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Abstract

When market disruptions started in March 2020, dealers maintained the usual liquidity provision in the agency MBS market by taking cash inventory and hedging inventory risk with forward contracts. However, cash and forward prices significantly diverged and began to converge only after the Federal Reserve deployed nonstandard purchase operations to promptly take MBS off dealers' balance sheets. Further cross-dealer analyses point to supplemental leverage ratio requirements as major constraints on dealers' balance sheets. Customers' selling increased when price divergence reverted, inconsistent with conjectures of some studies. Comparisons with corporate bond markets uncover additional dealer frictions.

Key words: arbitrage, cash, dealer, liquidity, MBS, specified pool, TBA

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1 Introduction

"*Asset purchases are a standard tool of monetary policy implementation. Traditionally, the Desk has used Treasury purchases to maintain the supply of reserves... Following the Global Financial Crisis, the FOMC used asset purchases primarily to exert downward pressure on longer-term interest rates, or in the case of MBS to ease mortgage rates ... The purchases during this most recent episode have been distinct in both their purpose,* ***to address disruptions in market functioning****, and their scale and speed, which have been unparalleled.*"

— Lorie Logan, Executive Vice President of the Federal Reserve Bank of New York, Remarks at SIFMA Webinar on July 15, 2020.

The COVID-19 pandemic caused substantial disruptions in the functioning of most U.S. fixed-income markets, including corporate bonds, municipal bonds, mortgage-backed securities (MBS), and even Treasury bonds. While investors reportedly sold bonds to scramble for cash,[1] broker-dealers, as the important liquidity providers in these over-the-counter (OTC) markets, seemed to fall short of providing liquidity and containing the market turmoil. In consequence, liquidity dried up abruptly and prices of securities with similar fundamentals diverged substantially in early March. To restore market functioning, the Federal Reserve (Fed) deployed a variety of policy operations quickly; the market stabilized towards the end of March.

Why were dealers unable to provide (enough) liquidity? Through which economic channels did the Fed restore market functioning? Answering these questions is important not only for understanding the COVID-19 market disruptions *per se* but also for the evaluation and design of the Fed's new "dealer of last resort" policy—using asset purchases to address market functioning problems—as outlined in the quote above. A few contemporaneous studies have conducted informative analyses in various markets.[2] However, because market disruptions and

[1] See https://www.wsj.com/articles/short-term-yields-go-negative-in-scramble-for-cash-11585227369.

[2] These include Duffie (2020), Schrimpf, Shin, and Sushko (2020), He, Nagel, and Song (2021), Haddad, Moreira, and Muir (2020), Kargar, Lester, Lindsay, Liu, Weill, and Zuniga (2020), O'Hara and Zhou (2021), and Ma, Xiao, and Zeng (2022), among others. The literature expanded largely later; see Kruttli, Monin, Petrasek, and Watugala (2021), Falato, Goldstein, and Hortacsu (2020), Vissing-Jorgensen (2020), D'Amico, Kurakula, and Lee (2020), Boyarchenko,

Fed interventions occurred quickly in a short period of time, it is challenging to isolate the effects of different economic forces; hence, no consensus has been reached on what were the key forces in the literature. For example, Duffie (2020) and He et al. (2021) explain dealers' inability to provide liquidity based on the supplemental leverage ratio (SLR) requirements of Basel III, whereas Haddad et al. (2020) and Vissing-Jorgensen (2020) cast doubts on the importance of dealer frictions and conjecture that investor selling pressure is the key channel through which the Fed restored market functioning.

In this paper, we contribute novel facts and analyses to improve our understanding of these issues, focusing on the agency MBS market that is one of the largest fixed-income markets in the US.[3] The novelty of our results derives from the granularity of available data and unique features of Fed interventions in the agency MBS market. Specifically, we use the supervisory version of the Trade Reporting and Compliance Engine (TRACE) database that includes agency MBS transactions with dealer identifiers. We hence can examine relatively high-frequency (daily in particular) changes of not only prices but also *quantities* during COVID-19 market disruptions; most previous studies examine weekly changes of quantities at best. Furthermore, unlike in Treasury and corporate bond markets, the Fed conducted agency MBS purchases using both standard forward contracts that settle on a monthly cycle and nonstandard forward contracts that settle almost on the spot. Comparing the effects of these two types of purchases reveals the severity of dealers' balance sheet constraints directly.

