Anatomy of a Liquidity Crisis: Corporate Bonds in the Covid-19 Crisis*

Maureen O'Hara§
Johnson College of Business, Cornell University

Xing (Alex) Zhou†
Federal Reserve Board

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Abstract

We examine the microstructure of liquidity provision in the Covid-19 corporate bond liquidity crisis. During the two weeks leading to Fed interventions, volume shifted to liquid securities, transaction costs soared, trade-size pricing inverted, and dealers, particularly non-primary dealers, shifted from buying to selling, causing dealers' inventories to plummet. Liquidity provisions in electronic customer-to-customer trading increased, though at prohibitively high costs. By improving dealer funding conditions and providing a liquidity backstop, the Primary Dealer Credit Facility (PDCF) and the Secondary Market Corporate Credit Facility (SMCCF) stabilized trading conditions. Most of the impact of SMCCF on bond liquidity seems to have materialized following its announcement. We argue that the Federal Reserve's actions reflect a new role as market maker of last resort.

JEL classification: G14, G21, G23, G24

Keywords: Corporate bonds, liquidity crisis, Covid-19, PDCF, SMCCF, electronic trading, customer-to-customer, market maker of last resort.

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§ Cornell University, 447 Sage Hall, Ithaca, NY 14853. E-mail: mo19@cornell.edu.
† Federal Reserve Board, 20th & Constitution Ave NW, Washington, DC 20551. E-mail: xing.zhou@frb.gov.

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The Covid-19 crisis almost claimed a new and unexpected victim: the U.S. corporate bond market. Beginning in early March 2020, the bond market faltered, with yield spreads soaring and liquidity seemingly evaporating. Factors influencing liquidity are often complex, reflecting both supply-side issues, such as funding difficulties and challenges posed by one-sided trading, and demand-side factors such as changes in risk preferences or asset value expectations. Over a remarkably short time period, the Federal Reserve created a variety of credit and liquidity facilities to address this liquidity crisis, even taking the unprecedented step of agreeing to buy corporate bonds and bond ETFs. Our focus in this paper is on understanding the evolution of the corporate bond market liquidity crisis and, equally important, what contributed to its resolution.

We do so by focusing on the microstructure of liquidity provision in corporate bond markets during the Covid-19 crisis. This microstructure focus aligns with Buiter and Sibert's (2007) observation that, in current markets, a credit crunch or liquidity crisis arises in a different way from the lender-based problems of times past. Instead, a liquidity crisis manifests in disorderly markets in which "there is no market maker with both the knowledge …and the deep pockets to credibly post buying and selling prices."[1] They argue that the solution to such a crisis is for the central bank to act as the market maker of last resort – i.e. be willing to buy assets directly

[1] See Buiter and Sibert (2007). These authors note that such a role is not without some longer-term downsides, but argue that "While the central bank should not be in this business during ordinary times, when markets are orderly and price formation and price discovery proceeds without the direct intervention of the central bank, it cannot avoid being in this business when markets are disorderly and fail to match buyers and sellers of securities."

or to facilitate such buying by taking such assets as collateral. As we document in this paper, that is an apt description of what happened here.

We measure the extent and evolution of corporate bond illiquidity by examining transaction costs in both investment-grade (IG) and high-yield (HY) bond trading. We analyze how the heightened demand for liquidity during the crisis differed across bonds. We investigate the actions of market players who provide liquidity – the primary dealers and non-primary dealers – with a particular focus on their ability and willingness to trade and their resultant inventory positions. We also examine the robustness of liquidity provided directly by customers through electronic trading and establish how customers fared in these new trade settings during the crisis. Equally important, we demonstrate how and when Fed actions affected the liquidity crisis, both directly through the Fed's provision of liquidity and indirectly through its effects on other liquidity providers.

Our analysis provides a number of results. We show that bond markets rapidly deteriorated after March 6, with average transaction costs rising sharply and peaking at over 90 bps before the Fed interventions, almost triple their levels in early February. Trading was particularly challenging for large quantities. Transaction costs for block trades in investment-grade bonds were only 24 bps in February, but jump to over 150 bps on March 23. Transaction costs also invert, with block trade costs moving from about 10 bps below micro lot costs to over 60 bps above. Similar movements are observed in high-yield bonds. We show that when market liquidity started to evaporate, trading shifts to bonds that were more liquid during the normal times. At the same time, dealers, particularly the non-primary dealers, shift from buying bonds to selling bonds, exacerbating market illiquidity, and resulting in a cumulative negative $8 billion inventory position

for the dealer community. These negative inventory positions might have exacerbated the liquidity crisis, as bonds sold more aggressively by dealers experienced a greater increase in transaction costs.

Unlike in times past, dealers were not the only source of bond liquidity, with electronic trading platforms offering buy-side institutions the ability to trade directly with each other. We examine customer-to-customer (C-to-C) trades, finding that C-to-C trade volume did increase, almost tripling compared to its levels prior to the start of the crisis, but it still remained small relative to overall bond market volume. More significant is that transaction costs in C-to-C trades, which were below those of customer-to-dealer (C-to-D) trades before the crisis, shift dramatically during the crisis, with C-to-C trading costs more than double the level in C-to-D. Trade sizes in C-to-C trades also remain much below those of the C-to-D trades. Obtaining liquidity from other customers, therefore, proved an expensive, and limited, alternative in the crisis period.[2] With neither dealers nor customers inclined to provide liquidity, there is little evidence that market forces were moving to resolve the bond market crisis.

The Fed responded quickly to the strained conditions in the corporate bond markets with the creation of the Primary Dealer Credit Facility (PDCF) and the Secondary Market Corporate Credit Facility (SMCCF). By offering term funding to primary dealers, PDCF sought to improve market liquidity through enhancing funding conditions for dealers. The SMCCF, by agreeing to purchase bonds (and bond ETFs), aimed to improve liquidity by directly rebalancing order flows in case of excessive selling. The PDCF was announced on Tuesday, March 17, and started

[2] That electronic C-to-C trading was not robust during the crisis is consistent with O'Hara and Zhou's (2019) finding that electronic RFQ bond trading was not robust in stress times following bond downgrades

operations on Friday, March 20. The SMCCF was announced on the following Monday, with an estimated implementation in early May.

We find that the Fed's actions were effective in mitigating but not completely ameliorating these liquidity problems. Within one week following the launch of PDCF and the creation of the SMCCF, bond transaction costs drop from their peak of over 90 bps right before Fed interventions to about 70 bps. Transaction costs decline further amid the expansion of SMCCF in early April. By the end of April, transaction costs decline to about 40 bps, and have remained stable since then. Cost for trading large blocks decline dramatically following Fed interventions, but remain substantially higher than their levels in February. Starting in late April, block trade costs have been similar to those for micro trades, which have largely returned to their February levels. While high-yield bonds as a whole benefit from the SMCCF expansion, we do not find any significant effects on the transaction costs of "fallen angels" (i.e. downgraded bonds) which were deemed eligible for purchase under the SMCCF on April 9.

What is particularly intriguing is how these facilities change dealer behavior. The PDCF had an almost immediate effect on primary dealers, who shift back to more balanced inventory positions. Such improvement is consistent with the Fed's actions easing funding liquidity problems via direct lending. Most of the impact of SMCCF on bond liquidity seems to materialize following its announcement. Despite the fact that during our sample period the Fed did not buy a single bond, the announcement of the SMCCF caused non-primary dealers to shift from off-loading bonds. The purchases of exchanged trade funds (ETFs) by SMCCF starting on May 12 however did not induce any noticeable improvement in bond liquidity provision. To some, the strong announcement SMCCF effect coupled with its minimal implementation effect may seem

puzzling. We argue, however, that these effects are consistent with the Fed's market maker role - by signaling a liquidity backstop for corporate bonds, the SMCCF reduced the risk to dealers of facing a one-sided market and, by extension, the risk of holding inventory.

We further investigate how PDCF and SMCCF each contributed to the improvement in corporate bond liquidity. Disentangling the PDCF effect from the SMCCF effect is challenging since SMCCF was created right after the PDCF became operational, and we use a variety of approaches to deal with this identification issue. Consistent with PDCF effects, we find that the incremental liquidity improvement in investment-grade bonds following Fed interventions were stronger in trades intermediated by primary dealers, the only eligible participants in PDCF. Consistent with SMCCF effects, we find the additional liquidity increase in investment-grade bonds after Fed interventions to be even greater in trades in bonds with remaining maturities of 5 years or less, as SMCCF only accepts short-term bonds below the 5 year cutoff, while PDCF has no maturity requirement on eligible collaterals.

Overall, our analysis provides some of the first evidence on the efficacy of the Federal Reserve's efforts to stem the Covid-19 liquidity crisis in the corporate bond market. The decision by the Fed to purchase corporate bonds and bond ETFs represents a new and, arguably, controversial direction for the central bank. Our results suggest that the Fed's immediate actions were effective at stemming the growing liquidity crisis. However, through outright purchases of corporate bonds and accepting corporate bonds as collateral for funding, the Feb will inevitably influence the assessing and pricing of credit risks (Small and Clouse (2005)). Whether and how such Fed actions ultimately affect the allocation of credit in the economy remains to be seen.

Our paper is related to several strands of research in the literature. A variety of authors looked at issues connected with liquidity and credit crises, with notable papers here by Allen and Carletti (2008); Brunnermeir (2009); and Kacpercyzk and Schnabl (2010). More specific analyses examining the impact and effectiveness of Federal Reserve and central bank actions in financial crises include Campbell et al (2011), Wu (2011), Duygan-Bump et al (2013), and Covitz, Liang, and Suarez (2013). Recent disruptions in the bond markets are also discussed extensively (see for example, Aramonte and Avalos (2020), , Duffie (2020), Falato, Goldstein, and Hortascu (2020), Haddad, Moreira, and Muir (2020), He, Nagel, and Song (2020), Kargar et al (2020), and Ma, Xiao and Zeng (2020)). Research by Haddad, Moreira, and Muir (2020) is particularly relevant as those authors provide evidence that asset pricing explanations for the crisis such as cash flow changes or compensation for risk are not supported by the data. They argue that financial frictions are a more likely explanation, a view akin to the microstructure focus taken here. Also related to our paper are Boyarchenko, Kovner, and Shachar (2020) and Kargar et al (2020) that both study liquidity movements in the corporate bond markets during the Covid-19 crisis. Our work complements this research but differs in that our richer data set allows a comprehensive analysis of dealer behavior and electronic customer-to-customer trading, and cleaner identification of the impact of the Fed's unprecedented initiatives to support the corporate bond markets.

It is worth noting that our paper focuses on understanding the microstructure of liquidity provisions under extraordinary selling pressures. What triggers such unusual high selling pressure remains to be further explored. Although our analysis reveals that trading shifts to bonds that were more liquid during the normal times, consistent with redemption induced fire sales by fixed income funds (Falato, Goldstein, and Hortascu (2020), and Ma, Xiao and Zeng (2020)), trading activities

by other bond investors, such as insurance firms, might have also exacerbated the selling pressures, as suggested by Haddad, Moreira, and Muir (2020). In addition, our study identifies the net effects of the announcement of the SMCCF on corporate bond liquidity. While we believe that the announcement effects were largely achieved by both reducing investors' incentives to liquidate their bond holdings and increasing dealers' willingness to provide liquidity, quantifying their respective contributions to the stabilization of market conditions would be useful to further evaluate the effectiveness of this liquidity facility.

Our analysis on the PDCF effects also highlights the role of dealer funding liquidity in affecting financial market liquidity. Brunnermeier and Pedersen (2008) argue that a trader's ability to provide market liquidity relies on its availability of funding. Duffie (2018) and Andersen, Song and Duffie (2019) show that dealer funding costs are important determinants of their bid and ask quotes. Empirically, several studies find that dealer balance sheet constraints and funding conditions affect the liquidity in the corporate bond markets (Rapp (2016), Adrian et al. (2017), Machiavelli and Zhou (2019)). Our study contributes to this line of research by showing how funding condition improvements brought by Fed liquidity facilities affect dealer inventory changes and investor transaction costs.

Our work also contributes to the growing literature on bond market microstructure. Recent work by Hendershott et. al. (2017), O'Hara, Wang, and Zhou (2018), and Goldstein and Hotchkiss (2020) analyze dealer behavior in bond markets, while Hendershott and Madhavan (2015) and O'Hara and Zhou (2019) investigate electronic bond market trading. Other recent work studied bond markets in the post-financial crisis era, with particular focus on how financial regulations affected dealer liquidity provision and corporate bond liquidity (Schultz (2017), Bao, O'Hara, and

Zhou (2018), Bessembinder et al (2018), Choi and Huh (2019), Dick-Nielson and Rossi (2019), Flanagan, Kedia, and Zhou (2019), and Saar, Sun, Yang, and Zhu (2019)). Although a number of studies examine corporate bond liquidity during the financial crisis (Bao, Pan and Wang (2011), Friewald, Jankowitsch and Subrahmanyam (2012), Dick-Nielson, Feldhutter, and Lando (2012), Feldhutter (2012), and DiMaggio, Kern and Song (2016)), we differ from these works by focusing on individual dealer behavior and customer liquidity provision through electronic trading. Our study provides new perspectives on the complex evolution of liquidity in corporate bond markets and highlights the limitations inherent in both dealer and electronic markets in a crisis period.

This paper is organized as follows. The next section provides a brief primer on corporate bond trading, sets out the time line of the crisis, the specific Federal Reserve actions to contain the bond market crisis, and discusses the data used in this analysis. Section 2 then analyzes the behavior of transaction costs in investment grade and high yield bonds, the disparate effects on trading size costs, and the immediate impact of the Federal Reserve's actions. Section 3 examines the microstructure of the crisis by looking at how trading shifted across bonds in the crisis, and who provides liquidity, focusing on dealer inventory, the differential behavior of primary and non-primary dealers, and electronic customer-to customer trading. In Section 4, we conduct a battery of analyses to evaluate further the impact of the Federal Reserve's bond liquidity programs. Section 5 is a conclusion.

