, we test whether HFMM withdraw their activity more from index stocks than non-index stocks, following an increase in margin requirements.

Our results strongly support theoretical models predicting that an increase in capital requirements leads to a decline in equity market liquidity. Our analysis provides three main findings. First, for our analysis on the ETFs tracking the S&P 500 index, we show that market liquidity deteriorates more for the U.K. traded ETF, which experienced a larger increase in margin, relative to the U.S. traded ETF, for which margins remained relatively static. Further, we find the reverse effect when the margin differential narrows. Specifically, while U.K. margins increased precipitously when U.S. margins remained relatively stable, the U.S. subsequently experienced a large jump in margin requirements, thereby narrowing the margin differential. Corresponding to this subsequent jump in U.S. margins, we show that the market liquidity of the U.S. traded ETF deteriorates relative to that of the U.K. traded ETF.

Second, generalizing our findings to a global setting, we report a larger deterioration in liquidity for index stocks when compared to non-index stocks. This result is consistent with the notion that increases in margin requirements have a larger impact on stocks that are more reliant on margin sensitive HFMM for liquidity provision. This result is also consistent with the theoretical model developed by Cespa and Foucalt (2014), which shows that liquidity contagion from the index derivatives has a muted impact on non-index stocks.

Finally, using the order to trade ratio as a proxy for HFMM activity, we show that HFMM withdrew more from index stocks than non-index stocks when margin requirements suddenly increased.

Our results are robust to a plethora of robustness and falsification tests. The sudden increase in exchange margin requirements in March 2020 also corresponded to large declines in stock prices, which could also be correlated with declining stock liquidity. To control for a falling stock price, we identify a period in 2015 when stock prices declined significantly without a corresponding change to exchange margin requirements. Importantly, for this falsification test, we do not find differential changes in stock liquidity following large stock declines. Our results are also robust to different sample windows and alternate regression frameworks.

Overall, our results show that an increase in funding costs due to higher margin requirements is correlated with 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 traders must de-leverage their positions precisely at the point in time when prices were declining, thereby potentially further depressing prices and increasing margin, consistent with the theoretical findings of Morris and Shin (2004). This process can create a margin loss-spiral, consistent with the rapid reduction in both market liquidity and prices observed in March 2020.

The significance of the capital constraints faced by existing high frequency market makers 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.

## 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 banking literature in response to the 2008 Global Financial Crisis (GFC), both theoretically (Repullo and Suarez, 2013; Hugonnier and Morellec, 2017) and empirically (Behn, Haselmann and Wachtel, 2016; Berger, Bouwman, Kick and Schaeck, 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. For example, in bond markets, Adrian, Boyarchenko and Shachar (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) examine the commodity futures markets and show that an increase in margins following the Dodd-Frank act increases transactions costs and reduces 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 been able to directly demonstrate this relation. For example, Hameed, Kang and Viswanathan (2010) document reductions in liquidity around market declines, particularly at times when the funding markets are tight, which are likely to arise from capital constraints on market makers. Similarly, Comerton-Forde, Hendershott, Jones, Moulton and Seasholes (2010) show that the inventory levels and trading revenues of NYSE market makers are correlated with their propensity to supply liquidity. In a global study, Karolyi, Lee and van Dijk (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, to date, no study has been able to clearly identify this mechanism.

Our global findings for the equity markets align well with evidence from Duffie (2020), who investigates U.S. Treasury markets and shows that the inventory risk faced by dealers results in bid-ask spreads that increase to over 10 times their (relatively stable) pre-pandemic levels. The larger magnitudes observed in these markets likely reflects the greater leverage (and lower historic volatility) utilized in these settings. Similarly, other recent papers, including Cheng, Wessel and Younger (2020), Fleming and Ruela (2020) and Bent, Duffie and Zhu (2019), 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. While the majority of these early papers aims to understand the asset pricing implications of the pandemic,[1] the literature focusing on the *working* of financial equity markets during the COVID-19 crisis is more limited. For example, Brogaard, Ringgenberg and Roesch (2020), show that the suspension of trading by physical market makers on the trading floor at the NYSE deteriorates overall market quality.

## 2. Data and sample selection

### *2.1. Sample selection*

Our analysis considers equity markets across a broad range of developed countries. Table 1 documents the markets and index stocks in our sample. This set of markets 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 1 illustrates the disruption to global stock markets, showing how our sample markets have fallen from their price levels on February 1, 2020 (normalized to 100).

**Table 1: Markets and Exchanges**

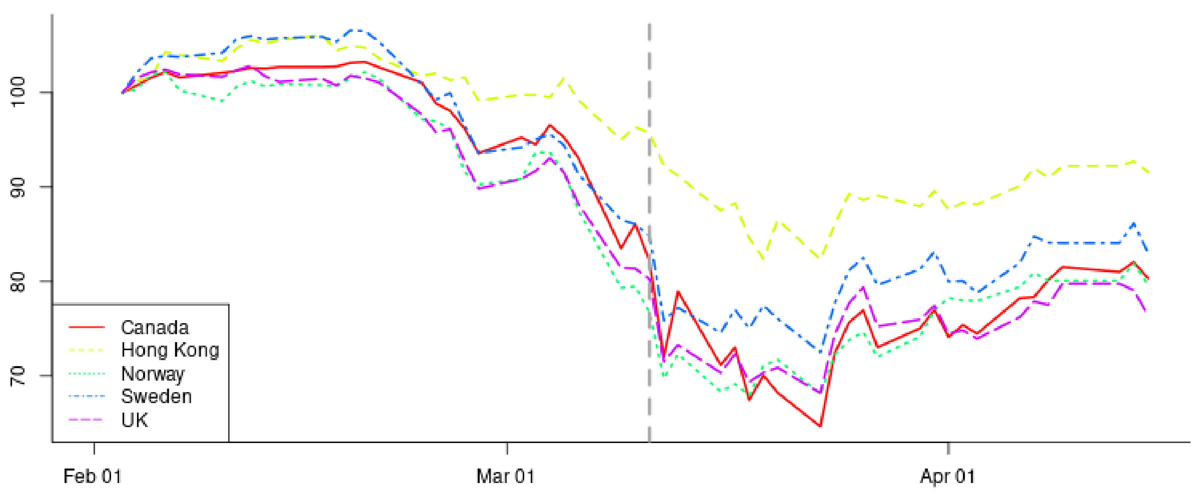
The table lists the sample markets considered in the study, the main index for the market and the number of constituents in the market's main index.

| Market | Index | No. constituents |
|---|---|---|
| Canada | TSX 60 | 60 |
| Hong Kong | Hang Seng Index | 58 |
| Norway | OBX | 25 |
| Sweden | OMX Stockholm | 30 |
| U.K. | FTSE 100 | 100 |

[1]See, for example, papers by Hansen (2020), Ellul, Erel and Rajan (2020), Baker, Bloom, Davis, Kost, Sammon and Viratyosin (2020), Ramelli and Wagner (2020), Ashraf (2020), and Gormsen and Koijen (2020).

**Figure 1: The evolution of stock market prices**

This figure illustrates the movement in stock market prices for the indices listed in Table 1. The plots show the change in index price levels, relative to the index level on February 1, 2020, which takes a value of 100. The gray vertical line represents March 11, 2020, when the World Health Organization declares the COVID-19 outbreak a pandemic.



### 2.2. Market Data

In Section 5.2, we investigate liquidity metrics for stocks that are index constituents of the market's main index, relative to stocks outside of the main index. For Hong Kong, we use stocks in the Hang Seng LargeCap and MidCap indices that are outside of the main Hang Seng Index as the sample of non-index stocks. For the U.K., we use data for the firms in the FTSE 250, but not within the FTSE 100, to represent our non-index stocks. For the remaining markets, 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 stocks, conditional on having more than 100 trades per day.

We source the data for this study 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. For the latter two, we use a 10 second delay in the calculations to capture the returns to high frequency market makers, consistent with the work of Conrad and Wahal (2020).[3] We consider only the trading activity during the continuous trading session at the main (listing) exchange.[4]

In Section 5.1, we investigate the liquidity of an U.S.-traded ETF tracking the S&P 500 relative to a U.K.-traded ETF that also tracks the S&P 500 [5] We also collect data on the trades and quotes for these ETFs from Refinitiv. Similarly, we calculate the same liquidity measures outlined above, but we compute them as averages every trading hour, rather than daily averages.

Table 2 provides descriptive statistics for the stocks in our sample. To illustrate a representative non-pandemic period, these tables provide averages for the liquidity measures over the period January 1 to February 15, 2020. Panel A presents statistics for the stocks that are constituents of the market's main index, as listed in Table 1, while Panel B provides descriptive statistics for the sample of relatively liquid stocks outside of the main index. We observe a high similarity in quoted spreads across markets, and as expected, the transaction costs for non-index stocks are substantially higher than those of their index-constituent counterparts.

[2]Previously called Thomson Reuters Tick History (TRTH).

[3]Detailed definitions of our liquidity measures are available in Appendix A.

[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 U.S. ETF trades on the New York Stock Exchange with Reuters instrument code (RIC) SPY, and the U.K. ETF trades on the London Stock Exchange with RIC CSPX.L

## Table 2: Descriptive Statistics

The 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. 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 Hong Kong, we use the constituents of the Hang Seng LargeCap and MidCap indices that are not in the main Hang Seng Index. For the U.K., we use the constituents of the FTSE 250 that are not in the FTSE 100. For the other markets (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 provide liquidity measures for the U.S. ETF (SPY), which trades at the NYSE, and the U.K. ETF (CSPX.L), which trades at the LSE. Both ETFs track the the S&P 500 index. We provide the average liquidity variables based on hourly estimates.

| | Quoted spread (bp) | Effective spread (bp) | Realized spread (bp) | Price impact (bp) |
|---|---|---|---|---|
| Panel A: Index stocks | | | | |
| Canada | 5.2 | 2.3 | -0.2 | 2.5 |
| Hong Kong | 14.1 | 6.8 | 3.9 | 4.5 |
| Norway | 9.9 | 4.4 | 7.0 | 0.7 |
| Sweden | 6.7 | 3.3 | 0.4 | 3.2 |
| U.K. | 6.2 | 2.5 | -0.3 | 2.8 |
| Panel B: Non-index stocks | | | | |
| Canada | 21.9 | 9.9 | 0.7 | 9.2 |
| Hong Kong | 25.1 | 12.1 | 3.9 | 8.2 |
| Norway | 36.2 | 13.1 | 9.7 | 3.5 |
| Sweden | 26.1 | 12.4 | 3.8 | 8.8 |
| U.K. | 19.0 | 7.1 | 0.4 | 6.8 |
| Panel C: ETFs | | | | |
| U.K. | 4.0 | 0.9 | 0.4 | 0.6 |
| U.S. | 0.8 | 0.3 | 0.2 | 0.2 |

*2.3. Margin Data*

Margins refer to the minimum amount of money a trader must deposit in their margin trading account to fund the notional exposure of their portfolio. These margins serve as a collateral deposit and 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 to open a new leveraged position. MM is the minimum collateral a trader must retain 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 the value of the margin account increasing by $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).

We collect the daily initial margin requirements for equity index futures contracts for multiple indices. We obtain this data directly from regulatory information available on each exchange webpage.[6] Typically, exchanges report margin as the dollar amount required to trade a contract.[7] For example, the margin to buy one S&P 500 futures contract that has a notional exposure of approximately $840,000 is reported as $31,500 at the start of our sample period. Table 3, Panel A, contains descriptive statistics for the dollar margin for each contract for a pre-pandemic and a post-pandemic period. The pre-pandemic period spans from February 11 to March 10, which occurs prior to the WHO declaring the COVID-19 outbreak a pandemic. In contrast, the post-pandemic period spans from March 11 to April 11 and occurs after the WHO's declaration of a pandemic.

Because the notional value for equity index futures contracts differs significantly across markets, the reported dollar margin can be hard to interpret. Accordingly, Table 3, Panel B, reports the margin required as a percentage of the notional exposure. For example, if a margin of $35,000 is required to purchase one contract with a notional exposure of $840,000, then the percentage margin is 4.167%. This percentage margin allows a more intuitive comparison across our global futures contracts.

While the figures reported in Panel B allow for an intuitive comparison across exchanges, a change in percentage margin can occur due to a change in the notional exposure (caused by a change in price), rather than a change in the dollar margin. Thus, to avoid any potential contamination of margin changes due to changes in the underlying price (or notional exposure), we use the dollar margin per contract, rather than the percentage margin, for our

[6] See Table B.1 in Appendix B for a list of webpages.

[7] See Appendix B for further details on the dollar margin reported across exchanges.