We start our analysis by constructing empirical measures of the price and quantity aspects of dealers' liquidity provision. In the agency MBS market, dealers provide liquidity by taking cash inventory and hedging inventory risk with forward contracts. Accordingly, we consider the cash and forward price wedge, which would arise if dealers face either funding or balance sheet constraints (inventory risk is netted out); this is similar to the cash-futures basis of Trea-

Kovner, and Shachar (2020), and Li, O'Hara, and Zhou (2021), among others. O'Hara and Zhou (2023) and Pence (2022) provide two recent surveys.

[3]The aggregate outstanding balance of agency MBS is about $8.8 trillion as of December 2019, according to the Securities Industry and Financial Markets Association (SIFMA). For comparison, the outstanding balances of corporate bonds and Treasury securities are about $8.9 and $16.7 trillion, respectively.

sury securities and Credit Default Swap(CDS)-bond basis of corporate bonds (Fleckenstein and Longstaff, 2020; Bai and Collin-Dufresne, 2019).[4] The TRACE data cover both cash and forward contracts of agency MBS, known as specified pool (SP) and to-be-announced (TBA) contracts, respectively (Gao, Schultz, and Song, 2017). We hence compute the *price* difference between TBA and SP contracts,[5] which we denote by the forward-cash basis; it would increase when dealers are constrained from taking the MBS that investors sell in the cash market.[6] To measure quantities, we separate dealers' trades with the Fed from those with non-Fed customers by combining the TRACE data with the Fed purchase data. We then compute dealers' daily net purchase amounts in cash and forward markets with the Fed and non-Fed customers separately.[7]

Using these measures, we analyze changes of dealers' liquidity provision in narrow windows around important event dates in the COVID-19 crisis, which allows us to separate the effects of the Fed's different interventions. We first consider March 9 that is widely taken as the start of COVID-19 market disruptions (Duffie, 2020; O'Hara and Zhou, 2021). We find that dealers maintained liquidity provision by purchasing cash MBS and selling forward contracts after March 9, and the amount of their liquidity provision shortly after March 9 remained the same as before March 9. Yet, the forward-cash basis increased significantly in the one-day window (from March 8 to 9) by about 60 cents per $100 face value. Together, these findings imply that when market disruptions started, dealers were constrained from *increasing* their liquidity

[4] In studying the cash and forward price divergence, our paper adds to the literature of fixed-income arbitrage strategies, including Duarte, Longstaff, and Yu. (2007), Fleckenstein, Longstaff, and Lustig (2014), Klingler and Sundaresan (2019), Jermann (2019), Du, Tepper, and Verdelhan (2018), and Boyarchenko, Eisenbach, Gupta, Shachar, and Tassel (2018) among others. To the best of our knowledge, we provide the first analysis of cash-forward arbitrage in the agency MBS market.

[5] We adjust the raw price difference for TBA and SP contracts' differential (spot versus forward) settlement schedules and for the "cheapest-to-deliver" feature of TBA contracts; see Appendix B for details. Moreover, we measure the forward-cash basis in *price* instead of *yield* because converting agency MBS prices into yields requires a prepayment model, which could be misspecified and introduce errors (Chernov, Dunn, and Longstaff, 2017).

[6] The forward-cash basis can also decrease when demand for holding agency MBS increases, e.g., when the liquidity coverage ratio (LCR) regulation prompted banks to increase their holdings of agency MBS substantially since 2016 (He and Song, 2022). Indeed, we find that the forward-cash basis decreased from about −10 cents (per $100 par) on average before 2016 to about −100 cents shortly before the COVID-19 crisis. Against this background, the increase of the forward-cash basis from very negative levels that we document in the COVID-19 crisis indicates "a disappearance of the safety attribute" of agency MBS as safe assets (Vissing-Jorgensen, 2020).

[7] Note that only Primary Dealers can trade with the Fed directly. As we mainly focus on the liquidity provision by all dealers in aggregate, we do not differentiate between Primary Dealers and other dealers throughout the paper, unless it is necessary.

provision so that MBS cash prices fell significantly below forward prices.

We then examine the effects of the Fed's different interventions, which are related to different economic drivers of dealers' constraints. First, on March 12 and 17, the Fed provided funding support to Primary Dealers, which would alleviate their funding constraints directly. Second, on March 16, the Fed began to purchase agency MBS through *standard* forward contracts that settle on a monthly cycle. Such purchases shorten the length of time for which dealers need to carry cash MBS on their balance sheet to less than a month. Third, on March 19, the Fed began to purchase MBS through *nonstandard* forward contracts that settle in three days (as early as the afternoon of March 23). Such t+3 forward purchases promptly take MBS off dealers' balance sheet, reducing the inventory-carrying time to less than three days.