1. Corporate Bond Trading, Federal Reserve Programs, and Sample Construction

1.1. A short primer on corporate bond market trading

As a useful preliminary, we set out a brief description of U.S. corporate bond trading. The U.S. corporate bond market totals almost $8.8 trillion, with investment-grade bonds approximately 6 times larger than high-yield bonds. Many institutional investors have limits (in some cases, zero) on the amount of high-yield debt they can hold. In 2019, the average daily trading volumes were $22.1 billion and $7.8 billion for investment-grade and high-yield segments respectively.[3]

Corporate bonds trade primarily in the over-the-counter dealer market. Corporate bonds are primarily held by institutional investors, so trade sizes tend to be large. Bond dealers act as counterparties, buying when a trader wishes to sell and selling when a trader wishes to buy. Although about 600 dealers intermediated trading in first quarter 2020, the largest 10 dealers controlled approximately 70% of volume. Most of these large dealers are bank-affiliated. Of particular importance are the primary dealers, a subset of 24 dealers who are trading counterparties of the New York Federal Reserve Bank in its implementation of monetary policy.[4]

Trading between customers and dealers primarily involves voice trading, whereby a customer calls a dealer, gets a quote, trades or not, and then may sequentially call other dealers until finally consummating a trade. Alternatively, trading can take place in electronic venues. Electronic trading is still a relatively small, but growing, part of corporate bond trading. Trading mechanisms used in most electronic corporate bond trading platforms can be classified into Request for Quote (RFQ) or All-to-All trading. In an RFQ trade, a customer can specify a list of pre-screened dealers, the trading platform sends to each dealer the desired trading information (i.e., bond CUSIP, trade size and direction), a dealer responds (or not) with a quote, the quotes are then

[3] For fixed income market data see SIFMA at https://www.sifma.org/resources/research/research-quarterly-fixed-income-fourth-quarter-2019/.

[4] See https://www.newyorkfed.org/markets/primarydealers.html for a list of primary dealers and their responsibilities.

given simultaneously to the customer, who can select (or not) a dealer with whom to trade.[5] In All-to-All trade, a customer's trade request is sent to all of the platform's participants, including both dealers and other customers. As many customers manage large bond portfolios, allowing them to bid against dealers introduces a new sources of liquidity to the market. This can be particularly valuable during market stress when the dealer community is unwilling or unable to provide liquidity. We analyze such customer-to-customer trading in the next section.

1.2. Setting the stage

The Covid-19 pandemic led to acute stress not only in the global economy but also in many parts of the global financial system. In the U.S., when concerns over the coronavirus escalated in early- to mid-March, many financial markets faced unusually high selling pressure. Fixed income funds suffered an unprecedented 12% outflows within a month (Ma, Xiao, and Zeng (2020)). Less liquid and more vulnerable bond mutual funds, as well as those holding bonds in Covid-19 affected industries, suffered greater outflows (Falato, Goldstein, and Hortascu (2020). Total assets under management for institutional prime money market funds dropped by around 30% within two weeks (Li et al (2020)). Amid the broad risk-off sentiment, equity prices plunged, Treasury yields declined, and corporate yield spreads widened substantially (Figure 1).

Meanwhile, liquidity provision by security dealers was limited. Some dealers reportedly reached their balance sheet capacity and hence were unable to absorb more sales. In addition, funding costs for dealers increased sharply amid increased demand for repo financing. Together, the surging demand for liquidity, accompanied by limited liquidity provision by securities dealers,

[5] For a detailed examination of RFQ trading see O'Hara and Zhou (2019).

led to severely constrained liquidity conditions in a number of dealer-intermediated markets, including the Treasury, agency MBS, municipal, and corporate bond markets.[6]

The Covid crisis led to a number of policy actions involving fiscal stimulus (including the Coronavirus Aid, Relief, and Economic Security (CARES) Act) and monetary policy responses, including the creation of numerous liquidity and credit facilities. In this study, we restrict our attention to examining the liquidity challenges in the corporate bond markets. In particular, we study the impact of dealer and customer behavior on corporate bond liquidity around the Covid-19 crisis, and the effectiveness of the Fed credit and liquidity facilities that were directly targeted at the corporate bond markets.

1.3. What the Fed did

Starting in mid-March, the Federal Reserve took actions to improve market functioning. A number of liquidity and credit facilities were created to either enhance the supply of liquidity, or to directly increase the demand for debt. The most relevant facilities for improving secondary market liquidity in the corporate bond markets were the Primary Dealer Credit Facility (PDCF), and the Secondary Market Corporate Credit Facility (SMCCF).

The PDCF offers overnight and term funding with maturities up to 90 days to primary dealers at the discount rate offered by the Federal Reserve Bank of New York. All credit extended by the PDCF must be collateralized by a broad range of investment-grade debt securities, including investment-grade corporate and municipal bonds and commercial paper. The Fed announced the

[6] For a discussion of these stressed market conditions see "Short-Term Bond Market Roiled by Panic Selling", *Wall Street Journal*, March 18, 2020. There is also the issue of whether post-financial crisis capital regulation limited the ability of dealers to commit capital to bond dealing as they had in prior times. See Bao, O'Hara, and Zhou (2018) for evidence of the effect of the Volker Rule on bank bond market trading. Data on increased repo funding rates are available at https://www.newyorkfed.org/markets/treasury-repo-reference-rates.

creation of PDCF on Tuesday, March 17, with credit extended to primary dealers starting on Friday, March 20.

On Monday, March 23, for the first time in its history, the Federal Reserve, together with the Department of the Treasury, created a facility to purchase investment-grade corporate bonds of U.S. companies from the secondary markets. Under the SMCCF, the Federal Reserve Bank of New York will provide recourse loans to a special purpose vehicle (SPV) that will purchase eligible investment-grade securities at fair market value. The corporate bonds to be purchased, which will be collateral for the loan, must have a remaining maturity of five years or less. The Department of Treasury will provide $10 billion in equity investment, and the SMCCF will leverage Treasury's equity at 10 to 1 when acquiring corporate bonds.

Although the PDCF also operated in 2008 in response to the subprime mortgage crisis and the collapse of Bear Stearns, it offered only overnight loans to primary dealers. The PDCF launched in 2020 provides term funding with maturities up to 90 days, and hence can be particularly helpful for corporate bond dealers to fund illiquid inventories. It is important to note that any improvement of funding conditions brought by the PDCF alone might not be sufficient for dealers to improve their liquidity provision. If excessive selling pressure were to persist, dealers would be reluctant to take bonds into inventories as they perceive future challenges in turning them over. By provide a liquidity backstop for corporate bonds, the announcement of SMCCF not only reduced investors' concerns, but also reassured dealers on their ability to turn over inventories and so increased their willingness to intermediate bond trading.

It is also worth noting that the liquidity focus of the SMCCF differentiates this program from the corporate sector purchase programme (CSPP) launched by the European Central Bank

(ECB) in June 2016 as the corporate arm of its quantitative easing. When interest rates were already negative, ECB directly purchased corporate bonds to improve the financing conditions of euro area firms and provide further stimulus. As the European corporate bond market is not particularly large or liquid, concerns arose that such direct ECB asset purchases could harm liquidity for investors due to a scarcity of eligible bonds. To mitigate potential negative effects on secondary market liquidity, CSPP specifically considered scarcity of specific debt instruments and general market conditions in its purchases and made its corporate bond holdings available for securities lending by the purchasing national central banks. Differing from CSPP, the primary objective of SMCCF is to support credit by providing liquidity to the corporate bond markets.

1.4. Data and Sample

Our study relies primarily on a regulatory version of corporate bond transaction data from the Trade Reporting and Compliance Engine (TRACE), provided by the Financial Industry Regulatory Authority (FINRA). These data provide detailed information for each secondary market corporate bond trade, including bond CUSIP, trade execution date and time, trade price and quantity, and an indicator for whether the dealer buys or sells the bond. In addition, the regulatory version of the data provides information on dealer identity for each trade. For inter-dealer trades, identities of both counterparties are included in the data. Information on dealer identity is essential to our study. It allows us to examine transaction costs and liquidity provision by individual dealers, as well as the impact of Fed liquidity facilities on different types of dealers. In addition, dealer identity is key to our identification of customer-to-customer trades, and our analyses on direct customer liquidity provisions around the Covid-19 crisis. For bonds included

in TRACE, we obtain from the Mergent Fixed Income Securities Database (FISD) characteristic information, such as credit rating, time of issuance and maturity, and total par amount outstanding.

To construct our sample, we start with all secondary market trades in corporate bonds executed from February 1, 2020 to May 19, 2020. To be included in our sample, we require each bond to be issued in US dollars by U.S. firms in the following three broad FISD industry group: industrial, financial and utility. In addition, each bond is required to be rated by at least one of the three major rating agencies: Moody's, S&P and Fitch. After removing private placements, we end up with a sample of 12,323 bonds issued by 1,470 firms.

One criterion for determining whether a bond is eligible for Fed facilities, either as an asset to be purchased or as collateral for pledge, is its credit rating. We follow the principle used in both SMCCF and PDCF in determining a bond's credit quality and assign a composite rating to each bond on each day. Specifically, we give a numeric value to each notch of S&P/Moody's/Fitch credit rating, with 1, 2, 3, 4 … denoting AAA/Aaa/AAA, AA+/Aa1/AA+, AA/Aa2/AA, AA-/Aa3/AA-, …, respectively. If a bond is rated by only one of the three rating agencies, the rating it receives is set to be its composite rating. For a bond rated by two rating agencies, we take the lower of the two ratings as its composite rating. For those rated by all three rating agencies, their composite ratings are determined by the median of the three ratings. Bonds with composite ratings lower than 10 are considered investment-grade, with the rest classified as high-yield.

2. Corporate Bond Market Liquidity and the Covid-19 Crisis

We capture a bond's transaction cost by measuring its price impact. As in Hendershott and Madhavan (2015), we use the closest in time inter-dealer trade in that bond as a benchmark price.

This measure allows us to obtain an estimate of transaction cost for each trade between a customer and a dealer. Compared to other transaction cost measures that have to be estimated at lower frequencies, this measure has several advantages. First, it is essential for tracking movements in bond liquidity within a short time window. Second, it allows us to study the cost imposed by different types of dealers (and customers) while controlling for both bond and trade characteristic (such as trade size) that have been shown to affect transaction costs. Lastly, the measure is particularly useful when the market is predominantly one-sided, and so obtaining information on both bids and asks is challenging.

Specifically, we estimate the transaction cost for each trade by:

$$Cost_j = ln\left(Trade\ Price_j / Benchmark\ Price_j\right) \times Trade\ Sign_j, \quad (1)$$

where $Trade\ Price_j$ refers to the transaction price for trade j, $Benchmark\ Price_j$ is the transaction price of the prior trade in that bond in the interdealer market, and $Trade\ Sign_j$ is an indictor variable for trade direction. $Trade\ Sign_j$ takes the value of +1 for an investor purchase and -1 for an investor sale. We multiple $Cost_j$ by 10,000 to compute transaction cost in basis points of value. Given the infrequent trading in corporate bonds, the benchmark inter-dealer trade could have occurred much earlier and hence be stale. To reduce the potential effects from noisy transaction cost measurement, we winsorize the top and the bottom 1% of the transaction cost estimates.

As shown in Figure 2 Panel A, liquidity conditions in corporate bond markets deteriorate precipitously in early March. Bond transaction costs skyrocket from about 40 basis points (bps) on March 5 to close to 90 bps within a week. Compared to February, average trade size increased

amid higher trade volume, consistent with traders seeking to offload large positions into what was becoming an increasingly illiquid market (Figure 2 Panel B).

The creation of these Federal Reserve liquidity and credit facilities had an immediate and significant impact on corporate bond liquidity. Bond transaction costs fell immediately following the launch of PDCF, and larger improvements to transaction costs follow the announcement of SMCCF. Transaction costs drop from over 90 bps right before the launch of PDCF, to about 70 basis points two days after the announcement of SMCCF (March 25), and continue to decline afterwards (Panel A of Figure 2). The scale and scope of SMCCF were increased on April 9. Treasury raised its equity investment in SMCCF from $10 billion to $25 billion, and eligible assets for purchase under SMCCF were expanded to include both high-yield bonds downgraded from investment-grade to BB-/Ba3 after March 22 ("recent fallen angels"), and ETFs primarily exposed to high-yield U.S. corporate bonds.[7] Although transaction costs spike on April 9 when S&P led the other two major rating agencies and downgraded a total of 143 bonds, the increase in transaction costs is more than retracted in the following couple of days and continues its downward trend afterwards. By the end of April, transaction costs decline to about 40 bps, and have remained stable since then. When the SMCCF starts operations by purchasing ETFs on May 12, its purchases have little discernible impact on bond liquidity.

Panel C of Figure 2 displays the movements in transactions costs separately for investment-grade and high-yield bonds. Despite their similar overall patterns, transaction costs in the two broad categories diverge between the launch of PDCF and the creation of SMCCF around March

[7] The majority of ETF holdings still must be those involving investment-grade debt. The SMCCF will leverage Treasury's equity at 7 to 1 when acquiring high-yield corporate bonds.

20, and the expansion of SMCCF on April 4. While transaction costs in investment-grade decrease substantially immediately after PDCF became operational on March 20, with further reductions after the creation of SMCCF, high-yield trading costs do not exhibit a clear decline until after April 9 when the scope of SMCCF is expanded to include recent fallen angels and high-yield ETFs. Such differential movements across investment-grade and high-yield bonds potentially reflect the effects of Fed credit and liquidity facilities as both the PDCF and the initial version of SMCCF were targeted only at the investment-grade segment. We turn in the following sections to examining how Fed credit and liquidity facilities affected corporate bond liquidity more generally.