## Table 3: Margin summary statistics

The table provides the summary statistics for the margin (Panel A) and percentage margin (Panel B) for the equity index futures contract of selected markets. Canada refers to the TSX 60 Index futures, which trades on the Montreal Exchange (expressed in CAD). Hong Kong refers to the Hang Seng Index futures, which trades on the Hong Kong Futures Exchange (expressed in HKD). U.K. refers to the margin for the FTSE 100 Index futures, which trades on the Intercontinental Exchange (expressed in pound). U.S. refers to the margin for the S&P 500 Index futures, which trades on the Chicago Mercantile Exchange (expressed in USD). In Panel B, we express the margin as a percentage the notional exposure of the contract. The pre-period covers the period February 11 to March 11, 2020 and the post-period covers the period March 12 to April 12, 2020.

| | Pre-period | | | Post-period | | |
|---|---|---|---|---|---|---|
| | Min. | Mean | Max. | Min. | Mean | Max. |
| Panel A: Margin per contract | | | | | | |
| Canada (CAD) | 5,988 | 7,089 | 7,480 | 8,653 | 18,161 | 24,739 |
| Hong Kong (HKD) | 82,300 | 83,300 | 83,750 | 82,300 | 106,987 | 116,200 |
| U.K. (£) | 3,629 | 3,745 | 4,191 | 5,667 | 6,563 | 6,699 |
| U.S. (USD) | 33,000 | 34,543 | 41,750 | 41,750 | 57,024 | 60,000 |
| Panel B: Margin as percentage of exposure | | | | | | |
| Canada | 3.10 | 3.42 | 3.52 | 5.79 | 11.43 | 14.45 |
| Hong Kong | 5.99 | 6.20 | 6.57 | 6.77 | 9.16 | 10.07 |
| U.K. | 4.82 | 5.40 | 7.03 | 10.56 | 12.06 | 13.08 |
| U.S. | 3.90 | 4.39 | 5.79 | 6.64 | 9.01 | 10.73 |

analysis in the following sections.[8] However, to allow for a comparison across each contract, we present the summary statistics for the dollar margin requirement on each day, relative to the average daily margin requirement in January, 2020.

Because we are unable to obtain margin data for the Nordic markets, for reasons outlined in Sections 3 and 5.2, we rely on the systemic increase in global margins to proxy for the margin requirements in these markets.

## 3. Margin during the COVID-19 crisis

To understand the impact of the pandemic on margin levels, Figure 2 plots the margin requirements for equity index futures in markets for which we are able to obtain margin data: Canada, Hong Kong, U.K. and U.S. From the figure, the margin requirements remain reasonably constant throughout January and February, 2020, but rapidly increases around the WHO's announcement of a pandemic on March 11, 2020, reaching over 300% of pre-pandemic levels in the case of Canada. Because of the systemic increase in global margin requirements in March, 2020, it is reasonable to assume that other markets for which we do not have margin data (i.e., Norway and Sweden), also experienced similar jumps in margin requirements, which we discuss further in Section 5.2.

The sudden dramatic jump in margin for equity index futures is likely to affect stock liquidity in several ways. First, while we are unable to obtain data on individual stock margins, it is reasonable to assume that stock margins experienced similar jumps,[9] thereby directly imposing binding constraints on leveraged traders, who subsequently withdraw from the market. Second, a jump in the margin requirements for equity index futures is likely to affect leveraged sophisticated investors and cross-market arbitrageurs, who typically hedge their underlying equity positions via equity derivative products, such as index futures. Thus, these sophisticated investors could also withdraw from equity markets if they are unable to effectively manage their risk via the futures markets.

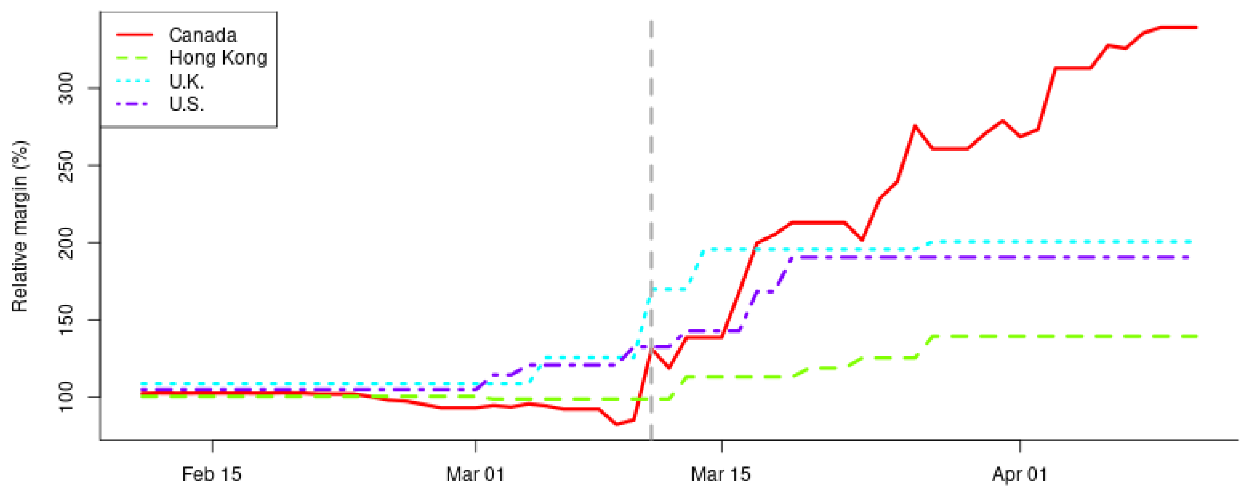
We argue that high frequency market makers (HFMM) are more sensitive to margin requirements than traditional traders due to their unique trading style. HFMM operate over short time horizons, and typically carry no overnight inventory risk (see Bartlett and McCrary (2019), Hasbrouck and Saar (2013), and Shkilko and Sokolov (2020)). Accordingly, their positions are unlikely to precipitate a margin call, as large adverse price moves are

[8] Our results are robust to either the dollar or percentage measure of margin.

[9] We confirm that margins for equity index futures are likely to be highly correlated with the margin requirements for their underlying stocks in Appendix C.

**Figure 2: The evolution of global margin requirements**

The figure shows the evolution in margin requirements for global markets. At each date, the margin requirement is presented as a percentage of the margin requirement in January 2020. Canada refers to the TSX 60 Index futures, which trades on the Montreal Exchange. Hong Kong refers to the Hang Seng Index futures, which trades on the Hong Kong Futures Exchange. U.K. refers to the margin for the FTSE 100 Index futures, which trades on the Intercontinental Exchange. U.S. refers to the margin for the S&P 500 Index futures, which trades on the Chicago Mercantile Exchange. Our data spans February 11 to April 11, 2020. The gray vertical line represents March 11, 2020, when the World Health Organization declares the COVID-19 outbreak a pandemic.



unlikely to occur during their short holding periods. For this reason, HFMM require less 'buffer' in their margin accounts and can effectively trade on higher leverage ratios closer to the binding margin limits than other market participants. Moreover, HFMM are often propriety trading firms, with smaller balance sheets than large institutional investors that use leveraged derivative positions to hedge price risk.

Consistent with our argument, there is anecdotal evidence that the significant spike in margin around the pandemic announcement in March, 2020 caused significant constraints on HFMM. Specifically, 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 similar firms to supply liquidity when it is most needed in financial markets.[10]

## 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. Figure 3 illustrates the evolution of liquidity during the crisis. We document the changes across two key metrics: *Quoted spread* (the anticipated cost of liquidity provision) and *Effective spread* (the cost of traded liquidity).

Panel A shows the quoted spread relative to the average daily levels during January, 2020. We observe that quoted spreads, which measure the marginal cost charged by a liquidity provider for an additional unit of liquidity, begin rising around the beginning of March. However, after the WHO's declaration of a pandemic on March 11, 2020, we observe a significant increase in this measure of transaction costs.[11] For Canada and the U.K., the quoted spread increases from around 200% of January levels in the beginning of March to upwards of 500% by the end of March. All other markets show a similar response, with significant increases from pre-pandemic levels. This sharp increase in quoted spreads supports the notion that liquidity providers became more cautious in their liquidity provision once it became clear that COVID-19 would become a global issue. By early May 2020, these costs had fallen to a more typical level, but still remain between 125-200% of their pre-pandemic levels.

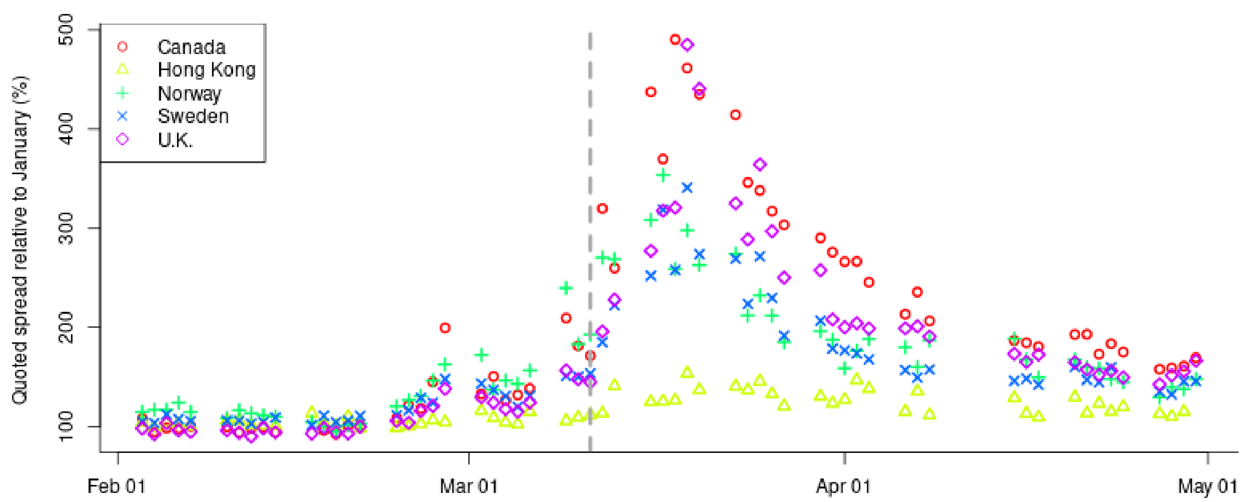
[10] Press Release: Virtu announces $450 million of additional broker dealer borrowing capacity.

[11] Consistent with the work of Donadelli, Kizys and Riedel (2017) we use the WHO's announcement of a pandemic as a significant announcement which has been shown to impact stock returns.

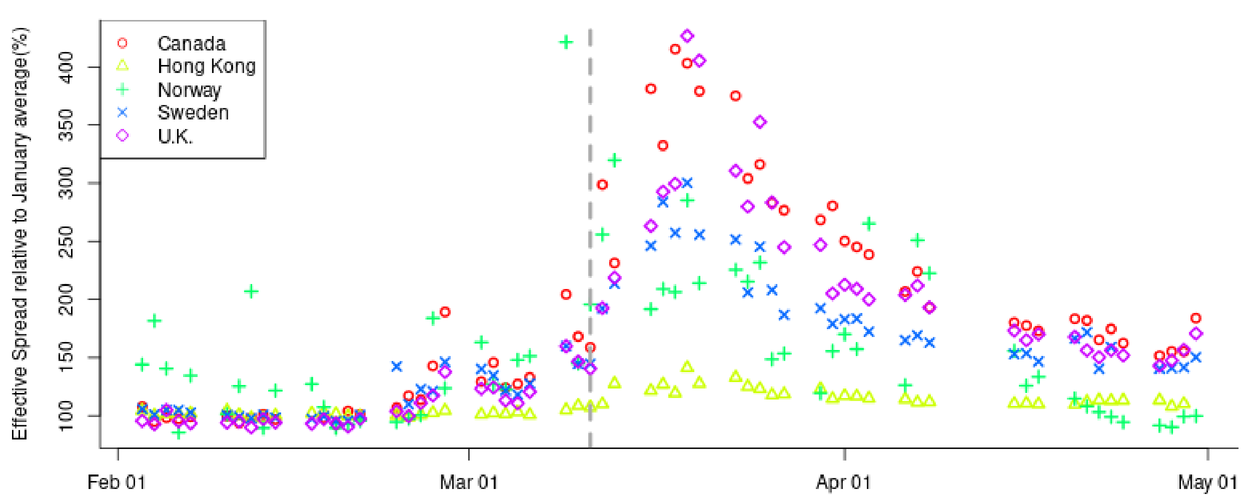
**Figure 3: Liquidity evolution during the COVID-19 crisis**

The figures illustrate the changes in liquidity during the COVID-19 crisis, starting in February 1, 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. The gray vertical line represents March 11, 2020, when the World Health Organization declares the COVID-19 outbreak a pandemic.