We examine how the quantity and price measures respond to these different interventions, by which we infer the importance of dealers' different constraints. First, we find that dealers began to increase their daily net cash purchase amount (to about $15 billion) when the Fed established the PDCF on March 17; yet, the forward-cash basis continued to widen. Hence, funding constraints were unlikely the most severe constraints on dealers. Second, we find that after the Fed started t+3 forward purchases on March 19, dealers kept buying $15 billion cash MBS per day and immediately turned these MBS around to the Fed through its t+3 forward purchases on the same day. Most importantly, the forward-cash basis decreased on March 19 and kept decreasing since the first settlement of the t+3 forward purchases. In contrast, when the Fed started standard forward purchases on March 16, neither dealers' cash purchases increased nor the widening of the forward-cash basis reverted. Therefore, balance sheet constraints were likely the most severe constraints on dealers.

Given the major role played by balance sheet constraints, we conduct two further analyses to understand the economic drivers of dealers' balance sheet constraints.

First, the SLR requirements introduced after the 2008 crisis are often cited as essential constraints on dealers' balance sheets in markets of liquid and safe assets (Duffie, 2018). Using the available dealer identities in the supervisory TRACE data, we divide dealers into the group asso-

ciated with the eight US-domiciled global systemically important banks (GSIBs) subject to the enhanced SLR requirements and the group of all other dealers. We find that (1) before the Fed set up the PDCF, GSIBs dealers decreased their net cash purchases while other dealers increased their net cash purchases, and (2) after the Fed began its t+3 forward purchases, GSIBs dealers offloaded a much higher amount of cash MBS through the Fed's t+3 purchases than other dealers. Both cross-dealer patterns point to SLR requirements as significant balance sheet constraints.

Second, we provide evidence regarding the importance of dealers' frictions versus customers' selling pressure. In particular, because of the strong effects of purchase announcements in the corporate bond market, Haddad et al. (2020) and Vissing-Jorgensen (2020) conjecture that the Fed contained market disruptions not by mitigating dealers' constraints but by reducing customers' selling. Using the TRACE data, we compute customers' gross and net cash selling cash amounts of agency MBS (customers' net selling amounts are equal to dealers' net purchase amounts). We find that customers' gross and net cash selling amounts both *increased* when price divergence began to revert on March 19, opposite to a reduction in customers' selling. Therefore, the Fed restored market functioning mainly by mitigating dealer frictions.[8]

The COVID-19 market disruptions took effect for various fixed-income securities, but distinct features of different markets make it challenging to analyze them all at once. That being said, in an additional analysis, we compare dealers' liquidity provision in the agency MBS and corporate bond markets to garner a further understanding. We measure the price dislocation of corporate bonds using the CDS-Bond basis and also compute dealers' daily net cash purchase amount of corporate bonds using the TRACE data of corporate bond transactions.[9] We find that dealers reduced their net cash purchase amount of corporate bonds when market disruptions started (O'Hara and Zhou, 2021; Kargar et al., 2020), in contrast to their maintaining of liquid-

[8]This finding demonstrates the importance of examining high-frequency changes in quantities for understanding a liquidity crisis; Haddad et al. (2020) did not check quantity measures while Vissing-Jorgensen (2020) examined weekly measures of quantities, likely because of data limitations when their analyses were done. We also note that we do not argue against the potential effects of Fed interventions on customers' selling. Rather, our point is that customers' selling did not weaken but strengthened *around the time* when price divergence reverted.

[9]Unfortunately, we do not have measures of dealers' CDS purchase amounts because of restrictive data access; see Section 3.1 for detailed discussions.

ity provision in the agency MBS market. Further, the widening of the CDS-Bond basis began to revert mainly from March 23 when the Fed *announced* corporate bond purchases and long before the actual purchases started on May 12 (Haddad et al., 2020); this is also in contrast to the agency MBS market where the widening of forward-cash basis began to revert only after the Fed *promptly took* MBS off dealers' balance sheets.