While the general patterns of transaction cost movements provide a useful picture on liquidity dynamics around the Covid-19 crisis, and are consistent with policy responses having a positive impact on corporate bond markets, they are subject to potential selection biases. As illustrated below, at the peak of the crisis, trading migrates to bonds that tend to be more liquid during normal times. There is also the possibility that some dealers were more reluctant to intermediate bond trading than others, results in a change in the distribution of trades across dealers. To address these concerns, we rely on trade-level transaction cost measures, and leverage our information on trade, bond characteristics, and dealer identities to further analyze liquidity movements around the crisis. To facilitate our empirical analysis, we divide our sample period into three sub-periods: normal period (February 1 – March 5), crisis period (March 6 – March 19), and regulation period (March 20 – May 19). This division is mainly dictated by the data and the timing of Fed interventions. As shown in Panel A of Figure 2, bond trading costs rise sharply on

March 6. The PDCF start operations on the Friday, March 20, followed by the established of SMCCF on the following Monday (March 23).[8]

We estimate the following empirical model:

$$Cost_j = \alpha + \beta_1 \times Crisis_t + \beta_2 \times Regulation_t + \gamma \times X_{i,t} + \mu_i + \mu_s + \mu_d + \varepsilon_j. \quad (2)$$

The dependent variable $Cost_j$ refers to the transaction cost for trade j, estimated using Equation (1). $Crisis_t$ ($Regulation_t$) is a dummy that takes the value of one if the execution date (t) is March 6 (March 20) or after. $X_{i,t}$ represents a set of time varying bond-level controls for bond *i* on day *t*, including the log of the number of years since issuance (*Log(Age)*), the log of the residual time to maturity of the bond in years (*Log(Time to Maturity*)), and a set of dummy variables for the 21 numeric composite credit ratings. We include μ_i, μ_s and μ_d to control for bond fixed effects, trade size fixed effects and dealer fixed effects respectively, as bond time-unvarying characteristics (such as issuance size and industry classifications), trade size, and dealer characteristic have all been shown to play important roles in determining bond transaction costs.[9] Transaction costs tend to increase at times when a bond experiences rating downgrades, so we exclude trades on days when bonds are downgraded from our sample to avoid potential influence from differential distributions of rating changes across the three sub-periods.[10] Standard errors are clustered at bond and day levels.

[8] Since PDCF was announced in the evening of March 17, we also used the March 18 to define the beginning of the regulation period and our results changed little.

[9] Trade size effects are based on the four size categories: Micro ($1 to $100,000), Odd-lot ($100,000 to $1,000,000), Round-lot ($1,000,000 to $5,000,000), and Block (above $5,000,000).

[10] We also took a more conservative approach by removing all trades in downgraded bonds from our sample and obtained similar results.

Results in Table 1 show that after controlling for bond and trade characteristics and dealer identities, bond transaction costs exhibit a similar pattern as in Figure 2 Panel A. Transaction costs during the crisis period are on average 57 bps higher than during the normal period. After the launch of PDCF, cost decline by 24 bps, but remain significantly higher compared to the normal period. We split our sample into investment-grade and high-yield bonds, and we find similar results in the investment-grade sub-sample (Column (II)). For high-yield bonds, liquidity costs rise substantially after the crisis started, but they do not show significant improvement following the launch of PDCF. Although both the PDCF and initial SMCCF reportedly lifted overall market confidence, this finding suggests that the spillover effect of these facilities to the high-yield segment, if any, is limited.

More direct liquidity impact on high-yield bonds should be evident after the SMCCF was expanded to include some fallen angels and high-yield ETFs. For that purpose, we create a new dummy, $SMCCF\ Expansion_t$, that takes the value of one if a trade occurs after April 9. We include $SMCCF\ Expansion_t$ as an additional explanatory variable and re-estimate Equation (2). As shown in Column (IV), while average trading cost in high-yield bonds is still slightly higher than before the regulation period, it declines by 28 bps following the expansion of SMCCF. It is worth noting that although our model allows for better control for other potential influences on transaction cost movements, the estimated coefficients only capture the average transaction costs for each sub-period, and hence may underestimate the severity of the crisis, as well as the immediate effects of Fed facilities. We turn to Section 4 to evaluate further the impact of policy interventions.

One interesting feature of corporate bond trading is that transaction costs usually decrease with trade size. This negative relationship between trade size and transaction costs is widely documented in the literature, and is generally attributed to either dealer bargaining power or fixed costs in executing bond trades. O'Hara and Zhou (2019) show that odd-lot trades have particularly benefited from the recent development of electronic trading in corporate bonds, as almost 50% of Odd-lot trades in investment-grade bonds executed electronically by 2017. Given the lower trading costs on electronic trading platforms (Hendershott and Madhavan (2015)), and the spillover effects of electronic trading on traditional voice trades (O'Hara and Zhou (2019)), it is not surprising to see odd-lot transaction costs comparable to, and often times lower than, costs for trading round-lots and blocks in the pre-crisis period (Figure 3 Panel B). Nevertheless, trading the even smaller micro lots was generally more expensive than trading in larger quantities.

The relationship between transaction costs and trade size completely reverses shortly after the beginning of March when liquidity supply fell short of liquidity demand. With dealers facing increasing selling pressures from customers, as well as balance sheet capacity and funding constraints, costs for trading larger quantities, especially blocks, soar and became much higher than for trading micro lots. In February, costs for trading blocks are only 24 bps, about 10 bps lower than for micro-lots. However, they jump to over 150 bps at the time of the creation of SMCCF, over 60 bps higher than micro-lot costs. This inversion between block trade costs and micro-lot costs shrinks substantially as strains in the corporate bond markets ease following the establishment of liquidity facilities by the Fed. High-yield bonds exhibit a similar pattern with respect to transaction costs and trade size, but a significant shrinkage in the gap between small and large trades does not occur until after the expansion of SMCCF.

3. The Microstructure of a Liquidity Crisis

The evolution of corporate bond liquidity around the Covid-19 crisis reflects the interplay of a number of forces that drove both the supply and the demand for liquidity. In this section, we expand our understanding of the liquidity crisis by examining the microstructure of liquidity provision under unusual high demand for liquidity. We start by analyzing how investors' trading activities migrated across bonds when demand for liquidity surges in March. We then focus on studying liquidity provision by both dealers and customers.

3.1. Which bonds are traded during the crisis?

In March 2020, demand for liquidity in the corporate bond market surged as investors rushed to sell their bond holdings amid escalating concerns over the coronavirus spread. While liquidity conditions were extremely strained in the overall corporate bond markets, certain bonds could come under particularly strong selling pressures. In this sub-section, we study how trading activities in corporate bonds relate to bond characteristics and how such relationships change during the crisis period.

We start by estimating the average transaction cost for each bond separately for the normal period and the crisis period. Specifically, we first estimate the daily volume weighted average transaction costs for each bond (i), and then average it across days within each sub-period to obtain bond i's transaction cost during the normal period ($Cost_{i,normal}$) and during the crisis period ($Cost_{i,crisis}$). We focus our analysis on the 7308 bonds for which we are able to obtain transaction and volume estimates during both sub-periods. We then estimate the following empirical model:

$$Log(Volume_{i,p}) = \alpha + \beta_1 \times Cost_{i,p} + \beta_2 \times Log(Time\ to\ Maturity_i) + \beta_3 \times Log(Age_i) + \mu_r + \mu_{ind} + \varepsilon_i, \qquad (3)$$

where p refers to either the normal period or the crisis period. $Volume_{i,p}$ refers to the total trade volume in bond i during sub-period p, and μ_r and μ_{ind} represent credit rating and industry fixed effects, respectively. Standard errors are clustered at the firm level.

Column I in Table 2 shows that the coefficient for $Cost_{i,normal}$ is negative and highly significant, suggesting that during the normal period, more liquid bonds trade more. $Cost_{i,normal}$ turns insignificant when we control for bond i's total par amount outstanding (Column II), suggesting that the previous result is driven by investors' preference for trading in larger issues. Interestingly, the relationship between trade volume and cost changes during the crisis period, with more heavily traded bonds experiencing higher transaction costs (Column (III)). This result holds even when we control for bond i's amount outstanding (Column (IV)).

To investigate further which bonds trade more heavily during the crisis period, we include each bond's average transaction cost and total trade volume during the normal period as additional explanatory variables and re-estimate Equation (3). Column IV shows that $Volume_{i,crisis}$ continues to be positively related to $Cost_{i,crisis}$, confirming our previous finding that during the crisis period, greater trading activities are associated with larger transaction costs. More importantly, the coefficient for $Cost_{i,normal}$ is negative and highly significant, suggesting that more liquid bonds during the normal period are traded more during the crisis period.

Ma, Xiao, and Zeng (2020) argue that bond mutual funds meet redemption requests by first selling more liquid assets in their portfolios to reduce liquidation discounts. They show that during the Covid-19 crisis bond mutual funds reduced their holdings of liquidity assets, which comprise cash, cash equivalents, and Treasuries, when facing increasing outflows. Our findings suggest that

bond mutual funds' pecking order of liquidation might have also occurred within the corporate bond space. Even after controlling for bond characteristics, such as credit rating and maturity, greater trade volume occurred in bonds that were considered as more liquid during the normal time. Our results are consistent with liquidity management by bond mutual funds documented for other time periods (e.g. Chernenko and Sunderam (2017), Jiang, Li and Wang (2020)).

3.2. Liquidity provision around the crisis

Despite elevated selling pressures, the bond market might still function properly if liquidity providers stand ready to buy. To gain a deeper understanding of the liquidity dynamics around the Covid crisis, we turn to studying the behavior of both bond dealers and some customers who might absorb some of the sales through direct customer-to-customer trading.

3.2.1. Dealer Inventory Changes

Dealers play an important role in the proper functioning of corporate bond markets. With orders arriving in large lots at irregular times, liquidity of the bond markets is essentially determined by dealers' ability to match buyers and sellers and absorb order imbalances. At the same time, dealers are also professional traders who aim to profit from their trades using their information and expertise on the markets. When market conditions are strained, and are likely to deteriorate further, these roles may conflict, leading dealers to turn their back on customer demands, and shift from providing liquidity to consuming liquidity.

Figure 4 Panel A describes dealers trading activities and the resulting inventory changes around the Covid-19 crisis area. From the beginning of February, aggregate cumulative purchases and sales by corporate bond dealers grow steadily, with both reaching over $1.1 trillion by May 19. Trading activities do not exhibit a significant slowdown during early- to mid-March,

suggesting that dealers were still trading actively under stress conditions. We find that the number of active dealer on each trading day stayed remarkably stable over our sample period. Similarly, we find that the share of volume done by primary dealers and the top ten dealers remains generally the same.[11]

When the crisis period began on March 6, however, dealers' cumulative inventory, defined as the difference between their cumulative purchase and cumulative sales, starts to decline substantially. Within one week, dealer inventories decline by about $8 billion. Although the magnitude of the decline is small compared to the aggregate trade volume (about $150 billion during the same week), this finding suggests that together, the dealer community is not fully absorbing customer sales when the market becomes stressed. Dealers do not increase inventories until the PDCF started operating on March 20, and more significantly so following the announcement of SMCCF on March 23. It is worth noting that by mid-May, dealers' aggregate corporate bond inventories have risen to substantially higher levels than they were at the beginning of February.

Panel B shows cumulative inventory changes for primary dealers and other dealers separately. Consistent with market commentaries that due to their already elevated inventories primary dealers were unable to absorb sales when selling pressure increased in early March, we find that cumulative inventories by primary dealers stay relatively stable since mid-February, before they begin to drop when the crisis period starts. Net selling by other dealers is much larger in magnitude and accounts for most of the decline in dealer inventories during the crisis period.

[11] The average daily number of active dealers was 280, with little variation across our sample period. Primary dealers on a daily basis did between 75% - 80% of volume, with the top ten dealers doing approximately 68% to 70% of volume.

This behavior also lasts much longer than that by primary dealers, and it does not stop until the launch of PDCF and SMCCF.

How did a dealer's inventory behavior change around the Fed's policy actions? To address this issue, we first estimate the following model:

$$Inv\ Chg_{d,t,r} = \alpha + \beta_1 \times Crisis_t + \beta_2 \times Regulation_t + \mu_d + \mu_r + \varepsilon_{d,t,r}. \quad (4)$$

$Inv\ Chg_{d,t,r}$ is defined as the difference between dealer d's net purchase and its net sales on day t in rating category r (i.e., either investment-grade or high-yield). The other variables are defined as in Equation (2). Table 3 shows that on average, a dealer's daily net purchasing decline by $1.8 million after the crisis started on March 6. However, this decline is more than reversed following the launch of PCDF and the creation of SMCCF, with daily net buying in the regulation period even higher than during the normal period. Most of the increase in dealer inventory changes occur prior to the SMCCF expansion, as the coefficients for both $SMCCF\ Expansion_t$ and $SMCCF\ Expansion_t$ are not significant after we include them as an additional explanatory variables in the estimation of Equation (4) (Column (II)).

One potential channel for dealers to absorb more sales into their inventory is that the credit lent under PDCF eased their funding conditions. To test this hypothesis, we explore the differential changes in primary dealers' inventory changes in investment-grade bonds as they are directly affected by the launch of PDCF. Specifically, for the period spanning both the crisis period and the regulation period that ends prior to the implementation of the SMCCF (as the SMCCF started trading only with primary dealers), we estimate the following model:

$$Inv\ Chg_{d,t,r} = \alpha + \beta_1 \times Regulation_t \times IG\ Dummy_t \times Primary\ Dealer_t + \beta_2 \times Regulation_t \times IG\ Dummy_t + \beta_3 \times Regulation_t \times Primary\ Dealer_t + \beta_4 \times IG\ Dummy_t \times Primary\ Dealer_t + \mu_r + \mu_d + \mu_t + \varepsilon_{d,t,r}, \quad (5)$$

where $Primary\ Dealer_t$ is a dummy for primary dealers. All other variables are defined as in Equation (4). Column (III) of Table 3 shows that after PDCF implementation, primary dealers on average increase their daily net buying by about $14 million. This finding is consistent with the hypothesis that PDCF improved corporate bond liquidity by enhancing dealer funding liquidity.

To understand further how dealer trading behavior affected bond liquidity and the potential policy impacts, we link bond transaction costs to dealer inventory changes and study how this relationship changes over the Covid-19 crisis period. We showed earlier that during the crisis dealers as a whole shifted to net selling, suggesting that dealers were becoming unwilling to hold inventory positions in some bonds. We conjecture that such behavior could lead to higher liquidity costs for such bonds.