Panel A: Quoted spread




Panel B: Effective spread



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 trading 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 liquidity, increasing the transaction costs borne by market participants. Panel B shows that effective spreads follow a similar evolution to quoted spreads, with the cost of demanding liquidity in the U.K. increasing the most, peaking at 450% of January levels during March 2020.

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 liquidity, 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.

## 5. Empirical Results

This section presents our main results. In Section 5.1, we examine a unique case of two ETFs tracking the S&P 500 index. While these ETFs track the same underlying asset, the ETFs trade on different markets, which experience different changes in their margin requirements during March 2020. We exploit this unique setting to test the relation between margin requirements and market liquidity. In Section 5.2, we extend the analysis to the world's major equity markets. We argue that changes to margin requirements affect stocks that are index constituents more than stocks that are outside the index due to a higher concentration of margin sensitive high frequency market makers (HFMM) in index constituents. Using a difference-in-difference analysis, we find a larger fall in liquidity for stocks that are index constituents than non-index constituents, following a margin increase. Last, in Section 5.3, using the order to trade ratio as a proxy for HFMM activity, we test whether HFMM withdraw more from index stocks, relative to non-index stocks, when margin requirements increase.

### *5.1. Liquidity of two ETFs tracking the S&P 500 index*

We investigate liquidity differentials between two ETFs that track the same underlying index and test if these differentials are correlated to changes in margin requirements. Specifically, we investigate SPY, an ETF tracking the S&P 500 that trades on the NYSE (the

U.S. ETF), and CPSX.L, an ETF that also tracks the S&P 500, but trades on the London Stock Exchange (the U.K. ETF). Accordingly, these two ETFs trade on different exchanges and are subject to their respective exchange margins, but track the same underlying asset. Thus, while not fungible, the ETFs are synthetically identical and primarily differ only by the margin required to trade them. Because the ETFs are synthetically identical, any shock to the fundamental value of the S&P 500 should equally affect both ETFs. For this reason, we can control for any common changes to liquidity in these ETFs due to falling prices or increased volatility of the S&P 500 using a difference-in-difference framework.

While all exchange margins increased around the time of the WHO's declaration of a pandemic (Figure 2), 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. We note, however, due to data limitations, we are unable to obtain the exact margin for the two ETFs. Thus, we proxy the respective ETF margin by using the margin corresponding to the main equity index future for each market. We proxy the margin requirement for the U.K. ETF using the margin for the FTSE 100 Index futures, which is traded on the Intercontinental Exchange (ICE). Similarly, we proxy the margin requirement for the U.S. ETF margin using the margin for the S&P 500 Index futures, which is traded on the Chicago Mercantile Exchange (CME).[12]

Figure 4 illustrates the differential increase in U.K. and U.S. ETF margin proxies. Panel A shows a large jump in the U.K. margin proxy (red line), relative to the U.S. margin proxy (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 U.K. and U.S. margin proxies. Panel B shows a clear increase in the margin differential for the period March 11 to March 16: over this period, the U.K. margin proxy increases more substantially, relative to the U.S. margin proxy. For this reason, we select the March 11 to March 16 period as the post-period for the difference-in-difference estimation, to test the prediction from Brunnermeier and Pedersen (2009) that binding margin constraints lead to deterioration in market liquidity.

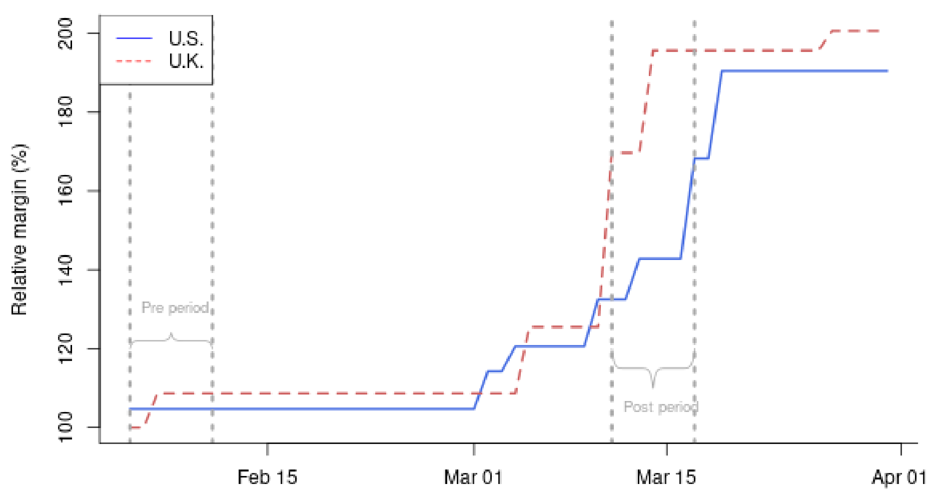
Because the U.K. margin proxy increased earlier, and by more than the U.S. margin proxy, we expect market liquidity to deteriorate more in the U.K. market than in the U.S. market. Turning to the two ETF contracts, Figure 5 shows the evolution of the effective spread in the U.K. ETF (red markers) and the U.S. ETF (blue markers). We see a much larger increase in

[12]In Appendix C, we provide evidence that a market's equity index futures margin is a suitable proxy for both ETF and individual stock margins traded in the market's primary exchange.

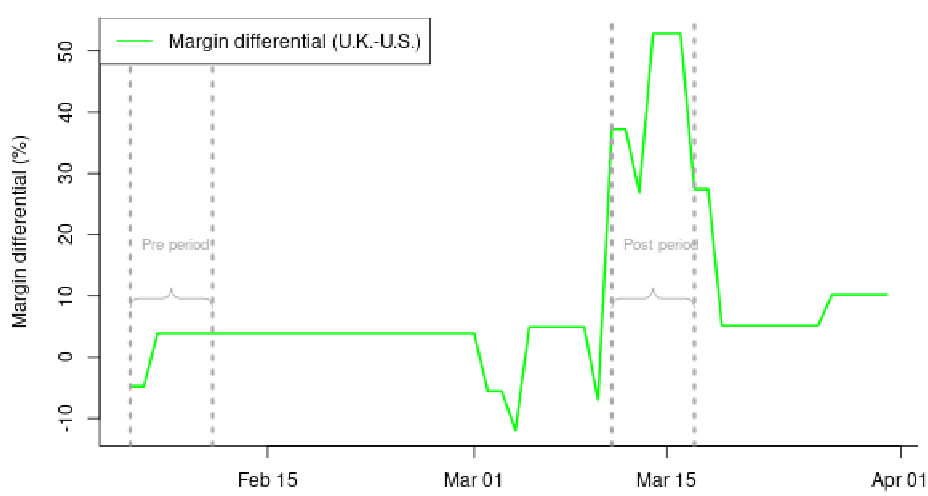
## Figure 4: Relative margins for U.S. and U.K. exchanges

Panel A plots the time series evolution of margins in the U.S. (blue line) and U.K. (red dotted line). The margin is presented as a percentage of the margin requirement on February 1, 2020. U.K. refers to the margin for the FTSE 100 futures, which trades on the Intercontinental Exchange. U.S. refers to the margin for the S&P 500 futures, which trades on the Chicago Mercantile Exchange. Panel B plots the margin differential, which is the *difference* between the U.K. and U.S. relative margins. The gray vertical lines indicate the pre (February 5 to February 10, 2020) and post (March 11 to March 16, 2020) periods for our difference-in-difference analysis.

Panel A: Relative margins for U.K. and U.S.



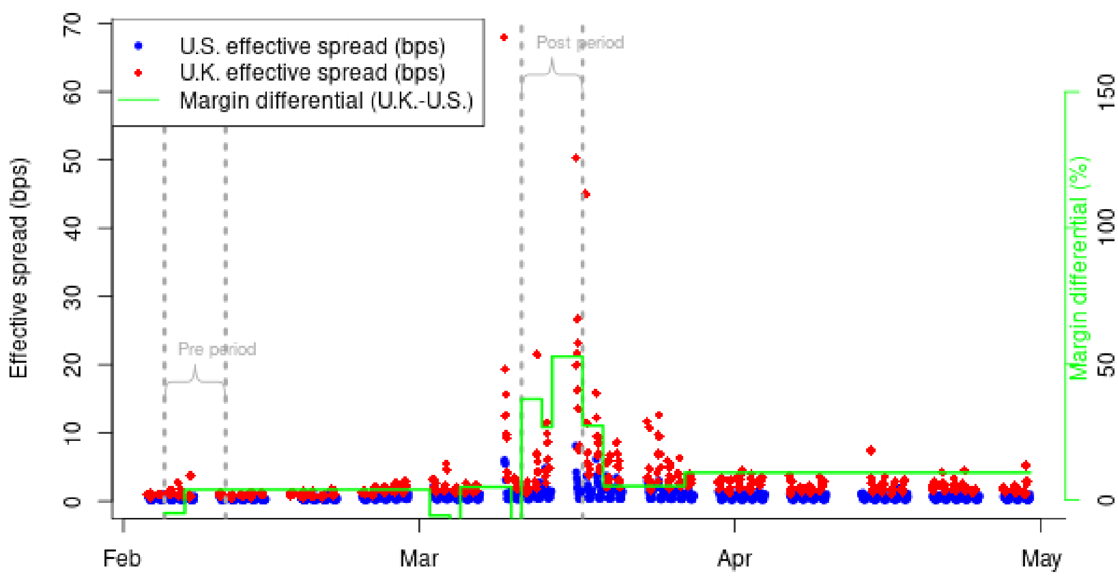

Panel B: Difference between U.K. and U.S. margins



the effective spread for the U.K. ETF, relative to the U.S. ETF, which is consistent with the theoretical prediction from Brunnermeier and Pedersen (2009) and Morris and Shin (2004).

**Figure 5: Effective spreads for U.S. and U.K. ETFs tracking the S&P 500 index**

The figure plots the evolution of effective spreads for the U.S. (SPY traded on the New York Stock Exchange) and U.K. (CSPX.L traded on the London Stock Exchange) ETFs. The effective spread is the time-weighted average effective spread (in basis points) over an hour. We only consider spreads for times of the day when both markets are open. On the right axis, we show the margin differential (in percent), which is the difference between the U.K. and U.S. margins. The U.K. margin refers to the margin for the FTSE 100 futures, which trades on the Intercontinental Exchange. The U.S. margin refers to the margin for the S&P 500 futures, which trades on the Chicago Mercantile Exchange. The gray vertical lines indicate the pre- (February 5 to February 10, 2020) and post- (March 11 to March 16, 2020) periods for our difference-in-difference analysis.




To formalize these observations, we perform a difference-in-difference estimation using pre- and post- periods indicated in Figure 4. The pre-period covers the interval February 5 to February 10, 2020, as Figure 4 shows there is no material deviation in the margin differential over this period. Our post-period covers the period March 11 to March 16, 2020, which corresponds to the jump in margin differential described earlier. Importantly, we observe a 43% margin differential in the post-period while the margin differential is only 1%

in the pre-period.[13] We run the following difference-in-difference regression model:

$$\begin{aligned} Liquidity_{i,t} &= \alpha_0 + \beta_1 UK_{i,t} + \beta_2 Margin\ increase_t \\ &\quad + \beta_3 UK_{i,t} \times Margin\ increase_t + Volatility_{i,t} + Return_{i,t} + \varepsilon_{i,t}, \end{aligned} \tag{1}$$

where $Liquidity_{i,t}$ is one of the following liquidity variables: Quoted spread, Effective spread, Realized spread or Price impact. Each liquidity variable is averaged over hourly intervals. $UK_{i,t}$ is an indicator variable equal to 1 if the ETF trades in the U.K., and 0 otherwise. $Margin\ increase_t$ is an indicator variable equal to 1 for the post-period from March 11 to March 16, 2020 and 0 for the pre-period from February 5 to February 10, 2020. The interaction term $UK \times Margin\ increase$ isolates the effect of the margin increase on stock liquidity. To control for differences between trading conditions in the U.K. and U.S., we include $Return_{i,t}$ and $Volatility_{i,t}$, where $Return_{i,t}$ is computed as $\log(Close\ Price_{i,t}/Open\ Price_{i,t})$ and $Volatility_{i,t}$ is computed as $\log(High\ Price_{i,t}/Low\ Price_{i,t})$. For *Return* and *Volatility*, we use index levels for the FTSE 100 and S&P 500 for the U.K. and U.S. markets, respectively.[14]

We report the results from the difference-in-difference regression models in Table 4. Consistent with the theoretical predictions of Brunnermeier and Pedersen (2009) and Morris and Shin (2004), our results show a decrease in liquidity for the U.K. ETF after the jump in the U.K. margin proxy, relative to the U.S. margin proxy. Across all model specifications, *UK* $\times$ *Margin increase* is positive and significant indicating that transaction costs (i.e., quoted, effective and realized spreads) increase for the U.K ETF after the margin differential widens between the U.K. and U.S. markets. Further, the price impact of trades for the U.K. ETF increases after the margin differential widens. Prior empirical studies show that increases in margin correspond to a deterioration in market quality for commodity futures markets (Daskalaki and Skiadopoulos (2016)) and CDS and bond markets (Aramonte and Szerszeń (2020)). Our results complement these studies by showing that the relation between increasing margins and deterioration in market quality extends to equity markets.