These two contrasting patterns indicate that in addition to SLR-related balance sheet constraints (which had been relaxed by Fed purchases before March 23 based on the findings on agency MBS), other frictions were also constraining dealers in the corporate bond market. One such type of dealer frictions is fragile dealer coordination theoretically analyzed in Yang and Zeng (2021), under which the market can switch between the equilibrium with high coordination of dealers in their liquidity provision and the equilibrium with low coordination. Specifically, the lack of liquidity provision by dealers for corporate bonds when market disruptions started is consistent with the low-coordination equilibrium, while the restoring of market functioning after the Fed's purchase announcements is consistent with a switching to the high-coordination equilibrium prompted by the change in the expectation of future Fed purchases. Note that corporate bond purchases had never occurred before, so the expectation of Fed purchases of corporate bonds was likely negligible before March 23. In contrast, agency MBS purchases have been regularly conducted by the Fed since 2008, so the expectation of Fed purchases of agency MBS was likely high in the very beginning of market disruptions; hence, lack of dealer coordination is unlikely the major channel behind agency MBS market disruptions.

In addition to the above contrasting patterns, we also document common patterns of dealers' liquidity provision across agency MBS and corporate bond markets. For example, in both markets, dealers began to increase their net cash purchases when the PDCF was introduced but price dislocations continued to worsen; such findings confirm that funding constraints were not the most severe frictions. Importantly, we find that customers' (gross and net) cash selling amounts of corporate bonds also *increased* when price divergence began to revert on March 23, confirming the central role of dealer frictions as opposed to customer selling pressure.

2 Institutional Background and Economic Framework

In this section, we first describe the agency MBS market briefly. We then discuss dealers' strategy of liquidity provision and the economic channels of price dislocation. Finally, we provide an overview of COVID-19 market disruptions, focusing on how the Fed's different interventions could mitigate price dislocation and restore market functioning.

2.1 Agency MBS Market

The market of agency MBS provides a major fraction of the funding for residential mortgages in the US. Specifically, as of the third quarter of 2020, 63% of the $11.5 trillion outstanding residential mortgage debt is securitized into agency MBS.[10] Most agency MBS are issued as pass-through securities in which interest payments (subtracting the credit guarantee and mortgage service fees) and principal payments on the underlying mortgages are passed through pro rata to MBS investors. Although the underlying loans can have distinct mortgage rates,[11] pass-through securities are mostly issued with coupon rates in 50-basis-point increments (e.g., 4.5%, 4.0%, 3.5%, etc).

All agency MBS are effectively default-free with principal balances guaranteed by Fannie Mae, Freddie Mac, or Ginnie Mae. They are, however, subject to uncertainty regarding the timing of cash flows, which is known as prepayment risk, because mortgage borrowers can prepay mortgage loans whenever they want. Specifically, when mortgage rates drop, increased refinancing activities lead to earlier principal payments; in consequence, MBS investors receive larger cash flows when they could only reinvest at lower rates (Gabaix, Krishnamurthy, and Vigneron, 2007).

[10] The remaining consists of 28.9% of unsecuritized first liens, 4% of home equity loans, and 3.7% of private-label MBS, based on the Urban Institute's reports (available at https://www.urban.org/research/publication/housing-finance-glance-monthly-chartbook-february-2021).

[11] Different mortgage loans can receive distinct mortgage rates because of differences in loan characteristics (such as loan amount, occupancy, and loan-to-value ratio), borrower characteristics (such as credit score, debt-to-income ratio, and employment status), and lender characteristics (such as the size, the pricing model, and whether the lender is a commercial bank or mortgage financing company).

Trading in agency MBS occurs via two parallel mechanisms: the specified pool (SP) contract and the to-be-announced (TBA) forward contract. The SP contract is the standard cash trade that settles on the spot and involves a specific MBS. The TBA contract, however, settles on a future date and accepts any MBS within a generic *cohort*—defined on agency×loan term×coupon—for delivery at a uniform price. For example, a TBA contract specifies the cohort of Fannie Mae 30-year fixed-rate MBS with a 4% security coupon rate, but the particular MBS that a seller delivers needs to be identified only two days before the settlement day. Like Treasury futures, TBA contracts settle once in a month.[12] Moreover, because of the uniform cohort-level pricing, TBA forward contracts are traded on a "cheapest-to-deliver" basis, like Treasury futures too (Labuszewski and Sturm, 2011; Fusari, Li, Liu, and Song, 2022).