To address this issue, we estimate for each bond i on each day t, both net buying across all dealers ($Dealer\ Net\ Buy_{i,t}$), and the accumulation of the daily net dealer buying since the beginning of February ($Cum\ Dealer\ Net\ Buy_{i,t}$). We then estimate the following model:

$$Cost_j = \alpha + \beta_1 \times Dealer\ Net\ Buy_{i,t-1} + \gamma \times X_{i,t} + \mu_i + \mu_s + \mu_d + \mu_t + \varepsilon_j. \quad (6)$$

Table 4 shows that during our sample period, transaction costs tend to be higher for bonds that were sold more by dealers on the previous day (i.e. net buying was negative). Replacing $Dealer\ Net\ Buy_{i,t-1}$ with $Cum\ Dealer\ Net\ Buy_{i,t-1}$ yield similar results, suggesting that bonds

sold more aggressively by dealers in the past tend to have higher transaction costs. This behavior is consistent with dealer inventory directly affecting bond illiquidity.

Interestingly, this relationship between past dealer trading and current transaction costs changes over time. We interact $Cum\ Dealer\ Net\ Buy_{i,t-1}$ with $Crisis_t$ and $Regulation_t$ respectively and include both interaction terms as explanatory variables when re-estimating Equation (6). Table 4 shows that during the normal period, past dealer trading has no significant impact on current transaction costs. However, following the start of the crisis period, bonds sold more by dealers in the past experience higher transaction costs. This effect weakens following Fed policy interventions.

3.2.2. Customer-to-Customer trading

Recent growth in electronic trading has brought additional sources of liquidity to the corporate bond market. In particular, customers, including many asset managers, insurance firms, and hedge funds, are now able to trade directly with each other without involving dealers. Such liquidity provision by customers can be particularly valuable when the whole dealer community is unable or unwilling to make markets.[12]

In this section, we study liquidity provided directly by customers around the recent crisis. We start by identifying Customer-to-Customer (C-to-C) trades in our TRACE data. Although details in the trading protocols used for execution might differ across different electronic trading platforms, most trades between two customers are executed on an anonymous basis. Electronic trading platforms facilitate the matching of buyers and sellers, and are responsible for reporting

[12] In an earlier paper (O'Hara and Zhou (2019)), we study the robustness of bond liquidity provided through electronic trading by focusing on RFQ trades around rating downgrades. We find that the benefit of electronic trading declines amid unusual demand for liquidity and trading shifted to voice trading venues.

the trades to FINRA. Using dealer identities in our TRACE data, we identify trades between two customers on all active electronic trading platforms, for which we obtained a list of their names from FINRA.

Since C-to-C trades are reported by trading platforms, each trade shows up twice in the TRACE tape – a report in which the seller trades with the platform, and a second where the buyer trades with the platform. At first glance, this seems unreasonable as there is really only one buyer and one seller involved and the platform is not taking a risk position. One can argue, however, that a trade between two customers should be considered as two trades since the trading platform replaces the dealer in matching the buyer and the seller. If the trade were intermediated by a dealer, we would see two reports on the TRACE tape, i.e., a dealer buy from customer A, and a dealer sell to customer B.[13] In addition, the price the buying customer pays is usually higher than what the selling customer received, with the difference going to the platform as the fee for using its service. Therefore, for one C-to-C trade, there are two prices. For these reasons, we double count each C-to-C trade in our analysis of the C-to-C trade volume.

As shown in Figure 5 Panel A, the share of C-to-C trade out of total bond trade starts to drift higher starting in late February. During the crisis period, C-to-C trade is volatile, but overall it remains elevated before starting a significant decline following policy interventions. This finding is consistent with customers stepping up at times when liquidity provision by the dealer community is hampered. The share of C-to-C trade is higher in the number of trades rather than in trade volume, as trade size for C-to-C trade tends to be significantly smaller than for C-to-D

[13] It might show up as more trades if the bond has to be passed through other dealers in the inter-dealer market before it lands on another customer's portfolio.

trade. It is worth noting that the increase in volume share around the crisis period does not outpace the increase in number of trades, as the ability of C-to-C to handle large trades seems to be limited when demand for trading in large quantities rose (Panel B of Figure 5).

Of particular interest is the cost that customers incur for obtaining liquidity provided outside the dealer community. Capturing such cost can be challenging, especially since when a customer trades with another customer, the resulting two trade prints (with opposite directions but similar prices) are evaluated against the same benchmark. Consider the following case in which customer A sold one bond at P_A to customer B, who received a price P_B which is equal to P_A less a small fee charged by the platform. As P_A and P_B are both likely to be lower than the benchmark price (i.e., the previous inter-dealer price), Equation (1) will generate a positive transaction cost estimate for the seller A. However, the cost estimate for the buyer B is negative, suggesting a profit, rather a cost, to the customer who provided the liquidity. To focus on the cost paid by the customer who consumed liquidity through C-to-C trading, we use the price from one leg of the C-to-C trade to estimate Equation (1).

Figure 6 shows that although customers provide more liquidity in stress times, this liquidity is very costly. Prior to the crisis period, transaction costs in C-to-C trading are consistently lower than in C-to-D trading. During the normal period, C-to-C trading costs average 24 bps, about 40% lower than in C-to-D trading. However, at the onset of the crisis period, C-to-C trading costs soar and surpass C-to-D trading costs. The gap in trading costs between C-to-C and C-to-D widens sharply and peaks right before the launch of Fed facilities, when C-to-C costs reach 165 bps, more than double C-to-D costs. This trading cost gap then shrinks during the regulation period. By late April, transaction costs for C-to-C trades fall below those for C-to-D and remain stable.

One potential concern for the pattern exhibited by these average transaction costs is that the respective liquidity provisions by dealers and customers could change over time. In particular, the types of trades and bonds intermediated by dealers vs. customers could be different across the sub-periods. Transaction costs are heavily affected by both trade and bond characteristics, so the picture revealed by Figure 6 could reflect time-series shift in the composition of the C-to-C and C-to-D subsamples.

This conjecture is not supported by our data. Table 5 provides summary information on both bond and trade characteristics for C-to-C and C-to-D trades and over time. Although bonds for C-to-C trading differ somewhat from those for C-to-D trading during the normal period, (i.e., greater outstanding amount, shorter time to maturity, younger, and less risky), the characteristics of bonds for C-to-C trading remain remarkably stable across the three sub-periods. Characteristics of bonds for C-to-D trading also change little over time. These results suggest that the pattern in the trading costs in the two types of trades is unlikely attributable to potential shifts in bond trading composition.

Trade size is known to play an important role in determining transaction costs in corporate bond trading, so the gap in transaction costs can potentially be due to differential changes in trade size for C-to-C and C-to-D trading. Table 5 shows that during the normal period, C-to-C trades are smaller than C-to-D trades, with average trade size less than half that of C-to-D trades. However, both types of trades experience similar increases in trade size during the crisis period. This finding refutes the argument that the extraordinary increase in C-to-C trading costs during the crisis period is due to a shift in the distribution of trades across sizes.

To control for the influence of bond and trade characteristics, as well as potential time trends in transaction costs, we estimate the following model:

$$Cost_j = \alpha + \beta_1 \times CtoC_j + \beta_2 \times CtoC_j \times Crisis_t + \beta_3 \times CtoC_j \times Regulation_t + \gamma \times X_{i,t} + \mu_i + \mu_s + \mu_t + \varepsilon_j. \quad (7)$$

$CtoC_j$ is a dummy for C-to-C trades. All the other variables are defined as in Equation (2).

Results in Table 6 shows that after controlling for bond characteristics, trade size effects, and time fixed effects, the pattern in transaction costs for C-to-C and C-to-D trades remains. C-to-C costs are lower during the normal period, but become substantially larger with the crisis onset. The gap in costs between the two types of trades narrows during the regulation period. The magnitude of the cost differences between C-to-C and C-to-D estimated from the regression is lower compared to that in Table 5, suggesting that bond and trade characteristics and potential time trends have some effect on the transaction costs for the two types of trades. We replace bond fixed effects, day fixed effects and trade size fixed effects with bond-day-trade size fixed effects and re-estimate Equation (7). This allows us to compare transaction costs between C-to-C and C-to-D in the same bond on the same day within the same trade size category. Column (II) shows that our results change little.

To examine differential transaction costs over time for investment-grade and high-yield bonds, we also estimate Equation (7) with bond-day-trade size fixed effects separately in the subsamples for the two broad categories of bonds. The findings for investment-grade bonds are very similar to the full sample (Column (III)). For high-yield bonds, C-to-C trades did not appear to have lower costs during the normal period. However, just as in C-to-D trading, they became substantially more expensive after the crisis started. We also find that the gap between C-to-C and

C-to-D costs declines in high-yield bonds during the regulation period (Column (IV)), and most of the narrowing in gap occurs after the SMCCF expansion (Column (V)).

In summary, our results portray interesting interactions involving liquidity provision between customers and dealers. While customers can step in and provide liquidity in stress times when dealers are unable or unwilling to warehouse inventory risks, such customer-provided liquidity can be extremely costly. The costs for consuming liquidity provided directly by customers declined when dealers increased liquidity provision following Fed interventions.

4. Policy interventions and bond liquidity

Our analyses on transaction cost movements and liquidity provision are consistent with an important role played by Fed credit and liquidity facilities during the bond liquidity crisis. However, one could argue that these findings are subject to identification problems. As shown in Figure 1, in addition to PDCF and SMCCF, other facilities were established and monetary policy actions were made around both March 20 and April 9. These policy actions could have also boosted investors' appetite for risk and improved overall financial market functioning.

To address this concern, we take a differences-in-differences approach by focusing on the segment of the bond market directly related to the objectives of the facilities. As PDCF accepts only bonds rated investment-grade as collateral for funding to dealers, the impact of PDCF through the funding liquidity channel should be stronger in the investment-grade segment after its launch on March 20. At its initial creation, SMCCF also only considered purchasing investment-grade bonds. Therefore, we expect the regulation effect observed previously to be stronger in investment-grade bonds after March 20.

To test this hypothesis, we use a sample that includes all trades one week before and one week after the launch of PDCF (i.e., from March 13 to March 26). We estimate the following empirical model:

$$Cost_j = \alpha + \beta_1 \times Regulation_t \times IG_t + \gamma \times X_{i,t} + \mu_i + \mu_s + \mu_d + \mu_t + \varepsilon_j. \quad (8)$$

IG_t takes the value of one if trade j occurred in a bond rated investment-grade, and μ_t controls for day fixed effects. The other variables are defined as in Equation (2).

Results in Table 7 Column (I) support the view that the PDCF and SMCCF had a positive impact on bond liquidity. The estimate of β_1 is negative and highly significant, suggesting that after controlling for time trends, bond and trade characteristics, and dealer identities, the average transaction costs in investment-grades declines more compared to high-yield bonds during the week following the launch of the PDCF.

Can these improved liquidity conditions during the regulation period be attributed to both PDCF and SMCCF? If not, which one is more effective in improving the severely strained liquidity conditions? Both facilities' objective is to support the credit needs of business, but they are designed to achieve the goal through different channels. PDCF is targeted at enhancing dealer funding liquidity and hence their market making capabilities. SMCCF, on the other hand, seeks to directly increase the demand for corporate bonds by having the Fed buy the bonds – essentially stepping in as a market maker on the buy side. This can both boost investor sentiment when markets are largely one-sided, and increase dealers' willingness to absorb bonds into their inventories.

To disentangle the PDCF effect from the SMCCF effect, we exploit differences in eligible participants and assets for these two facilities to shed light on their respective impact on bond

liquidity. First, funding is provided only to primary dealers under PDCF, while eligible sellers for SMCCF include a broad range of U.S. institutions provided they satisfy the conflicts-of-interest requirements of section 4019 of the CARES Act. Therefore, if PDCF was effective, we expect the incremental liquidity improvement in investment-grade bonds following PDCF to be even stronger in trades intermediated by primary dealers. Second, SMCCF only accept bonds with remaining maturities of 5 years or less, while PDCF has no maturity requirement on eligible collateral. Therefore, if SMCCF increased bond liquidity, we expect the additional liquidity increase in investment-grade bonds during the regulation period to be even greater in trades in bonds with time to maturity no longer than 5 years.

To test these hypotheses, we take a triple differences approach. Specifically, to test the PDCF effect, we create a dummy, $Primary\ Dealer_t$, that takes the value one if trade j was executed with a primary dealer. We then estimate the following panel regression:

$$Cost_j = \alpha + \beta_1 \times Regulation_t \times IG_t \times Primary\ Dealer_t + \beta_2 \times Regulation_t \times IG_t + \beta_3 \times Regulation_t \times Primary\ Dealer_t + \beta_4 \times IG_t \times Primary\ Dealer_t + \gamma \times X_{i,t} + \mu_i + \mu_s + \mu_d + \mu_t + \varepsilon_j. \quad (9)$$

If transaction costs in investment-grade bonds decline further for primary dealers due to the launch of PDCF, we would expect β_1 to be negative and highly significant. Table 7 Column (II) shows that this is the case. During the week following the launch of PDCF and for investment-grade bonds, trades intermediated by primary dealers have an additional 10 bps lower transaction costs. Note that the coefficient for $Regulation_t \times IG_t$ (β_2) is also negative but not significant, both statistically and economically, consistent with improved market making abilities mainly for primary dealers through PDCF. One might ask whether the announcement of PDCF in the evening

of March 17 had already started to affect liquidity before any credit was extended to dealers on March 20. Using a sample of all trades executed between two days before the announcement and two days after the announcement (i.e., from March 16 to March 19), we redefine the Regulation dummy using March 18 as the beginning of regulation period and we re-estimate Equation (9). The coefficient for the triple interaction term (i.e, β_1) is not significant. This finding suggests that the PDCF effect is mainly after it started providing funding to dealers.

One potential concern is that there might be natural differences in how fast bonds with different ratings recover as liquidity comes back. To address this concern, we zoom in close to the investment-grade and high-yield boundary for the PDCF and re-estimate Equation (9) on a small sample of bonds rated either BBB- or BB+. These bonds carry similar credit risks, but fall on different sides of the IG and HY boundary. Column (IV) shows that the coefficient for the triple interaction term remains negative with a substantially larger magnitude. The statistical significance declines somewhat in this much smaller subsample but it is still significant at the 10% level. We also check for parallel trends prior to the launch of PDCF. We extend our sample by including four weeks prior to the launch of the PDCF (i.e., from February 21 to March 26). Following Borusyak and Jaravel (2017), we divide the pre-regulation period into four weekly sub-periods, and pick the omitted categories to be the first and last sub-periods. We then evaluate the pre-trends in the remaining two sub-periods. The parallel trend assumption appears to hold in the data, and the coefficient for the triple interaction term remains negative and significant at the 10% level (Column (V)).