[13] In Appendix D, we report similar results using a smaller 2 day window around the March 11 event.

[14] Our regressions contain 56 observations. We have 24 observations for the pre-period, which consists of 4 trading days, each with 3 × 1 hour observations when both the U.K. and U.S. markets are open. In the post-period, because of daylight saving, there is a 4 hour overlap when both markets are open. Thus, our post-period contains 32 observations, which consists of 4 trading days, each with 4 × 1 hour observations when both markets are open.

## Table 4: Difference-in-difference regression for U.K. and U.S. ETFs (widening on March 11, 2020)

The table reports the changes to liquidity measures around the widening of the margin differential for the CSPX.L (U.K.) and SPY (U.S.), which are ETFs that track the performance of the S&P 500, traded on the LSE and NYSE, respectively. Specifically, we report the results for the following difference-in-difference regression:

$$Liquidity_{i,t} = \alpha_0 + \beta_1 UK_{i,t} + \beta_2 Margin\ increase_t + \beta_3 UK_{i,t} \times Margin\ increase_t + Volatility_{i,t} + Return_{i,t} + \varepsilon_{i,t}$$

where $Liquidity_{i,t}$ is one of the following liquidity variables: *Quoted spread*, *Effective spread*, *Realized spread* or *Price impact* for the U.S. or U.K. ETF, $i$. The dependent variables are calculated over one hour intervals, and are expressed in basis points. $UK_{i,t}$ is an indicator variable equal to 1 if the ETF trades in the U.K., and 0 otherwise. $Margin\ increase_t$ is an indicator variable equal to 1 for the post-period from March 11 to March 16, 2020 and 0 for the pre-period from February 5 to February 10, 2020. $Volatility_{i,t}$ and $Return_{i,t}$ are based on the FTSE 100 and S&P 500 index levels for the U.K. and U.S. markets, respectively. $Volatility_{i,t}$ and $Return_{i,t}$ are calculated as $\log(High\ Price_{i,t}/Low\ Price_{i,t})$ and $\log(Close\ Price_{i,t}/Open\ Price_{i,t})$, respectively. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

| *Dependent variable*: | Quoted spread | Effective spread | Realized spread | Price impact |
|---|---|---|---|---|
| UK | 4.47 | 1.09 | 0.84 | 0.24 |
| | (4.52) | (1.38) | (1.14) | (0.42) |
| Margin increase | −5.14 | −3.45* | −2.07 | −1.46** |
| | (6.47) | (1.98) | (1.63) | (0.60) |
| UK × Margin increase | 18.21*** | 7.32*** | 3.04* | 4.20*** |
| | (6.20) | (1.90) | (1.57) | (0.57) |
| Volatility | 247.90 | 154.02** | 87.07* | 71.33*** |
| | (199.41) | (61.05) | (50.35) | (18.43) |
| Return | 51.92 | 6.84 | 30.15 | −30.15** |
| | (147.30) | (45.09) | (37.20) | (13.62) |
| Constant | −0.37 | −0.32 | −0.25 | −0.07 |
| | (3.25) | (1.00) | (0.82) | (0.30) |
| Observations | 56 | 56 | 56 | 56 |
| $\overline{R}^2$ | 0.38 | 0.47 | 0.16 | 0.78 |

### *5.1.1. Reduction in the margin differential*

While the U.K. initially experiences a larger jump in margins relative to the U.S., shortly after, on March 17, 2020, the U.S. margin also jumps, and the difference between the U.K. and U.S. margins narrows (see Figure 4). Our second test exploits this narrowing in the margin differential. Because there is a narrowing in the margin differential between the U.K. and U.S. markets, there should be a reduction in the market quality differences between the markets. That is, we expect spreads on the U.K. market to decrease, relative to spreads on the U.S. market.

For this experiment, we use a similar difference-in-difference framework to Equation (1):

$$\begin{aligned} Liquidity_{i,t} &= \alpha_0 + \beta_1 UK_{i,t} + \beta_2 Margin\ narrowing_t \\ &+ \beta_3 UK_{i,t} \times Margin\ narrowing_t + Volatility_{i,t} + Return_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2)$$

where $Margin\ narrowing_t$ is an indicator variable equal to 1 for the post-period from March 17 to March 21, 2020 and 0 for the pre-period from March 12 to March 16, 2020. The remaining variables are defined in the same way as Equation (1). In Appendix E, we show that the average margin differential is 43% for the pre-period, which declines to 14% for the post-period.[15] Based on the predictions of Gârleanu and Pedersen (2011), we expect to see a negative and significant coefficient on *UK* × *Margin narrowing*.

Table 5 shows the results for the difference-in-difference regression around the March 17, 2020 margin narrowing event. Consistent with our expectations, we find that the interaction term *UK* × *Margin narrowing* is negative and significant across all model specifications. Complementing the results for the widening of the margin differential in Section 5.1, Table 5 shows that the narrowing of the margin differential is associated with an improvement in the market quality for the U.K. ETF, relative to the U.S. ETF, evidenced through tighter quoted, effective and realized spreads, and lower price impacts.

### *5.1.2. Robustness: Alternative specification*

Previously, we use a difference-in-difference approach, which relies on an indicator variable to define the post-period, when the margin differential between the U.K. and U.S. markets increased (Section 5.1) or reduced (Section 5.1.1). Based on the difference-in-difference approach, we are unable to capture the actual daily margin differences between the two

[15] We use a 5-day pre- and post- window to maintain consistency with the results in Section 5.1. In Appendix D, we show that our results are robust to a shorter 2-day window around the margin narrowing event.

## Table 5: Difference-in-difference regression for U.K. and U.S. ETFs (narrowing on March 17, 2020)

The table reports the changes to liquidity measures around the narrowing of the margin differential for the CSPX.L (U.K.) and SPY (U.S.), which are ETFs that track the performance of the S&P 500, traded on the LSE and NYSE, respectively. Specifically, we report the results for the following difference-in-difference regression:

$$Liquidity_{i,t} = \alpha_0 + \beta_1 UK_{i,t} + \beta_2 Margin\ narrowing_t + \beta_3 UK_{i,t} \times Margin\ narrowing_t + Volatility_{i,t} + Return_{i,t} + \varepsilon_{i,t}$$

where $Liquidity_{i,t}$ is one of the following liquidity variables: *Quoted spread*, *Effective spread*, *Realized spread* or *Price impact* for the U.S. or U.K. ETF, $i$. The dependent variables are calculated over one hour intervals, and are expressed in basis points. $UK_{i,t}$ is an indicator variable equal to 1 if the ETF trades in the U.K., and 0 otherwise. *Margin narrowing* is an indicator variable equal to 1 for the period March 17 to March 21, 2020 and 0 for the period March 12 to March 16, 2020. $Volatility_{i,t}$ and $Return_{i,t}$ are based on the FTSE 100 and S&P 500 index levels for the U.K. and U.S. markets, respectively. $Volatility_{i,t}$ and $Return_{i,t}$ are calculated as $\log(High\ Price_{i,t}/Low\ Price_{i,t})$ and $\log(Close\ Price_{i,t}/Open\ Price_{i,t})$, respectively. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

| *Dependent variable*: | Quoted spread | Effective spread | Realized spread | Price impact |
|---|---|---|---|---|
| UK | 25.80*** | 9.70*** | 4.66*** | 5.07*** |
| | (4.81) | (1.46) | (1.35) | (0.66) |
| Margin narrowing | −0.11 | 0.40 | 0.25 | 0.18 |
| | (4.20) | (1.27) | (1.18) | (0.58) |
| UK × Margin narrowing | −11.57** | −4.43** | −2.98* | −1.38* |
| | (5.73) | (1.74) | (1.60) | (0.79) |
| Volatility | 21.56 | 83.20 | 23.17 | 70.11** |
| | (208.64) | (63.24) | (58.43) | (28.75) |
| Return | 40.31 | 5.33 | 9.37 | −8.26 |
| | (102.83) | (31.17) | (28.80) | (14.17) |
| Constant | 0.77 | −2.14 | −0.77 | −1.64 |
| | (7.41) | (2.24) | (2.07) | (1.02) |
| Observations | 56 | 56 | 56 | 56 |
| $\overline{R}^2$ | 0.47 | 0.54 | 0.20 | 0.63 |

ETFs. To provide additional robustness, we repeat the prior experiment using an alternative approach, which captures the granularity of the daily differences in the margin proxies. For the daily analysis, we estimate the following regression:

$$\Delta Liquidity_t = \alpha_0 + \beta_1 \Delta Margin_t + \beta_2 \Delta Volatility_t + \beta_3 \Delta Return_t + \epsilon_t, \tag{3}$$

where $\Delta X_t$ is defined as $X_{UK,t} - X_{US,t}$, or the difference between the U.K. and U.S. variable on day $t$. $X_{i,t}$ represents one of the variables defined in Equation (1) (i.e., Quoted spread, Effective spread, Realized spread, Price impact, Volatility and Return) for market $i$. We estimate Equation (3) over the period February 11 to April 11, 2020, which covers the one month period before and after the WHO's declaration of a pandemic on March 11, 2020.[16]

The results reported in Table 6 show that $\Delta Margin_t$ is positive and significant for all but one model specification. Importantly, consistent with our earlier findings in Section 5.1, we show that when the margin on the U.K. ETF increases (decreases) more than the margin on the U.S. ETF, we observe a relative deterioration (improvement) in the liquidity measures for the U.K. ETF.

*5.1.3. Robustness: Falsification tests*

In Section 5.1, we exploit a period when the U.K. margin proxy increases by more than the U.S. margin proxy. However, during this interval, there were also significant falls in the underlying S&P 500. To provide further confidence that our results are driven by the widening of the margin differential, rather than the fall in the S&P 500, we conduct a similar analysis over an interval when the market fell without a change in margins. Because there is no change in the margin differential, we do not expect to observe changes to market quality between the two markets.

For this investigation, we identify the period with the largest fall in stock price, without a corresponding change in the margin differential.[17] Specifically, we identify the period August 19 to August 25, 2015, when the S&P 500 index fell by more than 10%. Importantly, the margins for both the U.K. and U.S. markets remain stable during the interval. We re-estimate Equation (1), where *Margin increase*$_t$ is equal to 1 for the post-period from August 19 to August 25, 2015 and 0 for the pre-period from August 12 to August 18, 2015. Because the stock price fall is not associated with a corresponding change in margin, we expect the

[16]In unreported results, our findings are robust to alternate sample windows.
[17]We have data on margin requirements for both the U.K. and U.S. markets from January 2015.

## Table 6: Alternate test for U.K. and U.S. ETFs

The table reports the relation between the margin differential and the liquidity differential for the CSPX.L (U.K.) and SPY (U.S.), which are ETFs that track the performance of the S&P 500, traded on the LSE and NYSE, respectively. Specifically, we report the results for the following equation:

$$\Delta Liquidity_t = \alpha_0 + \beta_1 \Delta Margin_t + \beta_2 \Delta Volatility_t + \beta_3 \Delta Return_t + \varepsilon_t,$$

where $\Delta X_t$ is computed as $X_{UK,t} - X_{US,t}$ or the difference between the U.K. and U.S. ETF variables on day $t$. $X_{i,t}$ represents one of the variables defined in Equation (1) (*Quoted spread*, *Effective spread*, *Realized spread*, *Price impact*, *Volatility* and *Return*) for the U.S. or U.K. ETF, $i$, for day, $t$. $\Delta Margin_t$ represents the difference between the U.K. and U.S. margin proxies. The U.K. margin is proxied using the margin for the FTSE 100 futures trading on the Intercontinental Exchange. The U.S. margin is proxied using the margin for the S&P 500 futures trading on the Chicago Mercantile Exchange. Variables are calculated daily for the period February 11, 2020 to April 11, 2020. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

| *Dependent variable*: | Quoted spread | Effective spread | Realized spread | Price impact |
|---|---|---|---|---|
| Δ Margin | 17.61*** | 7.21*** | 1.41 | 5.00*** |
| | (4.71) | (1.96) | (1.42) | (1.32) |
| Δ Volatility | −2.85 | −2.68 | 32.36** | −34.85** |
| | (51.31) | (21.38) | (15.47) | (14.40) |
| Δ Return | −5.31 | −4.72 | 9.85 | −13.49 |
| | (31.75) | (13.23) | (9.57) | (8.91) |
| Constant | 3.70*** | 1.48*** | 0.07 | 0.99*** |
| | (0.88) | (0.37) | (0.27) | (0.25) |
| Observations | 34 | 34 | 34 | 34 |
| $\overline{R}^2$ | 0.27 | 0.27 | 0.08 | 0.38 |

interaction term *UK* $\times$ *Margin increase* to be insignificant in our model specifications.