2.2 Dealers' Liquidity Provision

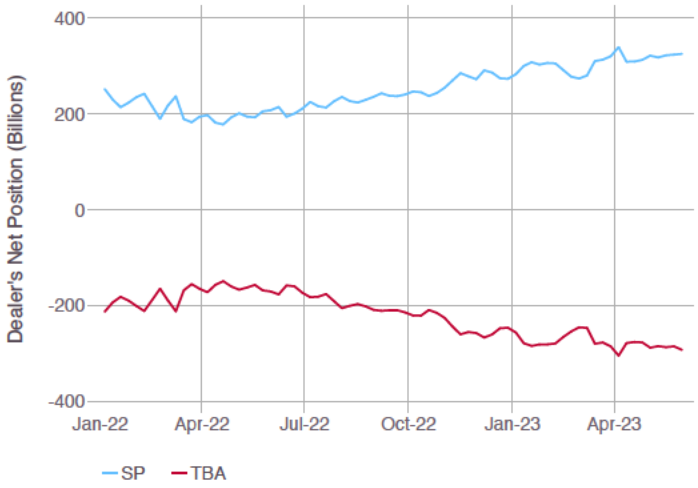
Both SP and TBA contracts are crucial for dealers' liquidity provision in the agency MBS market. In particular, dealers usually provide liquidity by taking MBS inventory in the SP market while hedging inventory risk using TBA contracts (Gao et al., 2017).

To demonstrate dealers' liquidity provision strategy, we obtain the weekly series of agency MBS positions of all Primary Dealers (in aggregate), from the FR2004 reports collected by the Federal Reserve Bank of New York.[13] The FR2004 reports only collected dealers' net positions of cash and forward contracts before January 2022, but have been collecting cash and forward positions separately since then. Figure 1 plots the weekly series of Primary Dealer's cash and forward positions of agency MBS from January 2022 to May 2023. We observe that dealers indeed hold net long cash positions and net short forward positions. The amounts of short forward positions and long cash positions are roughly the same, implying that dealers tend to fully hedge their inventory risk.[14]

Given that dealers hedge inventory risk using forward contracts in their liquidity provision,

[12]The TBA settlement schedules are set by the SIFMA, which can be found at https://www.sifma.org/resources/general/mbs-notification-and-settlement-dates. The SIFMA also sets the eligibility criterion for TBA delivery, known as the "Good Delivery" requirement, which can be found at https://www.sifma.

Figure 1: **Primary Dealers' Cash and Forward Positions of Agency MBS**



Note: This figure plots the weekly series of Primary Dealers' aggregate MBS cash (SP) and forward (TBA) positions in $ billions, reported in the FR 2004 data. The sample period is from January 2022 to May 2023.

the natural measure of dealers' constraints would be the price wedge between cash and forward contracts. As detailed in Appendix A, cash and forward prices would diverge when dealers face funding or balance sheet constraints, similar to the cash and futures prices of Treasury securities and cash and CDS prices of corporate bonds (Fleckenstein and Longstaff, 2020; Bai and Collin-Dufresne, 2019). In particular, cash prices would fall below forward prices when dealers are constrained from taking the MBS that investors with immediate cash needs sell in the SP market.[15]

org/wp-content/uploads/2017/06/uniform-practices-2019-chapter-8.pdf.

[13]For details, see https://www.newyorkfed.org/markets/gsds/search.

[14]This type of liquidity provision strategy—taking inventory in the cash market and simultaneously hedging inventory risk in the derivative market—is also used by dealers in other markets. For example, in the Treasury market, dealers usually take cash positions and hedge inventory risk using futures contracts (Fleckenstein and Longstaff, 2020). However, the agency MBS market is particularly appealing for studying dealers' liquidity provision because both cash and forward contracts are OTC-traded with dealers as counterparties. This same institutional organization of cash and derivatives markets eliminates potential confounding factors in detecting dealers' constraints. In contrast, while cash Treasury is OTC traded, Treasury futures trade on the Chicago Mercantile Exchange, with different trading protocols and arrangements of settlement and clearing.

[15]One may be concerned that dealers might not be able to fully hedge their cash inventory in March 2020. However, the Fed's standard TBA purchases that started on March 15 can uphold dealers' inventory risk hedging in the very short horizon (up to three weeks) of the COVID-19 crisis. Indeed, as shown in Section 3.2, dealers participated in the Fed's standard TBA purchase operations heavily.