We use a similar approach to test the SMCCF impact at its creation. Specifically, we create a dummy, $Short\ Term_t$, that takes the value one if trade j is in a bond with remaining maturity of

5 years or less. We then replace $Primary\ Dealer_t$ with $Short\ Term_t$ and re-estimate Equation (9). Results in Column (V) shows that SMCCF also has a significant impact on corporate bond transaction costs. The negative coefficient for the triple interaction term suggests that eligible short term bonds for the SMCCF experience an additional 9 bps decline in transaction costs during the regulation period compared to other investment-grade bonds with longer time to maturity.

To account for the possibility that liquidity for bonds with different maturities might recover at different speed amid improving market functioning, we focus on a sample of bonds with time to maturity greater than 4.5 years but less than 5.5 years, and re-estimate Equation (9). Although the sample shrinks substantially, the coefficient for the triple interaction remains negative with substantially larger magnitude, and still significant at the 10% level (Column (VII)). The parallel trend assumption again hold in the data, and the coefficient for the triple interaction term remains negative with somewhat smaller magnitude (Column (VIII)).

The expansion of SMCCF to include fallen angels and high-yield ETFs provides another opportunity to test the SMCCF effects on bond liquidity. While the increase in Treasury equity investment expanded the SMCCF's capacity and hence should benefit the whole corporate bond markets, the impact should be stronger for high-yield bonds as they are excluded from the SMCCF at its initial creation. For that purpose, we use a sample that spans one week before and one week after the SMCCF expansion (i.e., from April 2 to April 15), and estimate the following empirical model:

$$Cost_j = \alpha + \beta_1 \times SMCCF\ Expansion_t + \gamma \times X_{i,t} + \mu_i + \mu_s + \mu_t + \varepsilon_j. \quad (10)$$

Results in Column (I) of Table 8 are consistent with the hypothesis that the expansion of SMCCF brought additional liquidity to the bond market. On average, transaction cost decline by 9 bps

during the week after SMCCF expansion. To study whether SMCCF expansion affects high-yield bonds more strongly, we create a dummy, HY_t, that takes the value of one if trade j occurred in a bond when it is rated high-yield. We then estimate the following regression:

$$Cost_j = \alpha + \beta_1 \times SMCCF\ Expansion_t \times HY_t + \gamma \times X_{i,t} + \mu_i + \mu_s + \mu_d + \mu_t + \varepsilon_j. \quad (11)$$

Although investment-grade bonds also benefit from the increase in the size of SMCCF, high-yield bonds experience an additional 4 bps decline in transaction costs on average during the one week after the expansion (Column (II)). Because individual high-yield bonds eligible for purchase under SMCCF are limited to recent fallen angels with 5 years or less to maturity, we create a dummy, $Fallen\ Angel_t$, for BB-/Ba3 rated bonds that are downgraded from investment-grade bonds after March 22, and estimate the following model:

$$Cost_j = \alpha + \beta_1 \times SMCCF\ Expansion_t \times Fallen\ Angel_t \times Short\ Term_t + \beta_2 \times SMCCF\ Expansion_t \times Fallen\ Angel_t + \beta_3 \times SMCCF\ Expansion_t \times Short\ Term_t + \beta_4 \times HY_t \times Short\ Term_t + \beta_5 \times Short\ Term_t + \gamma \times X_{i,t} + \mu_i + \mu_s + \mu_d + \mu_t + \varepsilon_j. \quad (12)$$

The coefficient for the triple interaction term is negative, but it is not statistically significant. These findings suggest that the impact of SMCCF on high-yield bonds is not driven by recent fallen angels with short time to maturity. This could potentially be due to the inherent linkage between high-yield ETFs (which were also included into SMCCF at the same time) and the underlying high-yield bond markets through the redemption and creation process.[14]

[14] It might also be attributed to higher market expectation on the inclusion of other high-yield bonds into SMCCF following this move.

On May 12, SMCCF became operational and started to purchase ETFs. To test for SMCCF implementation effects while controlling for other potential drivers of transaction costs, we use a sample that spans one week before and one week after May 12 (i.e., from May 5 to May 18), and re-estimate Equation (10) by replacing $SMCCF\ Expansion_t$ with $SMCCF\ Implementation_t$, which takes the value one if a trade occurred on or after May 12. The results show very limited implementation effects. On average, transaction costs decline by only 1 bps during the one week after SMCCF started operations.

Although eligible sellers for SMCCF include a broad range of U.S. institutions, the SMCCF began by transacting with primary dealers that met the eligible seller criteria and completed the seller certification materials to expedite implementation. Consistent with this practice, we find additional yet very small improvement in transaction costs by primary dealers. Re-estimating Equation (11) with $SMCCF\ Expansion_t$ replaced by $SMCCF\ Implementation_t$ and HY_t replaced by $Primary\ Dealer_t$ shows that the coefficient of the interaction term is highly significant but with very small magnitude (about 1 bps). We also check for parallel trends prior to the implementation of SMCCF. The magnitude of the coefficient of the interaction term increases slightly but remains small. Together, these results suggest that most of the impact of the Fed's SMCCF intervention on the corporate bond markets were around the time of the announcement. Market conditions had stabilized prior to the actual operations of SMCCF.

5. Conclusions

Market liquidity is not a given but instead emerges from a complex process involving a variety of market players. The same can be said of market illiquidity. Our analysis of the anatomy

of the Covid-19 liquidity crisis reveals just how complicated this process is in the corporate bond market. As the crisis unfolded, we showed how trade volume shifted to liquid bonds, transaction costs soared, trade size pricing inverted, and dealers shifted from buying to selling behavior. We showed how the primary dealers played a mostly positive role in liquidity production, but other dealers less so. We demonstrated how the high yield and investment grade markets diverged. We also demonstrated how electronic customer-to-customer trading volume increased during the crisis, but at substantially higher trading costs than in customer-to-dealer trading.

Our analysis delineated how Federal Reserve actions contributed to easing the crisis. We showed how the PDCF had almost immediate effects: primary dealers reverted back to accumulating inventories, transaction costs began to fall, block trade effects subsided, with all of these effects primarily in the investment-grade market. The SMCCF was also effective, further lowering transaction costs, particularly for shorter maturity bonds, and with the SMCCF expansion, relieving the illiquidity effects in the high-yield market. As we noted, these SMCCF effects are particularly intriguing as over our sample period the SMCCF did not buy a single bond.

Some might argue that the story here is a simple one: the bond market liquidity crisis began, the Federal Reserve acted, the crisis subsided. But this characterization misses the most important, and novel, aspects of what happened here. One is the new role played by the Federal Reserve. As we showed, the Fed acted here more as a market maker of last resort, providing funding to facilitate the "deep pockets" dealers need to take on more inventory, and standing ready to provide direct relief from a one-sided market by buying bonds and ETFs. This new behavior, consistent with Buiter and Sibert's (2007) observation that the nature of crises has changed, suggests a new direction for central banking.

Going forward, what happens? Notably, the SMCCF is not a type of Quantitative Easing whereby the Federal Reserve is committed to holding the asset class, but more of a guarantee of market liquidity support if needed. Thus, unlike the Fed's substantial holdings of mortgage-backed securities in the global financial crisis, it may be that the Fed ends up holding relatively few bonds or ETFs. But the Fed's new role may still have a substantial impact on the overall market, particularly if it encourages greater risk, and leverage, in the corporate bond market. Early evidence from issuance in April 2020 are consistent with such effects, but it is clearly too soon to judge whether this is a pattern or an aberration.

Finally, we note that while the bond market crisis had largely subsided by the end of our sample period in mid-May 2020, bond market liquidity had yet to return to pre-crisis levels. This is not surprising to us. The Covid crisis has had wide-ranging effects, including higher uncertainty and increased credit risks of firms. These factors increase the risks facing dealers and so contribute to higher costs of liquidity provision, but they also affect the demanders of liquidity – the insurance companies, bond mutual funds and ETFs, and other bond market investors. Research into how the Federal Reseve's actions affected these groups may give a broader view of the bond market crisis. It appears that bond markets are now in a new normal – functioning well but still evolving.

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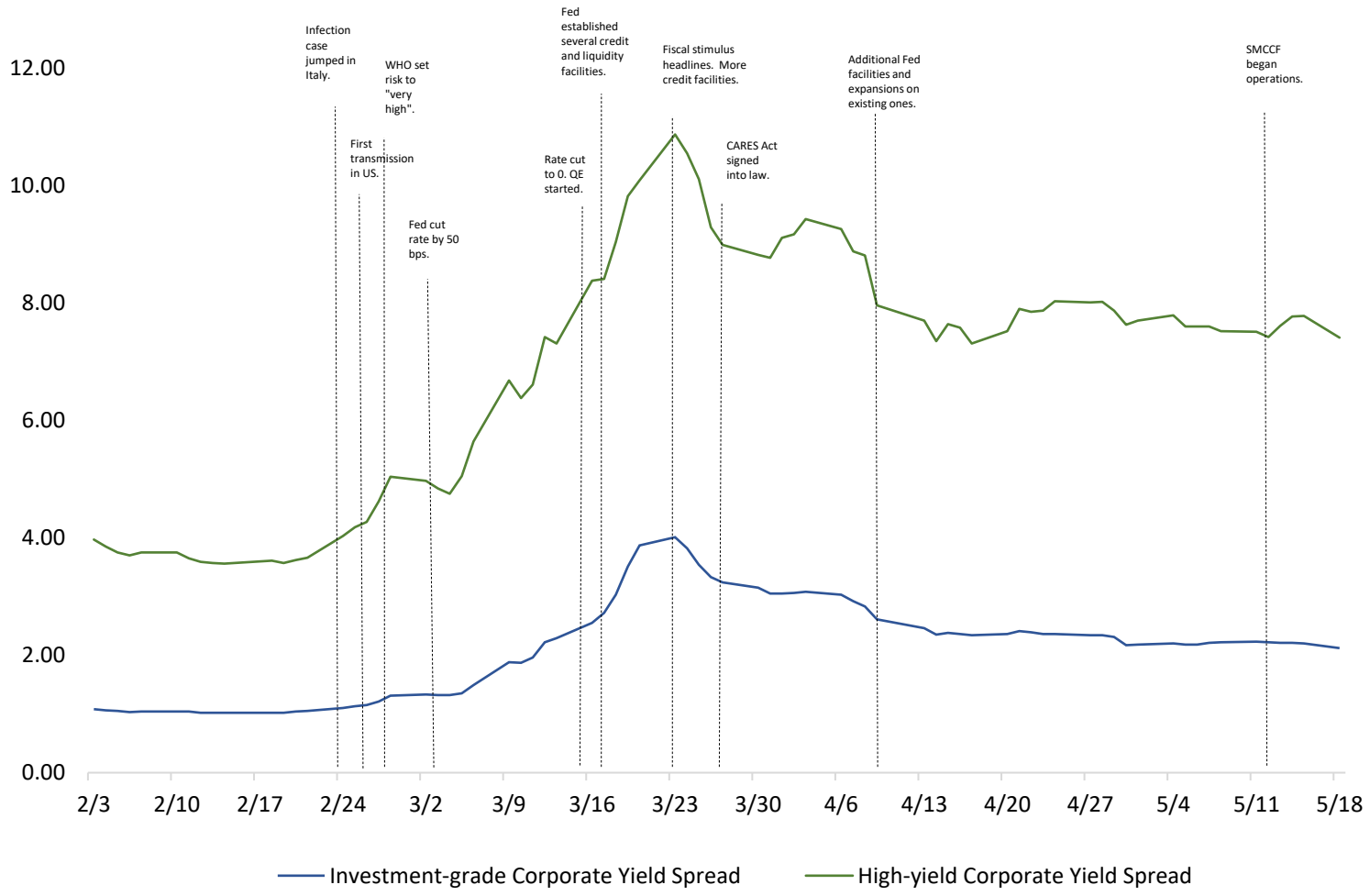
Figure 1: Timeline of the Covid-19 crisis evolution and macro policy responses

This figure shows movements in ICE BofA option-adjusted yield spreads for US investment-grade and high-yield bonds around the Covid-19 crisis period. Data are obtained through Federal Reserve Bank of St. Louis. The figure also presents the timeline of the Covid-19 pandemic and macro policy responses in the US.