Table 7 reports the results for the falsification test. Importantly, we find that *UK* $\times$ *Margin increase* is insignificant for all but one of the model specifications.[18] These findings show that market quality between the U.K. and U.S. markets does not change when there is no change to the margin differential. Based on these findings, the change in market quality reported in Section 5.1 is likely due to the change in the margin differential, rather than the fall in stock prices.

In Appendix F, we report the results of additional falsification tests, in which we repeat the difference-in-difference analyses from Sections 5.1 and 5.1.1 using data from March 2019, the year before the COVID-19 shock. Again, based on these falsification tests, we do not detect significant changes in market quality between the U.K. and U.S. ETFs when there is no change in the margin differential in 2019.

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 17, 2020. Our main result is also robust to several falsification tests over periods when there are no changes to the differential between the U.K. and U.S. margin proxies.

[18]For the *Effective spread* regression, *UK* $\times$ *Margin increase* is weakly significant at the 10% level.

### Table 7: Difference-in-difference regression for U.K. and U.S. ETFs: Falsification test

The table reports the results to a falsification test in August 2015, when the S&P 500 fell over 10% with no corresponding change to exchange margin requirements. The CSPX.L (U.K.) and SPY (U.S.) are ETFs that track the performance of the S&P 500, traded on the LSE and NYSE, respectively. Specifically, we report the results for the following difference-in-difference regression:

$$Liquidity_{i,t} = \alpha_0 + \beta_1 UK_{i,t} + \beta_2 Margin\ increase_t + \beta_3 UK_{i,t} \times Margin\ increase_t + Volatility_{i,t} + Return_{i,t} + \varepsilon_{i,t}$$

where $Liquidity_{i,t}$ is one of the following liquidity variables: *Quoted spread*, *Effective spread*, *Realized spread* or *Price impact* for the U.S. or U.K. ETF, $i$. The dependent variables are calculated over one hour intervals, and are expressed in basis points. $UK_{i,t}$ is an indicator variable equal to 1 if the ETF trades in the U.K., and 0 otherwise. *Margin increase* is an indicator variable equal to 1 for the period August 19 to August 25, 2015 and 0 for the period August 12 to 18, 2015. $Volatility_{i,t}$ and $Return_{i,t}$ are based on the FTSE 100 and S&P 500 index levels for the U.K. and U.S. markets, respectively. $Volatility_{i,t}$ and $Return_{i,t}$ are calculated as $\log(High\ Price_{i,t}/Low\ Price_{i,t})$ and $\log(Close\ Price_{i,t}/Open\ Price_{i,t})$, respectively. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

| *Dependent variable*: | Quoted spread | Effective spread | Realized spread | Price impact |
|---|---|---|---|---|
| UK | 21.65 | 1.07 | 0.31 | 0.77 |
| | (14.36) | (2.79) | (1.76) | (2.56) |
| Margin increase | −6.48 | −1.68 | −0.30 | −1.64 |
| | (11.16) | (2.17) | (1.37) | (1.99) |
| UK × Margin increase | 2.73 | 5.75* | 1.11 | 4.10 |
| | (17.01) | (3.31) | (2.09) | (3.03) |
| Volatility | 1,353.01** | 361.58*** | 36.67 | 380.69*** |
| | (581.08) | (112.98) | (71.24) | (103.58) |
| Return | −722.45 | −174.68 | −176.56** | −10.41 |
| | (609.68) | (118.54) | (74.75) | (108.68) |
| Constant | −4.98 | −1.20 | −0.14 | −1.29 |
| | (9.37) | (1.82) | (1.15) | (1.67) |
| Observations | 69 | 69 | 69 | 69 |
| $\overline{R}^2$ | 0.14 | 0.26 | 0.04 | 0.20 |

*5.2. Global analysis*

In the previous section, we investigate two ETFs tracking the same underlying index, but tradeing on separate exchanges, where the exchanges implemented differential changes to their margin requirements during the COVID-19 pandemic. Exploiting this unique scenario, we show strong evidence that market quality declines more for the U.K. ETF, which experienced larger increases in margin requirements, relative to the U.S. ETF. In this section, to generalize our main findings and to provide additional robustness for our results, we extend our analysis to a larger cross-section of listed equities. However, due to the difficulty in identifying additional ETFs that track the same underlying index while trading on different exchanges with varying margins, we use an alternate experimental design focusing on factors that are likely to affect some stocks more than others.

Specifically, we argue that an increase in a market's margin requirements is likely to affect stocks that are index constituents (index stocks) more than stocks that are not index constituents (non-index stocks). This argument is based on the assertion that HFMM are 1) more margin sensitive than traditional investors and, 2) are more likely to be present in index stocks than non-index stocks. For reasons outlined in Section 3, HFMM are likely to be more margin sensitive due to their unique trading style, which focuses on trading across short time horizons and using leveraged derivatives to hedge price risk. Similarly, Brogaard et al. (2014) and Shkilko and Sokolov (2020) show that high frequency traders are more prevalent in index stocks, which is also supported by our empirical tests in Section 5.3. Thus, because HFMM are more likely to withdraw their liquidity from stocks in which they are most active, we expect larger liquidity declines for index stocks, relative to non-index stocks, when margin increases.

For this investigation, we conduct a difference-in-difference test using the systemic increase in global margin requirements after the WHO's declaration of COVID-19 as a pandemic on March 11, 2020 for identification. Our treatment group contains stocks with a higher level of HFMM participation (i.e., stocks within the market's primary index as outlined in Table 1). Our control group contains stocks with a lower HFMM participation. To control for stock liquidity, we select the most liquid stocks outside the primary index for the sample of low HFMM stocks. Specifically, to be included in the sample of low HFMM stocks, we require the stock to have at least 100 daily trades and to be above the median market capitalization of non-index stocks.

For this difference-in-difference test, we use the systemic increase in global margin requirements after the WHO's declaration of a pandemic on March 11, 2020 to define our post period. While there exists some variation in the margin evolution across different equity index futures (which we exploit in Section 5.1), figure 2 shows striking similarities in both the level and timing of the sudden jump in margin requirements for all equity index futures after March 11, 2020. Given we use a difference-in-difference framework, we need only the average margin in the post-period to be different to the average margin in the pre-period and do not need the exact daily movements of margin. Accordingly, because of the sharp systemic jump in margin across all equity index futures, we believe the treatment period identified should capture the required increase in margin differential for the difference-in-difference analysis. Further, while we are unable to obtain margin data for the Nordic markets, given the sudden increase in global margins observed in figure 2, it is reasonable to assume that these markets also experienced significant increases in margin requirements.[19]

We also note that due to data limitations, we are unable to observe margin requirements on individual stocks and can only observe a systemic increase in equity index futures after March 11, 2020. We argue the observed systemic jump in margin requirement for equity index futures appropriately captures a jump in stock margins for three reasons. First, given that figure 2 shows a sudden jump in margin requirements for equity index futures across all the major exchanges after March 11, 2020, it is reasonable to assume that individual stocks also experience a similar jump in margin requirements. Second, in Appendix C, we conduct two empirical tests to show that the margin requirements for equity index futures closely approximate the margin requirements for individual equities using data from the Hong Kong Exchange.[20] Specifically, we create a 'synthetic' index margin from the individual stocks and show that the margin for the 'synthetic' index closely tracks the margin for the equity index futures and that the margin for all individual stocks have systemic, highly correlated changes. Finally, even if individual stock margins did not increase, and the increase in margin only applies to equity index futures, the liquidity of individual stocks is still likely to be affected. This is because HFMM, who provide liquidity to these stocks, typically hedge price risk for underlying equity positions in the futures market.

[19]Our results are robust to removing the Nordic markets from the analysis.

[20]While we can only obtain margin requirements for equity index futures for the majority of markets, we are able to obtain margin requirements for both the equity index futures and individual stock futures for the Hong Kong Exchange.

Using this design, we estimate the following difference-in-difference regression:

$$\begin{aligned} Liquidity_{i,t} &= \alpha_0 + \beta_1 High\ margin_t + \beta_2 Index\ constituent_i \\ &+ \beta_3 High\ margin \times Index\ constituent_{i,t} \\ &+ \beta_4 Volume_{i,t} + \beta_5 Return_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (4)$$

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 one month period after the WHO declares the COVID-19 outbreak a pandemic (i.e., March 11 - April 11, 2020), and 0 for the one month period prior (i.e., February 11 - March 10, 2020). *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 8 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 driven by margin constraints imposed on market makers. Our empirical evidence for the market quality impacts of margin on equity markets is complementary to the emerging results on COVID-19's impact on corporate bonds (O'Hara and Zhou, 2020) and government bonds (Duffie, 2020), where inventory risk generated significant increases in transaction costs.

### *5.3. HFMM behavior*

In the previous sections, we show that market liquidity declines when stock exchange margins increase. Here, we analyze a potential channel contributing to the reduction in market liquidity. In Section 5.2, we assert that margin sensitive HFMM withdraw more liquidity from index stocks than non-index stocks and thus, we expect to see a larger reduction (or withdrawal) of their activity from index stocks after the increase in margin requirements.

Due to the large number of markets investigated and the lack of available trader identifiers, following Hendershott, Jones and Menkveld (2011), Hagströmer and Nordén (2013) and Jørgensen, Skjeltorp and Ødegaard (2018), we use the order-to-trade ratio (OTR) as a proxy for the overall level of HFMM activity. As HFMM withdraw from the market, we expect to see a decline in the OTR as high frequency quote updates become less necessary.

### Table 8: Difference-in-difference analysis for index and non-index stocks around the COVID-19 pandemic

The table reports the changes to liquidity measures around the COVID-19 pandemic for index and non-index stocks in global markets. Specifically, we report the results for the following difference-in-difference regression:

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

where $Liquidity_{i,t}$ is one of the following liquidity variables: *Quoted spread*, *Effective spread*, *Realized spread* or *Price impact* for stock $i$ on day $t$. The dependent variables are calculated daily, and are expressed in basis points. 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 (March 11 - April 11, 2020), and 0 for the pre-pandemic period (February 11 - March 10, 2020). *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. *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 Canada, Hong Kong, Norway, Sweden and U.K.. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

| *Dependent variable*: | Quoted spread | Effective spread | Realized spread | Price impact |
|---|---|---|---|---|
| High margin | 109.9*** | 99.1*** | −66.9* | 114.8*** |
| | (1.0) | (0.9) | (38.7) | (1.5) |
| Index constituent | −10.7*** | −12.9*** | 81.0 | −7.5*** |
| | (1.8) | (1.6) | (81.1) | (2.6) |
| High margin × Index constituent | 36.2*** | 32.6*** | 227.7** | 10.4*** |
| | (2.1) | (1.9) | (100.5) | (3.1) |
| Volume | 3.9*** | 3.8*** | 0.1 | −1.5*** |
| | (0.4) | (0.3) | (14.5) | (0.5) |
| Return | −1.3*** | −0.9*** | −7.8 | −1.1*** |
| | (0.1) | (0.1) | (5.7) | (0.2) |
| Constant | 107.4*** | 100.0*** | −300.6 | 183.6*** |
| | (5.6) | (5.0) | (209.3) | (8.1) |
| Observations | 47,805 | 47,805 | 26,239 | 47,805 |
| $\overline{R}^2$ | 0.3 | 0.4 | 0.003 | 0.2 |

Further, this decline in the OTR is likely to be more pronounced for index stocks, which have a higher concentration of HFMM activity, relative to non-index stocks.

Following the empirical design from Section 5.2, we use a difference-in-difference regression framework to test whether HFMM activity falls more for index stocks, which are likely to have higher HFMM participation, versus non-index stocks. For this analysis, we replace the dependent variable in Equation ((4)) with $OTR$:

$$\begin{aligned} OTR_{i,t} &= \alpha_0 + \beta_1 High\ margin_t + \beta_2 Index\ constituent_i \\ &+ \beta_3 High\ margin \times Index\ constituent_{i,t} \\ &+ \beta_4 Volume_{i,t} + \beta_5 Return_{i,t} + \varepsilon_{i,t}, \end{aligned} \tag{5}$$

where $OTR_{i,t}$ is the sum of the number of asks and bid updates at the top of book, divided by the number of trades for stock $i$ on day $t$. All other variables are defined in Equation (4).