Table 1: **Major Events in the COVID-19 Disruptions of U.S. Fixed-Income Markets**

Date	Events
3/9	The first market-wide circuit breaker triggered in equity markets since 1997.
3/12	The Fed announced three additional term repo operations each up to $500 billion.
3/16	The Fed started to purchase agency MBS though standard TBA contracts and Treasury securities, following the announcement on Sunday, March 15.
3/17	The Fed announced a number of liquidity and credit facilities, including the Primary Dealer Credit Facility (PDCF) among others.
3/19	The Fed began to purchase agency MBS through the nonstandard t+3 TBA contracts.
3/23	The Fed announced to establish the Primary Market Corporate Credit Facility (PMCCF) and the Secondary Market Corporate Credit Facility (SMCCF), to purchase agency MBS and Treasury securities "in the amounts needed," and to purchase agency CMBS, and to establish the Term Asset-Backed Securities Loan Facility (TALF).
3/27	The Fed conducted the last t+3 TBA purchases (while standard TBA purchases continued). and reserve bank deposits from the SLR calculation.
4/9	The Fed expanded the size and scope of the PMCCF, SMCCF, and TALF.
5/12	SMCCF began purchases of exchange-traded funds (ETFs).

Note: This table provides a list of major events of the COVID-19 disruptions in the agency MBS market, as well as in other fixed-income markets.

2.3 The COVID-19 Market Disruptions and Fed Interventions

To facilitate the design of our analysis, we first give an overview of COVID-19 market disruptions following the timeline of major events. Then based on the cash and forward price wedge as discussed above, we spell out specific channels through which the Fed's different interventions could restore market functioning.

Overview of major events. Table 1 provides a list of major events of the COVID-19 disruptions in both the agency MBS market and the related markets of Treasury securities and corporate bonds. The fixed-income markets did not show much stress before March 9 when a market-wide circuit breaker was triggered in the stock market for the first time since 1997. From March 9, yields soared and volatility skyrocketed in most U.S. fixed-income markets (Duffie, 2020; He et al., 2021; O'Hara and Zhou, 2021).

In response to the severe market disruptions, the Fed implemented a number of policy actions to restore market functioning. First of all, on March 12, the Fed offered term repo funding

to Primary Dealers. In particular, since the 2008 financial crisis, the Fed has been conducting overnight and term repo operations regularly, which provide funding liquidity to Primary Dealers directly in order to facilitate the smooth functioning of short-term funding markets. Concerned that funding shortage might be an important problem of COVID-19 market disruptions, the Fed added three term repo operations of huge size, each of which is up to $500 billion.

Then, on Sunday, March 15, the Fed announced to purchase at least $200 billion of agency MBS and $500 billion of Treasury securities. The Fed made it explicit that such purchases were to "support the smooth functioning of markets for Treasury securities and agency MBS," different from the purchases conducted in the 2008 crisis period that were to "exert downward pressure on long-term interest rates" when short-term interest rates hit the zero-lower bound. These purchases started immediately on the following Monday, March 16. Like what it has done since the 2008 crisis, the Fed conducted agency MBS purchases through standard TBA contracts that settle on a monthly cycle.[16]

On March 17, the Fed announced to establish the Primary Dealer Credit Facility (PDCF),[17] which provides better funding support to Primary Dealers than the term repo operations announced on March 15. First, the PDCF is a standing facility, available any time during the day before the closing hour, whereas term repo is only conducted on scheduled dates. Second, the PDCF has a more flexible term as funding is up to 90 days and can be repaid at any time, whereas the term repo has fixed maturities of up to 84 days and not all maturities are available on all days. Third, the term funding rate of the PDCF is lower than that of the term repo.

On March 19, observing that market disruptions continued to worsen, the Fed changed the mechanism of its agency MBS purchases. Specifically, the Fed began to conduct purchases through nonstandard TBA contracts that settle in three days rather than on a monthly cycle (meanwhile, the Fed kept the standard TBA purchases). Such t+3 TBA purchases allowed deal-

[16]The Fed implements these purchases with Primary Dealers as exclusive direct trading counterparties. See Bonaldi, Hortacsu, and Song (2015), Song and Zhu (2018), and An and Song (2023) for studies on the mechanisms and outcomes of the trades between the Fed and Primary Dealers.