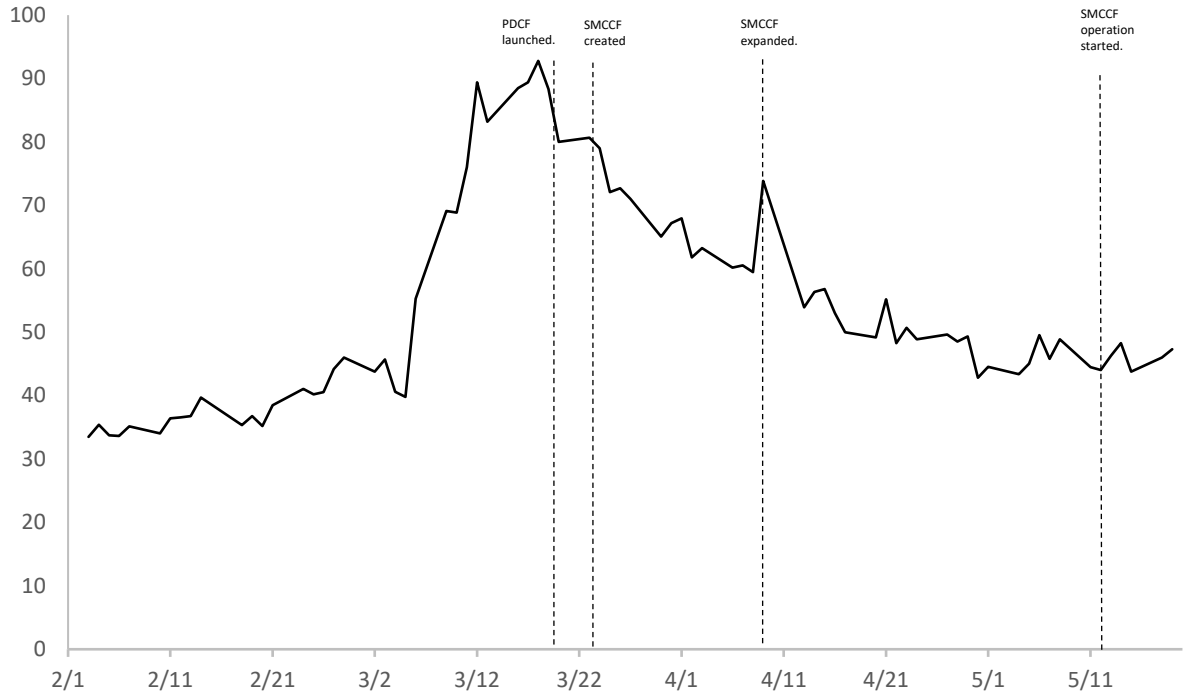
Date	Events
February 24	Confirmed cases in Italy jumped to more than 200 from just a few a couple of days ago.
February 26	The Centers for Disease Control and Prevention (CDC) confirmed first possible community transmission of coronavirus in US.
February 28	World Health Organization (WHO) raised coronavirus threat assessment to its highest level.
March 3	In response to the rapidly spreading virus, the Federal Open Market Committee (FOMC) made an emergency rate cut by half a percentage point, the biggest single cut since 2008.[15]
March 15	The Federal Open Market Committee (FOMC) cut the federal funds rate by a full percentage point to the effective zero bound. In addition, the Fed relaunched emergency measures from the 2007-2008 financial crisis, including restarting the quantitative easing (QE) program that will entail $700 billion worth of asset purchases entailing Treasuries and mortgage-backed securities (MBS).
March 17[16]	The Fed launched a number of credit and liquidity facilities, including the Commercial Paper Funding Facility (CPFF), the Primary Dealer Credit Facility (PDCF) and the Money Market Mutual Fund Liquidity Facility (MMLF).
March 23	The FOMC announced that the Fed is committed to purchasing Treasury securities and agency MBS "in the amounts needed." In addition, the Fed launched three new credit facilities to further mitigate the stress caused by the COVID-19 crisis: the Primary Market Corporate Credit Facility (PMCCF), the Secondary Market Corporate Credit Facility (SMCCF), and the Term Asset-Backed Securities Loan Facility (TALF). On the same day, Treasury Secretary Steven Mnuchin told CNBC that Democrats and Republicans are nearly in agreement on a congressional stimulus package.
March 27	$2 trillion coronavirus economic stimulus bill was passed in congress, and signed into law by President Trump.
April 9	The Fed established four new facilities: the Municipal Liquidity Facility (MLF), the Main Street New Loan Facility (MSNLF), the Main Street Expanded Loan Facility (MSELF) and the Paycheck Protection Program Lending Facility (PPPLF). In addition, the Fed expanded the size and scope of three existing facilities: PMCCF, SMCCF, and TALF. Together, the additional credit provided through these facilities totals $2.3 trillion.
May 12	SMCCF began purchases of exchange-traded funds (ETFs).

[15] On the same day, the G-7 released a statement noting that it would also take action to help the global economy meet the threat of coronavirus.
[16] Including events occurred between market close on March 17 and market open on March 18.

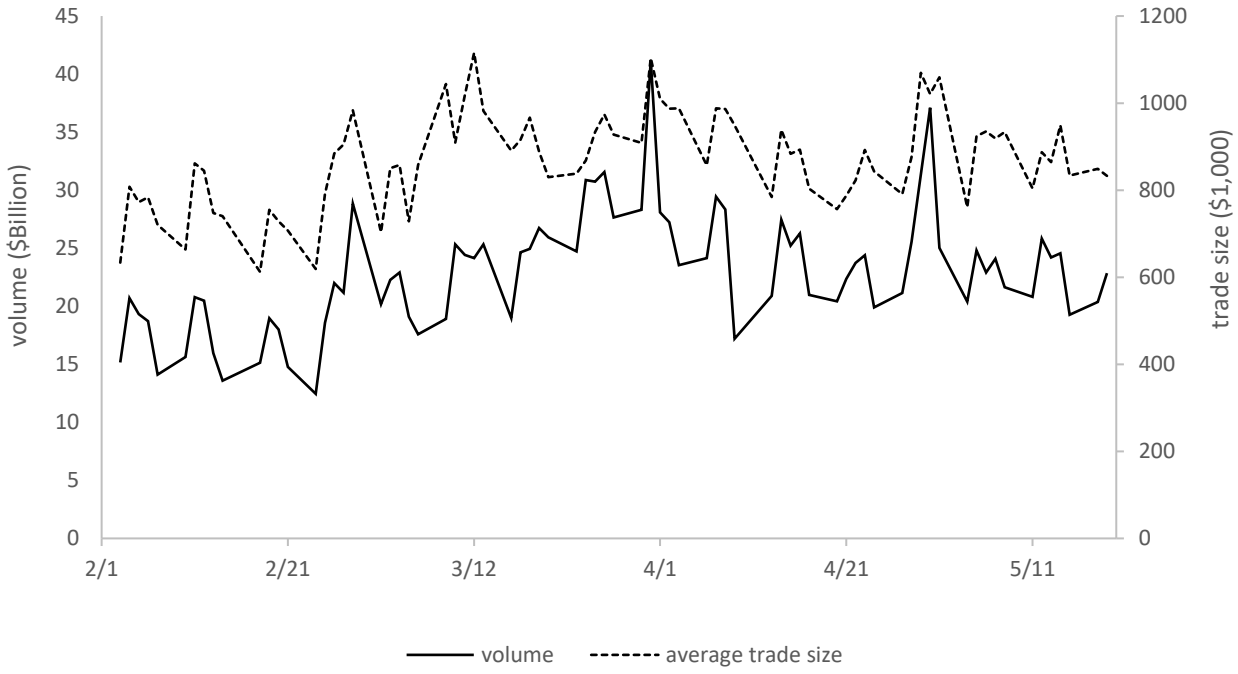
Figure 2: Corporate bond trading and Fed liquidity facilities

Panel A presents daily average transaction costs in corporate bonds. Transaction cost is calculated for each customer trade using Equation (1). The transaction level estimates are then averaged across trades and bonds within the day to obtain daily estimates for the market, which are plotted in Panel A. Panel B presents daily aggregate trade volume (in $ Billion) and average trade size (in $1,000). Panel C plots daily average transaction costs for investment-grade and high-yield bonds separately.

Panel A. Transaction costs



Panel B. Trade volume and average trade size



Panel C. Transaction costs in investment-grade and high-yield bond

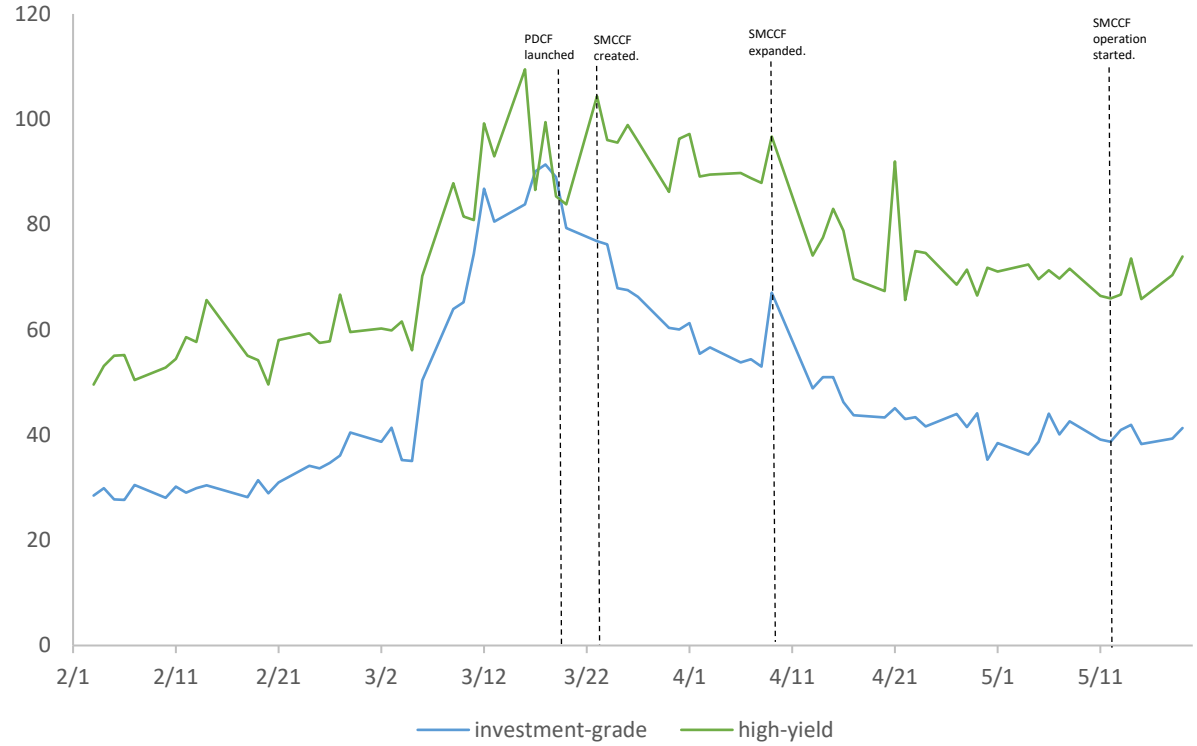
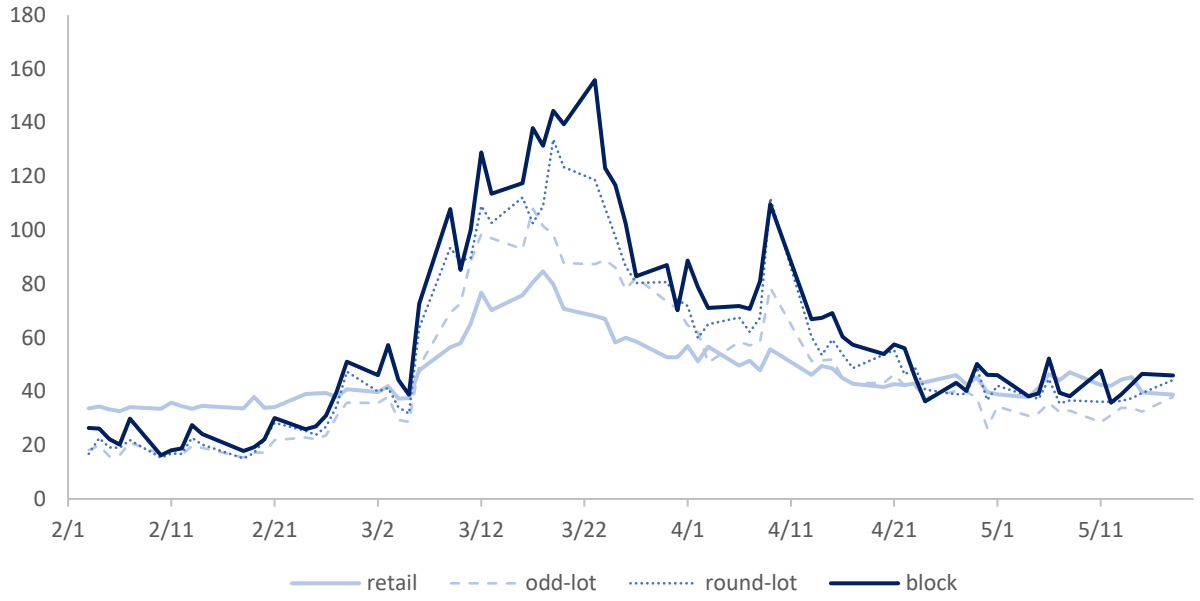


Figure 3: Transaction cost and trade size around the Covid-19 crisis

This figure presents the daily average transaction cost for trades with different sizes separately for investment-grade bonds (Panel A) and high-yield bonds (Panel B). Transaction cost is calculated for each customer trade using Equation (1). Trades are classified into four size categories based on their par amount: Micro ($1 to $100,000), Odd-lot ($100,000 to $1,000,000), Round-lot ($1,000,000 to $5,000,000), and Block (above $5,000,000).