The results reported in Table 9 support the assertion that index stocks, which have higher HFMM participation, experience a larger fall in HFMM activity, relative to non-index stocks with lower HFMM participation, after the increase in margin requirements. 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 margin requirements.

To provide additional robustness to these results, we perform a falsification test to show that our results are due to increasing margins, rather than the falling stock price. For this test, we estimate Equation (5) for a period in 2015. During August 2015, the S&P 500 fell by more than 10% with no corresponding changes to margin requirements, as discussed in Section 5.1.3. Importantly, our results for the falsification test in Appendix F show no differential changes in *OTR* for index stocks, relative to non-index stocks, for this period when margins did not increase.

Together, our findings from Tables 8 and 9 are consistent with the hypothesis that escalating margins during times of crises negatively impacts market liquidity via the withdrawal of margin sensitive high frequency market makers.

## 6. Discussion and Conclusion

Recent theory models suggest that exchange margin requirements could become destabilizing and procyclical, leading to negative liquidity spirals. Studies including Morris and Shin (2004) and Brunnermeier and Pedersen (2009) propose that when traders face funding

## Table 9: Changes in the Order to Trade ratio around the COVID-19 pandemic

The table reports changes to Order to Trade ratio (OTR) around the COVID-19 pandemic for index and non-index stocks in global markets. Specifically, we report the results for the following difference-in-difference regression:

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

where $OTR_{i,t}$ is the sum of the number of asks and bid updates at the top of book, divided by the number of trades for stock $i$ on day $t$, 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 (March 11 - April 11, 2020), and 0 for the pre-pandemic period (February 11 - March 10, 2020). *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. *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 Canada, Hong Kong, Norway, Sweden and U.K.. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

| | Canada | Hong Kong | Norway | Sweden | U.K. |
|---|---|---|---|---|---|
| High margin | $-134.6^{**}$ | $1.8^{***}$ | $16.2^{***}$ | $11.2^{***}$ | $24.4^{***}$ |
| | (56.2) | (0.4) | (3.1) | (1.4) | (1.6) |
| Index constituent | 39.4 | $4.8^{***}$ | $22.2^{***}$ | $30.4^{***}$ | $30.2^{***}$ |
| | (102.9) | (0.8) | (4.8) | (2.3) | (2.6) |
| High margin × Index constituent | 118.1 | $-1.9^{*}$ | $-11.1^{**}$ | $-20.6^{***}$ | $-38.0^{***}$ |
| | (123.3) | (1.1) | (5.2) | (2.6) | (2.9) |
| Volume | $-57.4^{***}$ | $-3.6^{***}$ | $-14.2^{***}$ | $-12.0^{***}$ | $-11.1^{***}$ |
| | (18.0) | (0.1) | (1.2) | (0.5) | (0.6) |
| Return | 0.2 | −0.01 | $-2.1^{***}$ | 0.01 | 0.3 |
| | (5.4) | (0.1) | (0.4) | (0.2) | (0.2) |
| Constant | $1,102.9^{***}$ | $159.4^{***}$ | $318.1^{***}$ | $279.6^{***}$ | $268.5^{***}$ |
| | (271.2) | (2.4) | (16.8) | (7.1) | (8.9) |
| Observations | 11,908 | 11,200 | 2,933 | 8,133 | 13,631 |
| $\overline{R}^2$ | 0.001 | 0.1 | 0.1 | 0.1 | 0.1 |

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 WHO'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 that an increase in capital requirements correlates with a decline in market liquidity. Using ETFs tracking the S&P 500 index listed in the U.K. and U.S. markets, we show that market liquidity deteriorates more for the U.K. ETF, which experienced a larger increase in margin, relative to the U.S. ETF.

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 (HFMM), than for non-index stocks. Because of their higher portfolio turnovers and shorter holding periods, HFMM are more reliant on margin as they hold leveraged portfolios. This finding is consistent with the notion that increases in margin requirements have a larger impact on the liquidity of stocks in which HFMM are more active.

Third, our findings suggest that HFMM 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. 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. The increases in equity market margins observed during 2020 are some of the largest and fastest on record. The associated withdrawal of HFMM 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, or regulatory capital reserves to act as a 'counter-cyclical buffer' in times of stress, could potentially mitigate the liquidity crisis observed during such turbulent times.

We contribute to the extant literature in two key ways. First, we empirically test theories documenting the pro-cyclical 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 Global 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. For example, there are existing papers seeking to understand dislocations in U.S. Treasury assets (see Duffie (2020) and (Cheng et al., 2020)), dislocations from the NYSE trading floor (Brogaard et al., 2020), and the magnitude of asset price responses and dislocations (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.

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## Appendix

## Appendix A. Data definitions

### *Appendix A.1. The liquidity variables for individual stocks*

We use trade-and-quote data from Refinitiv to construct standard measures of market quality. We calculate our market quality metrics using data from continuous trading sessions. Accordingly, we exclude trades that occur during the first and last 15 minutes of each trading day.

- The **Quoted Spread** is the difference between the current best bid and ask in that venue's order book divided by the midpoint, $m_{ji}$. The quoted spread is recalculated whenever the limit order book is updated. The daily Quoted $\text{Spread}_{it}$ for stock $i$ on day $t$ is the daily time-weighted average.

- **Effective Spread** is defined as:

$$\text{Effective Spread}_{ji} = \frac{q_{ji}(p_{ji} - m_{ji})}{m_{ji}} \tag{A.1}$$

  where $q_{ji}$ is an indicator variable that equals +1 for buyer-initiated trades and −1 for seller-initiated trades; $p_{ji}$ is the trade price; and $m_{ji}$ is the quote midpoint prevailing at the time of the trade. To determine whether an order is buyer or seller initiated, the transaction price is compared to the previous quote midpoint — if the price is above (below) the midpoint, we classify the order as buyer (seller) initiated. Effective $\text{Spread}_{it}$ is the volume-weighted average of all $j$ trades for stock $i$ on day $t$.

- The **Price Impact** is defined as:

$$\text{Price Impact}_{ji} = \frac{q_{ji}(m_{i,j+10\text{sec}} - m_{i,j})}{m_{ji}} \tag{A.2}$$

  where $m_{i,j+10\text{sec}}$ is the quote midpoint ten seconds after the $j$th trade for stock $i$ and $q_{ji}$ has the same definition used for Effective Spread. Price $\text{Impact}_{it}$ is the volume-weighted average of all$j$ trades for stock $i$ on day $t$.

- The **Realized Spread** is defined as:

$$\text{Realized Spread}_{ji} = \frac{q_{ji}(p_{ji} - m_{i,j+10\text{ sec}})}{m_{ji}} \tag{A.3}$$

where $m_{i,j+10\text{sec}}$ is the quote midpoint ten seconds after the $j$th trade for stock $i$ and $q_{ji}$ has the same definition used for Effective Spread. Realized Spread$_{it}$ is the volume-weighted average of all $j$ trades for stock $i$ on day $t$.

*Appendix A.2. The liquidity variables for the U.K. and U.S. ETFs*

For the ETFs traded in the U.S. and the U.K., we calculate the same market quality metrics defined above at an hourly, rather than daily, frequency. Thus, rather than taking averages across all trade observations in the day, we compute hourly averages using only trades contained within each respective hour. We use hourly intervals for two reasons: 1) to compare market quality across the U.S. and U.K. during the interval when both markets are open; 2) to ensure a large enough sample size to conduct meaningful analyses.

## Appendix B. Margins

Margins are collected from exchange homepages, and are specific to an underlying contract. We choose the contract whose underlying best reflects the market's equity index. For the U.S., we consider the margin requirement on S&P 500 Index Futures traded on the Chicago Mercantile Exchange. For the U.K., we consider the margin requirements for the FTSE 100 Index Futures traded on the Intercontinental Exchange (ICE). Similarly, for Hong Kong and Canada, we choose the Hang Seng Index futures and TSX 60 Index Futures traded on the Hong Kong Futures Exchange (HKX) and the Montreal Exchange, respectively. Table B.1 illustrates the monthly evolution of selected margins and provides the links to the data sources.

**Table B.1: Selected margins**

The table shows the currency margin requirements for selected markets and the links to the data sources. Panel A shows the average currency margin required to trade one futures contract for each market. We average the daily observations and provide the monthly average. Canada refers to the TSX 60 Index futures, which trades on the Montreal Exchange (expressed in CAD). Hong Kong refers to the Hang Seng Index futures, which trades on the Hong Kong Futures Exchange (expressed in HKD). U.K. refers to the margin for the FTSE 100 Index futures, which trades on the Intercontinental Exchange (expressed in pounds). U.S. refers to the margin for the S&P 500 Index futures, which trades on the Chicago Mercantile Exchange (expressed in USD). Panel B provides the links to the data sources.

| | Canada (CAD) | Hong Kong (HKD) | U.K. (£) | U.S. (USD) |
|---|---|---|---|---|
| Panel A: Margin requirements | | | | |
| 2 Jan 2020 | 7,288 | 83,450 | 3,339 | 31,500 |
| 3 Feb 2020 | 4,725 | 83,750 | 3,339 | 33,000 |
| 2 Mar 2020 | 6,883 | 82,300 | 3,629 | 36,000 |
| 1 Apr 2020 | 19,579 | 116,200 | 6,699 | 60,000 |
| 1 May 2020 | 24,556 | 116,200 | 6,699 | 60,000 |
| Panel B: Data sources | | | | |
| Canada | reg.m-x.ca | | | |
| Hong Kong | www.hkex.com.hk | | | |
| U.K. | www.theice.com | | | |
| U.S. | www.cmegroup.com | | | |

## Appendix C. Margin proxy

### *Appendix C.1. Margin for index futures as proxy for ETF margins*

Due to data limitations, we are unable to obtain margin requirements for ETFs in the U.S. and U.K markets. For this reason, in Section 5.1, we use the margin for the S&P 500 Index futures to proxy the margin for the SPY ETF, which trades on the New York Stock Exchange, and the margin for the FTSE 100 Index futures to proxy the margin for the CSPX.L ETF, which trades on the London Stock Exchange. In this Appendix, we show that the margin of a market's equity index futures is a reasonable proxy for the margin of the ETFs trading in that market. For this analysis, we use data from the Hong Kong Exchange, which provides margins for selected index futures and ETF futures. Specifically, the Hong Kong Exchange data contains margin requirements for futures on the iShares FTSE China A50 ETF (*ETF future*) and margin for futures on the Hang Seng China Enterprises Index (*Index future*).[21] Figure C.1 plots the margin for the *ETF future* and *Index future* over the sample period. The plots show a remarkable similarity between the margins of the *ETF future* and the *Index future* ($correlation = 0.928$), which provides confidence that the margin of the index future is a reasonable proxy for the margin of the ETF future.[22]

### *Appendix C.2. Margin for index futures as proxy for equity margins*

Next, we conduct two tests to provide assurance that the margin for the index future is an appropriate proxy for the margin on individual equities trading in the market. First, we compare the margin of an equity index futures with the margin of a 'synthetic' equity index, which we construct from the margin of individual stock futures. Second, we test that changes in margin are systematic across all stocks.

To conduct these tests, we use Hong Kong Exchange margin data, which contains margins for both index futures and individual stock futures. Our aim is to create the margin for a 'synthetic' Hang Seng Index using the margins for the individual stock futures of the index constituents.[23] To create the 'synthetic' Hang Seng Index margin, we weight the percentage margin of each index constituent by market capitalization. On the days the margin changes,

[21] The underlying instrument for the *ETF future* and *Index future* are not identical, but both reflect trading on the Hong Kong Exchange.

[22] While we cannot obtain the margin requirements for the ETF trading on the Stock Exchange of Hong Kong, it is reasonable to assume that the margin requirements for the ETF future trading on the Hong Kong Futures Exchange are highly correlated as both exchanges are owned by the same parent company.