Panel A. Investment-grade bonds



Panel B. High-yield bonds

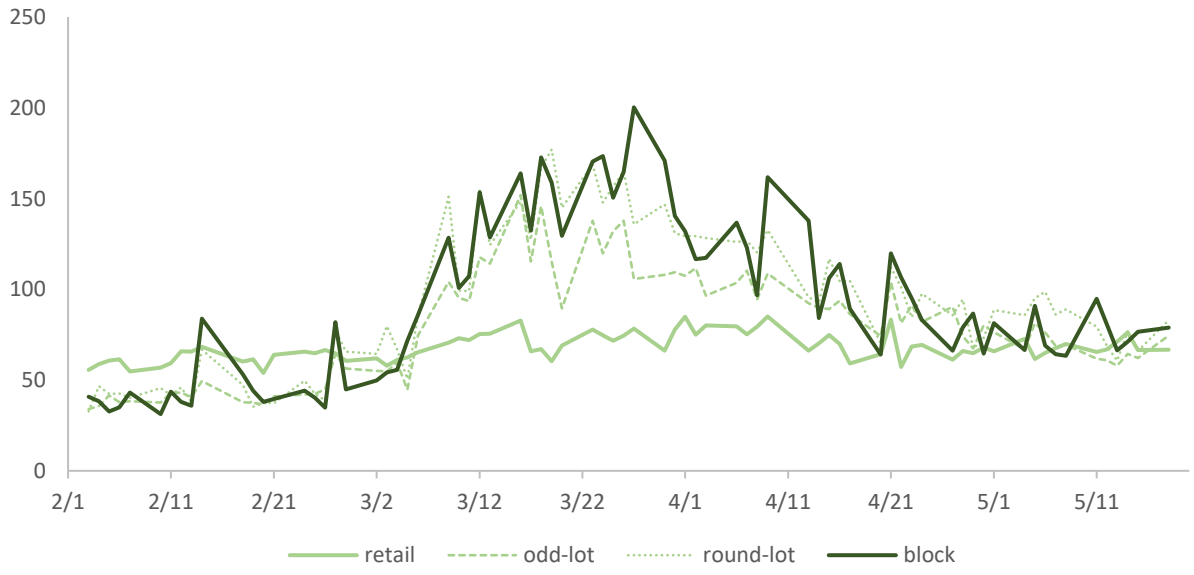
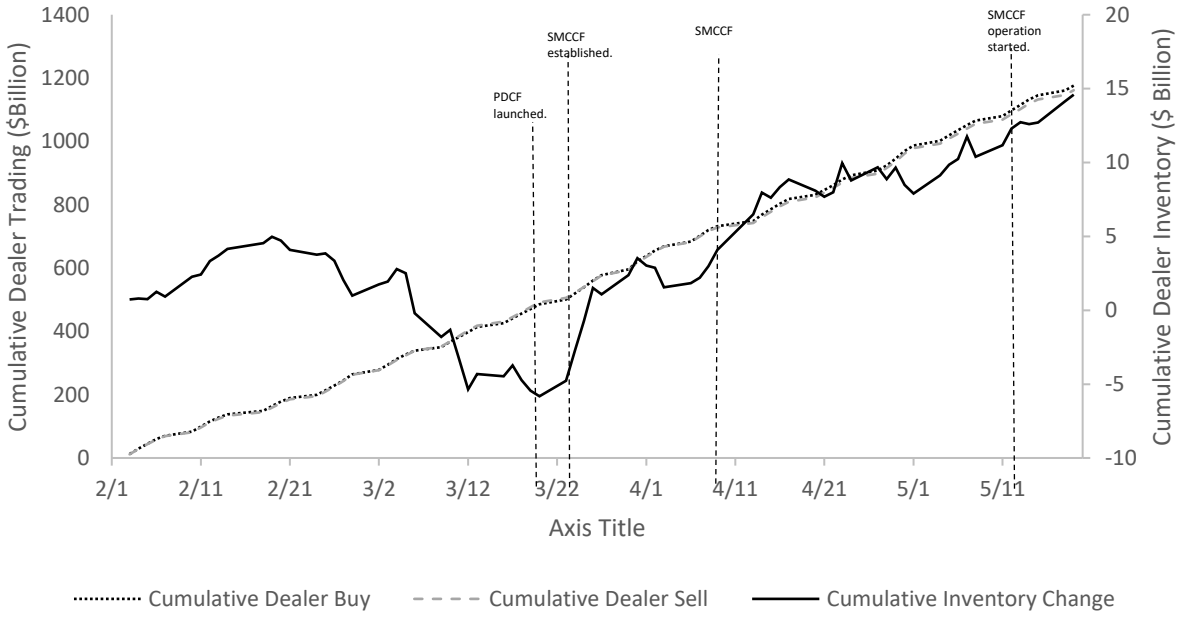


Figure 4: Dealer cumulative inventory changes around the Covid-19 crisis

Panel A presents bond dealers' aggregate cumulative buying from customers (*cumulative dealer buy*) and aggregate cumulative selling to customers (*cumulative dealer sell*), as well as cumulative inventory changes since Feb 1, 2020. *Cumulative inventory changes* are defined as *cumulative dealer buy* less *cumulative dealer sell*. Panel B plots *cumulative inventory changes* separately for prime dealers and other dealers.

Panel A. Dealer aggregate cumulative trading and cumulative inventory changes

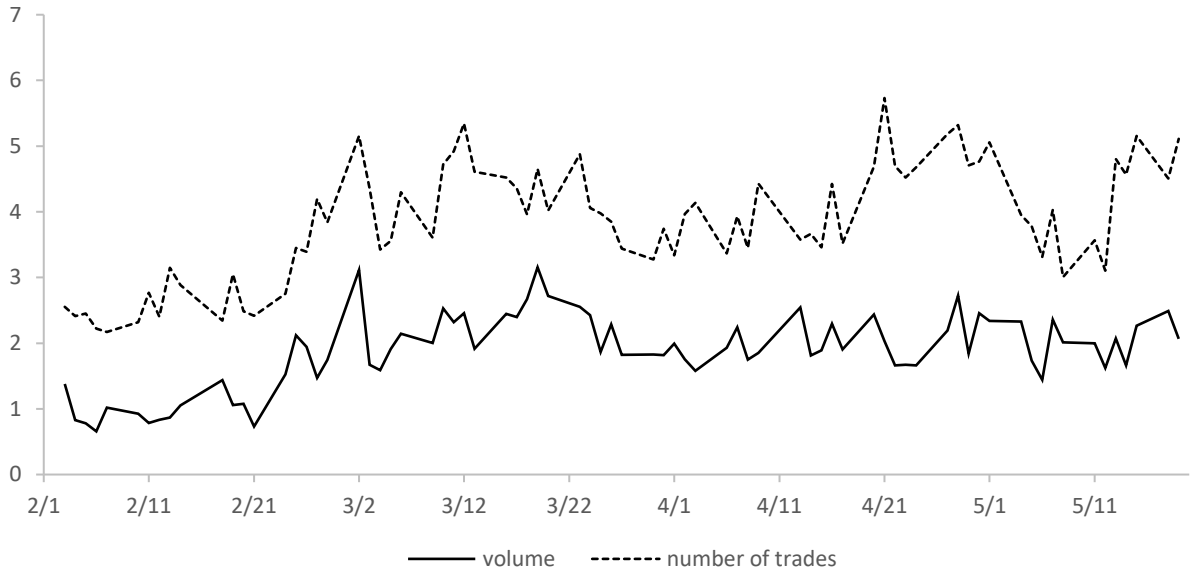


Panel B. Cumulative inventory changes for primary and other dealers

Figure 5: Customer-to-Customer trades

Panel A presents daily share of customer-to-customer (C-to-C) trades that are executed on electronic trading platforms out of total customer trades, both in terms of number of trades and total par amount traded. The list of electronic trading platforms is obtained from FINRA. Panel B presents the daily average trade size of customer-to-customer (C-to-C) trades and customer-to-dealer (C-to-D) trades.

Panel A. Market share of C-to-C trades (%)



Panel B. Average size of C-to-C and C-to-D trades ($1,000)

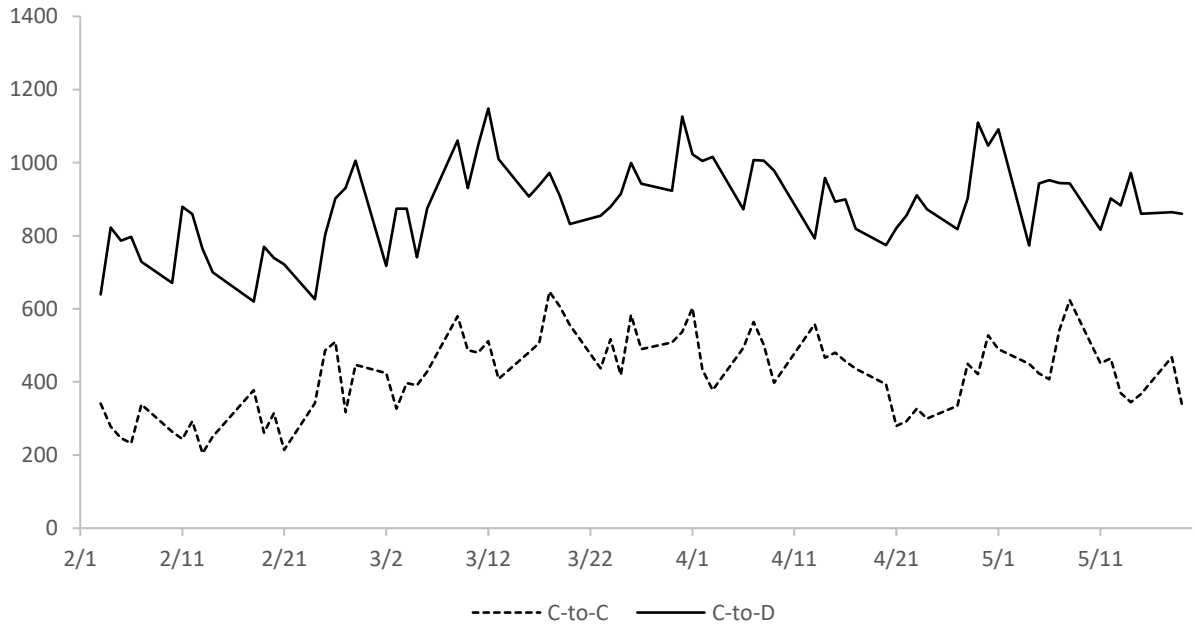


Figure 6: Transaction costs: C-to-C vs. C-to-D

This figure presents daily average transaction costs for C-to-C trades and C-to-D trades respectively. Transaction cost is calculated for each customer trade using Equation (1). For each of the two types for trades, the transaction level estimates are averaged across trades and bonds within the day to obtain daily estimates. As C-to-C trades are double counted in the data, we use only one record for each C-to-C trade in our sample.

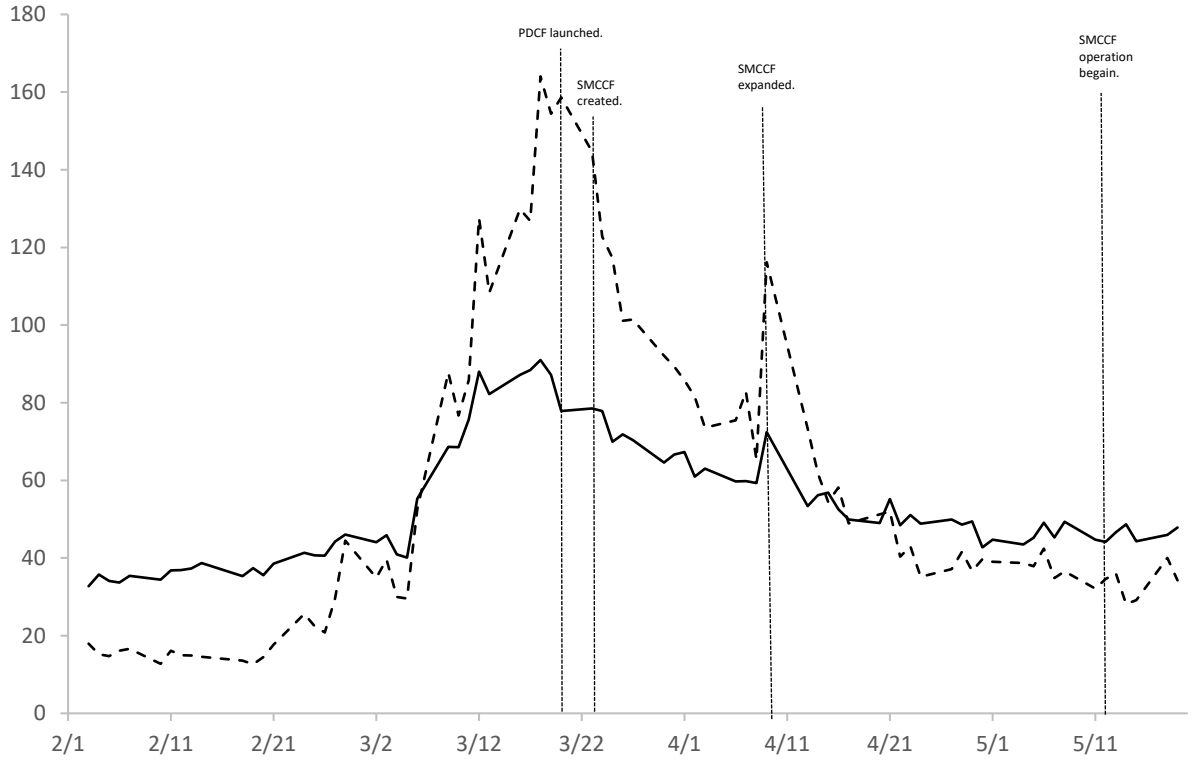


Table 1: Corporate bond trading costs around the Covid-19 crisis.

This table present results from estimating Equation (2) and its variants. Sample is from Febuary 1, 2020 to May 19, 2020. The dependent avariable is $Cost_j$, the transaction cost for trade j, estimated using Equation (1). $Crisis_t$ ($Regulation_t$) is a dummy that takes the value of one if the execution date (t) is March 6 (March 20) or after. $SMCCF\ Expansion_t$ takes the value of one if a trade occurred on or after April 9. *Log(Age)* and *Log(Time to Maturity*) refer to the log of number of years since issuance, and number of years to maturity respectively. *Credit Rating Fixed Effects* are based on each bond's composite rating. *Trade size Fixed Effects* are based on the four size categories (i.e., Micro, Odd-lot, Round-lot, and Block). Standard errors are clustered at bond and day levels.

	I	II	III	IV
Crisis	56.977***	58.652***	49.663***	49.057***
	(140.69)	(135.58)	(50.50)	(50.04)
Regulation	-23.555***	-25.858***	-13.042***	2.314**
	(-56.91)	(-58.74)	(-12.35)	(1.99)
SMCCF Expansion				-28.265***
				(-34.88)
Log(Time to Maturity)	49.845***	49.014***	52.098***	21.380***
	(38.77)	(36.85)	(12.97)	(5.79)
Log(Age)	-0.412	-0.787**	-1.469	2.535
	(-1.12)	(-2.21)	(-0.66)	(1.32)
Bond Fixed Effects	Yes	Yes	Yes	Yes
Credit Rating Fixed Effects	Yes	Yes	Yes	Yes
Dealer Fixed Effects	Yes	Yes	Yes	Yes
Trade Size Fixed Effects	Yes	Yes	Yes	Yes
Observations	1,224,923	966,286	258,637	258,637
R^2	0.29	0.29	0.30	0.31

Table 2: Liquidity and trading activities

This table presents results from estimating Equation (3) and its variants. Sample is from March 6, 2020 to March 19, 2020. For columns (I) and (II), the dependent variable is $Log(Volume_{i,normal})$, and for Columns III to V, the dependent variable is $Log(Volume_{i,crisis})$. $Volume_{i,normal}$ and $Volume_{i,crisis}$ represents bond *i*'s trade volume during the normal and the crisis periods respectively. $Cost_{i,normal}$ and $Cost_{i,crisis}$ represents bond i's average transaction costs during the normal and the crisis periods respectively. *Age* and *Time to Maturity* refer to the number of years since issuance, and the number of years to maturity respectively. *Amount Outstanding* refers to the total par amount outstanding of bond *i*. *Credit Rating Fixed Effects* are based on each bond's composite rating. *Industry Fixed Effects* are based on each bond's two-digit industry code from FISD. Standard errors are clustered at firm level.