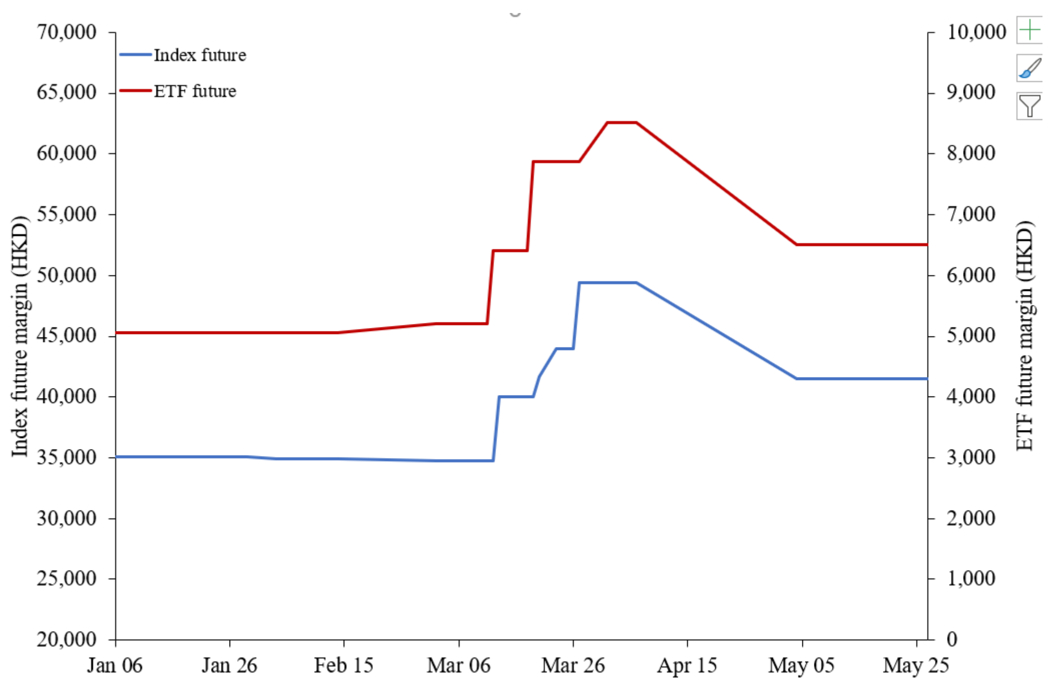
[23] The Hang Seng Index is the most widely quoted index for the Hong Kong equities market and contains approximately 60 constituents.

we observe a correlation of 0.956 between the 'synthetic' index percentage margin and the percentage margin requirements for the Hang Seng Index futures, as reported by the Hong Kong Exchange. This finding provides confidence that changes in margin on index futures is a reasonable proxy for changes in the margin on individual stocks.

Next, we show that the correlation of 0.956 is driven by a systematic margin change for all stock futures in the index, rather than by a change in margin for a small number of stock futures. Specifically, on the days margin changes for the future of at least one index constituent, we calculate the correlation between the margins of all stock futures for the constituents of the Hang Seng Index. During our sample period, we find that the margin of all stocks move in unison with a mean correlation of 0.93. Figure C.2 provides a histogram of all correlations between the index constituents. The figure shows high correlations between all constituents, with only 0.6% of the sample reporting a correlation below 0.8.

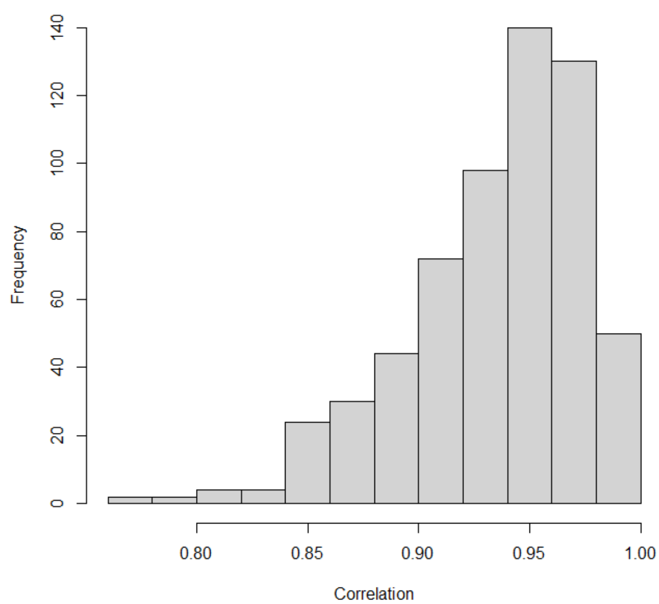
**Figure C.1: Margin requirements for an Index future and an ETF future**

The figure plots the margin requirements for the Hang Seng China Enterprises Index Futures (Index margin, left axis) and I-Shares FTSE China A50 ETF (ETF margin, right axis) over the period January 6 to May 27, 2020.



## Figure C.2: Histogram of correlations

This figure shows a histogram of the correlation in margins for stocks in the Hang Seng Index. We analyze data for the period January 1 to May 27, 2020. During this period, there are 33 days that the dollar margin changed for at least one index constituent. On these days, we calculate the correlation between the margin for all constituents in the index.



## Appendix D. Window Robustness

In this Appendix, we conduct robustness tests to ensure our results in Table 4 and Table 5 are insensitive to sample windows of different lengths. Specifically, we use a shorter 2 day window for our pre and post periods to provide robustness for our primary findings around the widening and narrowing of the margin differential between the U.K. and U.S. markets.

Table D.1 reports the results for the widening of the margin differential using a pre-period from February 5 to February 6, 2020 and a post-period from March 11 to March 12, 2020. Consistent with our primary findings, we find the interaction term (*UK* × *Margin increase*) is generally positive and significant, which confirms the correlation between higher margins and lower market quality.

Table D.2 reports the results for the narrowing of the margin differential using a pre-period from March 15 to March 16, 2020 and a post-period from March 17 to March 18, 2020. Again, consistent with our primary findings, we find the interaction term (*UK* × *Margin narrowing*) is generally negative and significant. This finding confirms that market quality improves for the U.K. market (i.e., there is a decline in spreads), relative to the U.S. market, when the margin differential narrows.

## Table D.1: Difference-in-difference regression for ETFs tracking the S&P 500 index

The table reports the changes to liquidity measures around the widening of the margin differential for the CSPX.L (U.K.) and SPY (U.S.), which are ETFs that track the performance of the S&P 500, traded on the LSE and NYSE, respectively. Specifically, we report the results for the following difference-in-difference regression:

$$Liquidity_{i,t} = \alpha_0 + \beta_1\, UK_{i,t} + \beta_2 Margin\ increase_t + \beta_3\, UK_{i,t} \times Margin\ increase_t + Volatility_{i,t} + Return_{i,t} + \varepsilon_{i,t}$$

where $Liquidity_{i,t}$ is one of the following liquidity variables: *Quoted spread*, *Effective spread*, *Realized spread* or *Price impact* for the U.S. or U.K. ETF, $i$. The dependent variables are calculated over one hour intervals, and are expressed in basis points. $UK_{i,t}$ is an indicator variable equal to 1 if the ETF trades in the U.K., and 0 otherwise. $Margin\ increase_t$ is an indicator variable equal to 1 for the post-period from March 11 to March 12, 2020 and 0 for the pre-period from February 5 to February 6, 2020. $Volatility_{i,t}$ and $Return_{i,t}$ are based on the FTSE 100 and S&P 500 index levels for the U.K. and U.S. markets, respectively. $Volatility_{i,t}$ and $Return_{i,t}$ are calculated as $\log(High\ Price_{i,t}/Low\ Price_{i,t})$ and $\log(Close\ Price_{i,t}/Open\ Price_{i,t})$, respectively. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

| *Dependent variable*: | Quoted spread | Effective spread | Realized spread | Price impact |
|---|---|---|---|---|
| UK | 5.61 | 1.31 | 0.92 | 0.40 |
| | (3.66) | (1.84) | (1.54) | (0.58) |
| Margin increase | −8.25* | −4.24* | −3.36 | −1.22 |
| | (4.66) | (2.34) | (1.96) | (0.74) |
| UK × Margin increase | 9.93* | 5.32** | 2.08 | 3.47*** |
| | (5.02) | (2.52) | (2.11) | (0.79) |
| Volatility | 369.30** | 193.03** | 139.92** | 68.36*** |
| | (147.68) | (74.17) | (62.05) | (23.34) |
| Return | −224.91 | −101.50 | −91.55 | −23.62 |
| | (144.75) | (72.70) | (60.83) | (22.88) |
| Constant | −0.79 | −0.46 | −0.43 | −0.08 |
| | (2.63) | (1.32) | (1.11) | (0.42) |
| Observations | 28 | 28 | 28 | 28 |
| $\overline{R}^2$ | 0.48 | 0.39 | 0.16 | 0.72 |

## Table D.2: Difference-in-difference regression for U.K. and U.S. ETFs (narrowing on March 17, 2020)

The table reports the changes to liquidity measures around the narrowing of the margin differential for the CSPX.L (U.K.) and SPY (U.S.), which are ETFs that track the performance of the S&P 500, traded on the LSE and NYSE, respectively. Specifically, we report the results for the following difference-in-difference regression:

$$Liquidity_{i,t} = \alpha_0 + \beta_1 UK_{i,t} + \beta_2 Margin\ narrowing_t + \beta_3 UK_{i,t} \times Margin\ narrowing_t + Volatility_{i,t} + Return_{i,t} + \varepsilon_{i,t}$$

where $Liquidity_{i,t}$ is one of the following liquidity variables: *Quoted spread*, *Effective spread*, *Realized spread* or *Price impact* for the U.S. or U.K. ETF, $i$. The dependent variables are calculated over one hour intervals, and are expressed in basis points. $UK_{i,t}$ is an indicator variable equal to 1 if the ETF trades in the U.K., and 0 otherwise. *Margin narrowing* is an indicator variable equal to 1 for the period March 17 to March 18, 2020 and 0 for the period March 15 to March 16, 2020. $Volatility_{i,t}$ and $Return_{i,t}$ are based on the FTSE 100 and S&P 500 index levels for the U.K. and U.S. markets, respectively. $Volatility_{i,t}$ and $Return_{i,t}$ are calculated as $\log(High\ Price_{i,t}/Low\ Price_{i,t})$ and $\log(Close\ Price_{i,t}/Open\ Price_{i,t})$, respectively. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

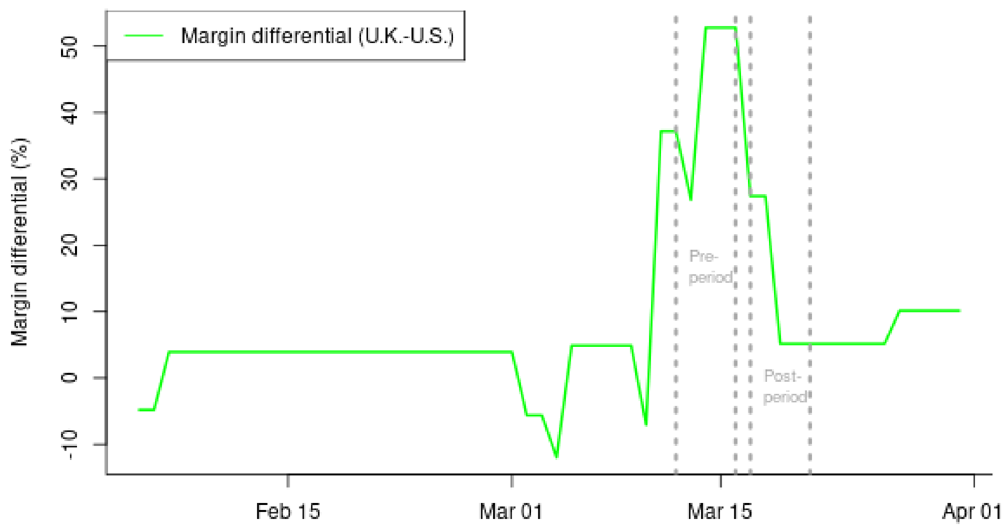
| *Dependent variable*: | Quoted spread | Effective spread | Realized spread | Price impact |
|---|---|---|---|---|
| UK | 40.82*** | 12.98*** | 8.24*** | 4.30*** |
| | (9.67) | (2.67) | (1.94) | (1.09) |
| Margin narrowing | −2.08 | 0.03 | 0.18 | −0.13 |
| | (7.34) | (2.03) | (1.47) | (0.83) |
| UK × Margin narrowing | −27.66** | −7.54** | −5.67*** | −1.48 |
| | (9.72) | (2.69) | (1.95) | (1.09) |
| Volatility | −251.67 | 22.29 | −26.64 | 51.31 |
| | (377.95) | (104.51) | (75.69) | (42.53) |
| Return | −122.17 | −21.80 | −12.09 | −7.71 |
| | (161.29) | (44.60) | (32.30) | (18.15) |
| Constant | 9.95 | −0.20 | 0.59 | −0.79 |
| | (14.11) | (3.90) | (2.83) | (1.59) |
| Observations | 24 | 24 | 24 | 24 |
| $\overline{R}^2$ | 0.65 | 0.67 | 0.62 | 0.56 |

## Appendix E. Margin narrowing illustration

Figure E.1 illustrates the evolution of the differential between the U.K. and U.S. ETF margin proxies. We observe a sharp narrowing in the margin differential on 17th March. Accordingly, we use the period just prior to this narrowing as our pre period and the interval directly after the narrowing as our post period, as indicated in the figure.

**Figure E.1: Margin differential for U.S. and U.K. exchanges**

The figure shows the time series evolution of the margin differential between the U.K. and U.S. margin proxies. The gray vertical lines indicate the pre (March 12 to March 16, 2020) and post (March 17 to March 21, 2020) periods for our difference-in-difference analysis.



## Appendix F. Additional falsification tests for the U.K. and U.S. ETFs

In this Appendix, we conduct falsification placebo tests over the same time intervals in the previous year to provide robustness to our main results. In our primary analysis, we investigate changes to market liquidity around the margin increase in March 2020. Accordingly, for our placebo margin increase test, we repeat the difference-in-difference using the full second and fourth trading weeks in March 2019 for our pre and post periods, respectively. In contrast to our main results, we observe that *UK* $\times$ *Margin increase* is insignificant across all model specifications for the placebo tests in 2019, when there is no change in the margin differential between the U.K. and U.S. markets.

Next, we extend our falsification placebo tests to our analysis of the narrowing of the margin differential. Specifically, in our main results, we use a pre-period from March 12 to March 16, 2020 and a post-period from March 17 to March 21, 2020 to investigate the narrowing of the margin differential. For our falsification placebo tests, we use these same intervals during the previous year. In contrast to our main results, the placebo results in Table F.2 show that *UK* $\times$ *Margin narrowing* is insignificant across all model specifications.

### Table F.1: Difference-in-difference regression for U.K. and U.S. ETFs (placebo widening in March, 2019)

The table reports the changes to liquidity measures around the placebo widening of the margin differential for the CSPX.L (U.K.) and SPY (U.S.), which are ETFs that track the performance of the S&P 500, traded on the LSE and NYSE, respectively. Specifically, we report the results for the following difference-in-difference regression:

$$Liquidity_{i,t} = \alpha_0 + \beta_1 UK_{i,t} + \beta_2 Margin\ increase_t + \beta_3 UK_{i,t} \times Margin\ increase_t + Volatility_{i,t} + Return_{i,t} + \varepsilon_{i,t}$$

where $Liquidity_{i,t}$ is one of the following liquidity variables: *Quoted spread*, *Effective spread*, *Realized spread* or *Price impact* for the U.S. or U.K. ETF, $i$. The dependent variables are calculated over one hour intervals, and are expressed in basis points. $UK_{i,t}$ is an indicator variable equal to 1 if the ETF trades in the U.K., and 0 otherwise. *Margin increase* is an indicator variable equal to 1 for the period March 25 to March 29, 2020 and 0 for the period March 11 to March 15, 2020. $Volatility_{i,t}$ and $Return_{i,t}$ are based on the FTSE 100 and S&P 500 index levels for the U.K. and U.S. markets, respectively. $Volatility_{i,t}$ and $Return_{i,t}$ are calculated as $\log(High\ Price_{i,t}/Low\ Price_{i,t})$ and $\log(Close\ Price_{i,t}/Open\ Price_{i,t})$, respectively. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

| *Dependent variable*: | Quoted spread | Effective spread | Realized spread | Price impact |
|---|---|---|---|---|
| UK | 7.00 | 0.77*** | 0.08 | 0.68* |
| | (4.34) | (0.05) | (0.40) | (0.41) |
| Margin increase | 3.93 | −0.01 | −0.10 | 0.09 |
| | (5.09) | (0.06) | (0.47) | (0.48) |
| UK × Margin increase | 0.31 | 0.04 | 0.42 | −0.37 |
| | (6.19) | (0.07) | (0.57) | (0.58) |
| Volatility | −1,770.74 | 9.69 | 31.62 | −23.00 |
| | (1,403.45) | (15.24) | (130.36) | (131.66) |
| Return | 454.92 | 2.55 | −4.16 | 7.31 |
| | (757.73) | (8.23) | (70.38) | (71.09) |
| Constant | 4.42 | 0.14*** | −0.04 | 0.19 |
| | (4.69) | (0.05) | (0.44) | (0.44) |
| Observations | 80 | 80 | 80 | 80 |
| $\overline{R}^2$ | 0.07 | 0.88 | −0.04 | −0.01 |

## Table F.2: Difference-in-difference regression for U.K. and U.S. ETFs (placebo narrowing in March, 2019)

The table reports the changes to liquidity measures around the placebo narrowing of the margin differential for the CSPX.L (U.K.) and SPY (U.S.), which are ETFs that track the performance of the S&P 500, traded on the LSE and NYSE, respectively. Specifically, we report the results for the following difference-in-difference regression:

$$Liquidity_{i,t} = \alpha_0 + \beta_1 UK_{i,t} + \beta_2 Margin\ narrowing_t + \beta_3 UK_{i,t} \times Margin\ narrowing_t + Volatility_{i,t} + Return_{i,t} + \varepsilon_{i,t}$$

where $Liquidity_{i,t}$ is one of the following liquidity variables: *Quoted spread*, *Effective spread*, *Realized spread* or *Price impact* for the U.S. or U.K. ETF, $i$. The dependent variables are calculated over one hour intervals, and are expressed in basis points. $UK_{i,t}$ is an indicator variable equal to 1 if the ETF trades in the U.K., and 0 otherwise. *Margin narrowing* is an indicator variable equal to 1 for the period March 17 to March 21, 2019 and 0 for the period March 12 to March 16, 2019. $Volatility_{i,t}$ and $Return_{i,t}$ are based on the FTSE 100 and S&P 500 index levels for the U.K. and U.S. markets, respectively. $Volatility_{i,t}$ and $Return_{i,t}$ are calculated as $\log(High\ Price_{i,t}/Low\ Price_{i,t})$ and $\log(Close\ Price_{i,t}/Open\ Price_{i,t})$, respectively. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

| *Dependent variable*: | Quoted spread | Effective spread | Realized spread | Price impact |
|---|---|---|---|---|
| UK | 4.70** | 0.72*** | 0.02 | 0.70*** |
| | (1.80) | (0.06) | (0.24) | (0.25) |
| Margin narrowing | −0.31 | −0.0002 | −0.08 | 0.07 |
| | (1.94) | (0.06) | (0.26) | (0.27) |
| UK × Margin narrowing | −1.27 | −0.02 | 0.29 | −0.30 |
| | (2.52) | (0.08) | (0.33) | (0.35) |
| Volatility | 207.20 | 2.98 | −30.60 | 23.66 |
| | (772.92) | (24.62) | (102.20) | (108.17) |
| Return | −196.68 | 4.69 | −92.63** | 101.36** |
| | (348.46) | (11.10) | (46.08) | (48.77) |
| Constant | 0.09 | 0.16** | 0.20 | −0.02 |
| | (2.24) | (0.07) | (0.30) | (0.31) |
| Observations | 64 | 64 | 64 | 64 |
| $\overline{R}^2$ | 0.10 | 0.83 | 0.04 | 0.11 |

## Appendix G. Falsification test for the Order to Trade ratio

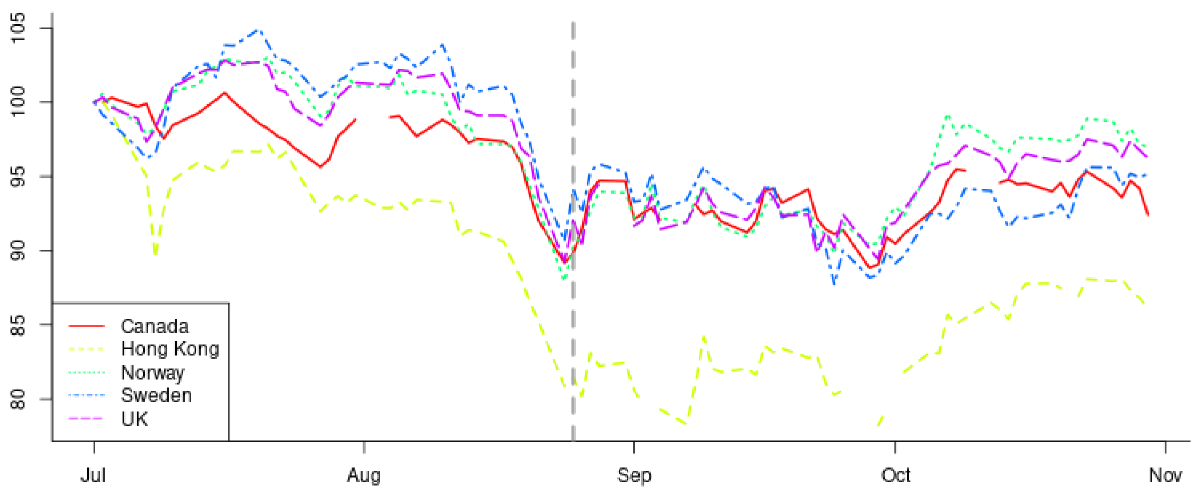
In Section 5.1.3, we perform a falsification test to provide further confidence that our results are driven by the widening of the margin differential during the pandemic period, rather than a sudden fall in stock price. Specifically, we use a period in August 2015 when the S&P 500 fell by over 10% with no corresponding change to exchange margin requirements.

In this Appendix, we conduct a similar falsification test during August 2015 to show that the reported change in *OTR* in Section 5.3 is associated with the change in margin, rather than a fall in stock price. Figure G.1 shows that the fall in stock prices is not limited to the U.S. market: we observe similar falls in global stock values during August 2015. Using the same length of sample window in Section 5.3, for our falsification test, we use a pre-period from August 1 to August 24, 2015 and a post-period from August 25 to September 30, 2015.

The results reported in Table G.1 show that *OTR* did not decline more for index stocks, relative to non-index stocks, as a result of the price decline in August 2015 (*High margin* × *Index constituent* is not negative and significant for any of the markets). This result provides support for the hypothesis that high frequency market makers withdrew more liquidity from index stocks, relative to non-index stocks, as a result of rising margins, rather than the sharp fall in prices, during the 2020 pandemic period.

**Figure G.1: The evolution of stock market prices, July-October 2015**

The figure illustrates the movement in stock market prices for the indices listed in Table 1. The plots show the change in index price levels, relative to the index level on July 1, 2015, which takes a value of 100. The gray vertical line marks August 25, 2015.



## Table G.1: Changes in the Order to Trade ratio during August-September 2015

The table reports changes to the Order to Trade ratio (OTR) for a period during August to September 2015, when global stock markets declined, with no corresponding change to exchange margin requirements. Specifically, we report the results for the following difference-in-difference regression:

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

where $OTR_{i,t}$ is the sum of the number of asks and bid updates at the top of book, divided by the number of trades for stock $i$ on day $t$, normalized based on the average of January OTRs. *High margin* is an indicator variable equal to 1 for the period after the market decline (August 25 - September 30, 2015), and 0 for the period immediately before the market decline (August 1 - August 24, 2015). *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. *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 Canada, Hong Kong, Norway, Sweden and U.K.. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

| | Canada | Hong Kong | Norway | Sweden | U.K. |
|---|---|---|---|---|---|
| High Margin | $-6.6^{***}$ | $-2.3^{***}$ | $-30.1^{**}$ | $5.2^{***}$ | $10.1^{***}$ |
| | (1.0) | (0.7) | (13.3) | (1.5) | (0.8) |
| Index Consituent | $5.8^{***}$ | $10.4^{***}$ | 45.3 | $6.3^{***}$ | 1.3 |
| | (2.2) | (1.5) | (28.5) | (2.4) | (1.2) |
| High margin × Index constituent | $-2.4$ | $8.6^{***}$ | 40.9 | $-1.5$ | 0.2 |
| | (2.7) | (1.7) | (31.7) | (2.8) | (1.5) |
| Volume | $-5.6^{***}$ | $-4.6^{***}$ | $-13.7^{***}$ | $-2.7^{***}$ | $-1.8^{***}$ |
| | (0.3) | (0.2) | (2.8) | (0.4) | (0.2) |
| Return | $-0.6^{*}$ | $0.8^{***}$ | 2.9 | $-0.8^{**}$ | $-1.7^{***}$ |
| | (0.3) | (0.2) | (3.8) | (0.4) | (0.2) |
| Constant | $189.4^{***}$ | $176.1^{***}$ | $318.4^{***}$ | $145.4^{***}$ | $133.0^{***}$ |
| | (4.8) | (3.8) | (39.6) | (6.3) | (3.2) |
| Observations | 17,491 | 8,443 | 7,024 | 7,283 | 13,223 |
| $\overline{R}^2$ | 0.02 | 0.1 | 0.003 | 0.01 | 0.02 |