	I	II	III	IV	V
$Cost_{normal}$	-0.024***	-0.001			-0.005***
	(-10.48)	(-1.05)			(-5.78)
$Cost_{crisis}$			0.007***	0.004***	0.003***
			(8.99)	(8.76)	(7.11)
Log(Time to Maturity)	0.176***	0.060***	-0.339***	-0.181***	-0.138***
	(4.39)	(2.69)	(-8.36)	(-8.38)	(-6.94)
Log(Age)	-0.682***	-0.579***	-0.935***	-0.688***	-0.251***
	(-12.30)	(-22.64)	(-14.09)	(-21.85)	(-10.58)
Log(Amount Outstanding)		1.251***		1.246***	0.418***
		(51.17)		(44.17)	(15.10)
$Log(Volume_{normal})$					0.639***
					(36.32)
Rating Fixed Effects	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	7308	7308	7308	7308	7308
R^2	0.32	0.35	0.11	0.12	0.76

Table 3: Dealer inventory changes around the Covid-19 crisis

This table presents the results from estimating Equation (4), its variant, and Equation (5). For Columns (I) and (II), sample is from from Febuary 1, 2020 to May 19, 2020. For Column (III), sample is from March 6, 2020 to May 11, 2020. The dependent variable is $Inv\ Chg_{d,t,r}$, defined as the difference between dealer d's net purchase and its net sales in a broad rating category r (i.e., investment-grade or high-yield) on day t. $Crisis_t$ ($Regulation_t$) is a dummy that takes the value of one if date (t) is March 6 (March 20) or after. $SMCCF\ Expansion_t$ takes the value of one if date (t) is April 9 or after. $SMCCF\ Implementation_t$ takes the value of one if date (t) is May 12 or after. IG_t is a dummy for investment-grade bonds. $Primary\ Dealer_t$ takes the value one if a dealer is a primary dealer. *Log(Age)* and *Log(Time to Maturity*) refer to the log of number of years since issuance, and number of years to maturity respectively. *Trade Size Effects* are based on the four size categories (i.e., Micro, Odd-lot, Round-lot, and Block). Standard errors are clustered at dealer and day levels.

	I	II	III
Crisis	-1.835**	-1.834**	
	(-2.46)	(-2.46)	
Regulation	2.551**	2.893**	
	(2.44)	(2.33)	
SMCCF Expansion		-0.613	
		(-1.34)	
SMCCF Implementation		0.362	
		(0.82)	
IG*Prime Dealer			-8.576
			(-1.38)
IG*Regulation			-0.15
			(-0.36)
Prime Dealer*Regulation			-1.419
			(-0.91)
IG*Prime Dealer*Regulation			14.225**
			(2.02)
Dealer Fixed Effects	Yes	Yes	Yes
Day Fixed Effects	Yes	Yes	Yes
Rating Category Fixed Effects	Yes	Yes	Yes
Observations	38,541	38,541	23,641
R^2	0.01	0.01	0.02

Table 4: Dealer inventory and transaction costs

This table presents results from estimating Equation (6) and its variants. Sample is from Febuary 1, 2020 to May 19, 2020. The dependent avariable is $Cost_j$, the transaction cost for trade j, estimated using Equation (1). $Dealer\ Net\ Buy_{i,t-1}$ is the net buying across all dealers for bond i on day $t-1$. $Cum\ Dealer\ Net\ Buy_{i,t-1}$ is the accumulation of the daily net dealer buying since the beginning of February. $Crisis_t$ ($Regulation_t$) is a dummy that takes the value of one if the execution date (t) is March 6 (March 20) or after. *Log(Age)* and *Log(Time to Maturity*) refer to the log of number of years since issuance, and number of years to maturity respectively. *Credit Rating Fixed Effects* are based on each bond's composite rating. *Trade Size Effects* are based on the four size categories (i.e., Micro, Odd-lot, Round-lot, and Block). Standard errors are clustered at bond and day levels.

	I	II	III
Dealer Net Buy	-0.025***		
	(-4.19)		
Cum Dealer Net Buy		-0.068***	0.016
		(-4.98)	(0.71)
Crisis* Cum Dealer Net Buy			-0.064***
			(-3.43)
Regulation*Cum Dealer Net Buy			0.053***
			(3.01)
Log(Time to Maturity)	11.596***	11.577***	11.589***
	-11.48	-11.45	-11.46
Log(Age)	6.789***	6.720***	6.689***
	-19.96	-20.18	-20.09
Bond Fixed Effects	Yes	Yes	Yes
Credit Rating Fixed Effects	Yes	Yes	Yes
Dealer Fixed Effects	Yes	Yes	Yes
Trade Size Fixed Effects	Yes	Yes	Yes
Day Fixed Effects	Yes	Yes	Yes
Observations	1,224,923	1,224,923	1,224,923
R^2	0.32	0.32	0.32

Table 5: Bond and trade characteristics: Customer-to-Customer vs. Customer-to-Dealer

This table presents summary information on both bond and trade characteristics for both C-to-C and C-to-D trades across the three sub-periods in our sample: normal period (February 1 – March 5), crisis period (March 6 – March 19), and regulation period (March 20 – May 19). *Amount Outstanding* is a bond total par amount outstanding at the time of trade. *Credit Rating* is the composite rating we assigned based on the ratings that each bond receives from S&P, Moody's, and Fitch. *Time to Maturity* and *Age* refer to the number of years to maturity and the number of years since issuance respectively. *Trade Size* is the par amount traded. *Transaction Cost* is estimated using Equation (1).

	Customer-to-Customer			**Customer-to-Dealer**		
	Normal	**Crisis**	**Regulation**	**Normal**	**Crisis**	**Regulation**
Amount Outstanding ($M)	1,425	1,486	1,476	1,212	1,321	1,253
Credit Rating	8	8	8	9	8	8
Time to Maturity (Year)	7	7	7	9	8	8
Age (Year)	4	4	4	5	5	4
Trade Size ($1,000)	342	517	442	786	959	925
Transaction Cost (bps)	24	117	60	39	80	55

Table 6: Transaction costs in Customer-to-Customer trades and market liquidity

This table presents results from estimating Equation (7) and its variants. Sample is from Febuary 2, 2020 to May 19, 2020. The dependent avariable is $Cost_j$, the transaction cost for trade j, estimated using Equation (1). $CtoC_j$ is a dummy for C-to-C trades. $Crisis_t$ ($Regulation_t$) is a dummy that takes the value of one if the execution date (t) is March 6 (March 20) or after. $SMCCF\ Expansion_t$ takes the value of one if a trade occurred on or after April 9. *Log(Age)* and *Log(Time to Maturity*) refer to the log of number of years since issuance, and number of years to maturity respectively. *Credit Rating Fixed Effects* are based on each bond's composite rating. *Trade Size Effects* are based on the four size categories (i.e., Micro, Odd-lot, Round-lot, and Block). Standard errors are clustered at bond and day levels.

	I	II	III	IV	V
C-to-C	-4.495***	-5.247***	-5.656***	-2.823	-2.823
	(-10.32)	(-10.43)	(-12.25)	(-1.31)	(-1.31)
C-to-C*Crisis	48.940***	41.826***	40.445***	48.949***	48.949***
	(26.03)	(18.16)	(16.55)	(7.43)	(7.43)
C-to-C*Regulation	-30.932***	-26.954***	-26.949***	-20.805***	-7.953
	(-16.16)	(-11.54)	(-10.90)	(-2.95)	(-0.88)
C-to-C*SMCCF Expansion					-21.331***
					(-2.89)
Log(Time to Maturity)	16.216***				
	(17.03)				
Log(Age)	5.962***				
	(17.87)				
Bond Fixed Effects	Yes	No	No	No	No
Credit Rating Fixed Effects	Yes	No	No	No	No
Trade Size Fixed Effects	Yes	No	No	No	No
Day Fixed Effects	Yes	No	No	No	No
Bond-Day-Trade Size Fixed Effects	No	Yes	Yes	Yes	Yes
Observations	1,224,923	966,286	751,811	214,475	214,475
R^2	0.19	0.51	0.52	0.46	0.46

Table 7: The effects of SMCCF and PDCF on bond liquidity in the crisis period

This table presents results from estimating Equation (8), Equation (9) and their variants. The dependent avariable is $Cost_j$, the transaction cost for trade j, estimated using Equation (1). $Regulation_t$ is a dummy that takes the value of one if the execution date (t) is March 20 or after. IG_t takes the value of one if trade j occurred in a bond rated investment-grade. $Primary\ Dealer_t$ takes the value one if trade j was executed with a primary dealer. $Short\ Term_t$ takes the value one if trade j was in a bond with remaining maturity of 5 years or less. *Log(Age)* and *Log(Time to Maturity*) refer to the log of number of years since issuance, and number of years to maturity respectively. *Credit Rating Fixed Effects* are based on each bond's composite rating. *Trade Size Effects* are based on the four size categories (i.e., Micro, Odd-lot, Round-lot, and Block). Standard errors are clustered at bond and day levels.

	I	II	III	IV	V	VI	VII	VIII
IG*Regulation	-5.181***	-2.44	13.089***	6.261	0.779	0.112	10.642	6.074
	(-2.70)	(-1.26)	(4.74)	(1.35)	(0.20)	(0.04)	(1.26)	(0.85)
IG*Primary Dealer		-9.289***	-12.918***	7.498	-1.669			
		(-3.02)	(-2.59)	(1.11)	(-0.49)			
Primary Dealer*Regulation		-1.741	9.956*	4.409	7.953			
		(-0.44)	(1.72)	(0.62)	(1.27)			
IG*Primary Dealer*Regulation		-10.420**	-5.44	-16.380*	-13.315*			
		(-2.50)	(-0.88)	(-1.85)	(-1.86)			
Short Term						-19.586	-57.533**	-12.138
						(-1.34)	(-1.99)	(-1.23)
Short Term * Regulation						7.348**	14.333	7.58
						(2.05)	(1.33)	(0.83)
IG*Short Term						12.77	52.304*	16.387
						(1.10)	(1.66)	(1.50)
IG*Short Term*Regulation						-9.367**	-21.234*	-16.631*
						(-2.45)	(-1.80)	(-1.67)
Log(Time to Maturity)	-6.24	-3.895	51.374*	-25.037	25.970***	-8.57		
	(-0.68)	(-0.43)	(1.79)	(-1.45)	(3.56)	(-0.91)		
Log(Age)	37.103***	38.371***	71.333***	46.951	331.635***	37.279***	54.28	307.021***
	(8.56)	(8.84)	(7.66)	(1.37)	(6.17)	(8.35)	(0.16)	(3.62)
Bond Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Credit Rating Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Dealer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Trade Size Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Day Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	178,581	178,581	62,299	20,565	54,014	178,581	13,598	33,113
R^2	0.36	0.37	0.42	0.39	0.34	0.36	0.32	0.31

Table 8: The effects of SMCCF expansion and implementation on bond liquidity

This table presents results from estimating Equations (10)-(12) and their variants. For Columns (I)-(III), sample is from April 2, 2020 to April 15, 2020. For Columns (IV)-(VI), sample is from May 5, 2020 to May 18, 2020. The dependent avariable is $Cost_j$, the transaction cost for trade j, estimated using Equation (1). $SMCCF\ Expansion_t$ takes the value of one if a trade occurred or or after April 9. HY_t takes the value of one if trade j occurred in a bond rated high-yield. $Fallen\ Angel_t$ refers to BB-/Ba3 rated bonds that were downgraded from investment-grade after March 22. $Short\ Term_t$ takes the value one if trade j was in a bond with remaining maturity of 5 years or less. $SMCCF\ Implementation_t$ takes the value of one if a trade occurs on or after May 12. $Primary\ Dealer_t$ takes the value one if trade j was executed with a primary dealer. *Log(Age)* and *Log(Time to Maturity*) refer to the log of number of years since issuance, and number of years to maturity respectively. *Credit Rating Fixed Effects* are based on each bond's composite rating. *Trade Size Effects* are based on the four size categories (i.e., Micro, Odd-lot, Round-lot, and Block). Standard errors are clustered at bond and day levels.

	I	II	III	IV	V	VI
SMCCF Expansion	-8.529***					
	(-17.85)					
HY*SMCCF Expansion		-4.020***				
		(-2.74)				
Fallen Angel*SMCCF Expansion			-2.052			
			(-0.41)			
Short Term			-6.24			
			(-1.52)			
Fallen Angel*Short Term			-6.159			
			(-0.28)			
SMCCF Expansion*Short Term			2.183**			
			(2.34)			
Fallen Angel*Short Term*SMCCF Expansion			-0.845			
			(-0.11)			
SMCCF Implementation				-1.022***		
				(-2.91)		
SMCCF Implementation*Prime Dealer					-1.345**	-2.702***
					(-2.01)	(-3.67)
Log(Time to Maturity)	-11.458**	-22.146***	-16.930***	-15.029	-9.577	-8.826

	(-2.05)	(-3.64)	(-2.92)	(-1.59)	(-0.98)	(-0.90)
Log(Age)	12.907***	13.731***	14.812***	8.951***	8.799***	8.930***
	(10.34)	(10.93)	(11.44)	(10.64)	(10.29)	(10.43)
Bond Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Credit Rating Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Dealer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Trade Size Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Day Fixed Effects	No	Yes	Yes	No	Yes	Yes
Observations	158,129	158,129	158,129	156,816	156,816	156,816
R^2	0.38	0.38	0.38	0.45	0.45	0.45