[17]On the same day, the Fed also announced to establish the Commercial Paper Funding Facility (CPFF) to ensure the smooth functioning of the commercial paper markets and the Money Market Mutual Fund Liquidity Facility (MMLF) to ensure that money market funds can meet demands for redemptions.

ers to offload the MBS they purchased in the cash market to the Fed much more quickly than standard TBA purchases (the first settlement of the Fed's t+3 TBA purchases occurred in the afternoon of March 23, while the first settlement of the Fed's standard TBA purchases occurred in the afternoon of April 15). The Fed conducted the last t+3 TBA purchases on March 27, while the standard TBA purchases continued.

On March 23, the Fed announced a further set of programs to address market disruptions. The most salient ones among them are the Primary Market Corporate Credit Facility (PMCCF) and the Secondary Market Corporate Credit Facility (SMCCF) that the Fed created (together with the Department of the Treasury) to purchase investment-grade corporate bonds for the first time in its history; after all, corporate bonds are private securities rather than government securities like Treasury and agency MBS. Furthermore, although announcements of corporate bond facilities were made on March 23 (and their size and scope were expanded on April 9), actual purchases did not occur until May 12 when the first purchases of corporate bond exchange-traded funds (ETFs) were conducted.

The economic channels of Fed interventions. As discussed in Section 2.2, funding and balance sheet constraints can hinder dealers' liquidity provision and result in price dislocation between cash and forward markets of agency MBS. Accordingly, we spell out how the Fed's different interventions can mitigate dealers' funding and balance sheet constraints:

- The term repo operations announced on March 12 and the PDCF announced on March 17 can mitigate dealers' funding constraints.
- The standard TBA purchases that started on March 16 can mitigate dealers' balance sheet constraints by reducing the inventory-carrying time of agency MBS to less than 30 days.
- The t+3 TBA purchases that started on March 19 can mitigate dealers' balance sheet constraints by reducing the inventory-carrying time of agency MBS to less than three days.[18]

[18]The Fed's purchases, through either standard TBA contracts or nonstandard TBA contracts, can also shorten the time span for which dealers need funding. This effect is usually minor in stressful times during which the term

- The PMCCF and SMCCF announcements on March 23, though without immediate purchases, can mitigate dealers' balance sheet constraints by reducing dealers' uncertainty or strategic holdup on inventory carrying of corporate bonds.[19]

In addition to mitigating dealers' constraints, the Fed's asset purchases can also mitigate customers' selling pressure. For example, some customers may be selling due to expectations of future price drops, while other customers with capital are unwilling to step in and purchase also due to such expectations (Allen, Morris, and Shin, 2006; Eisenbach and Phelan, 2023). By providing an anchor for price expectations, the Fed's announcement of purchases alone can reduce selling and encourage buying, which would help contain market disruptions.

3 Empirical Analyses

In this section, we present our main empirical analyses of dealers' liquidity provision and the Fed's interventions during the COVID-19 crisis.

3.1 Data and Measures

We first introduce the data and measures used in our analyses of the agency MBS market.

Data of agency MBS transactions. We use two data sets of agency MBS transactions. The first is the TRACE data set of agency MBS transactions that the Financial Industry Regulatory Authority (FINRA) started to collect since May 2011. Each transaction record contains the trade type (TBA or SP), trade date, settlement date, price, and par value, among others. Both inter-dealer trades and trades between dealers and customers are included. The version of TRACE data we use is at the supervisory level, in which dealer identifiers are included for each trade.

structure of short-term funding rates is quite flat. Indeed, the results in Section 3.2 show that funding constraints were not the most severe force that constrained dealers' liquidity provision.

[19] The Fed's announcement on agency MBS purchases on March 23 is only to expand the overall purchase size beyond the $200 billion previously announced on March 16, which does not affect how purchases are conducted.

We first apply a number of standard algorithms to clean the TRACE data.[20] We then retain only outright TBA trades and SP trades of TBA-eligible MBS,[21] and also consider only 30-year Fannie Mae and Freddie Mac MBS that account for the largest fraction of all agency MBS outstanding. Furthermore, to ensure that we use actively traded MBS, we restrict the sample to those with moneyness (defined as the difference between the cohort coupon rate and the current-coupon rate for a synthetic par TBA contract that is obtained by interpolation of TBA prices trading near par) in the range of $[-1\%, 4\%]$, similar to Song and Zhu (2019). In addition, we only use front-month TBA contracts that are most active (results remain robust when back-month contracts are included). To eliminate potential outliers, we also drop transactions with very low prices (less than 80 cents per dollar face value) or those of very small sizes (less than $\$1,000$ face value).

The second data set we use contains the records of the Fed's agency MBS purchases, provided by the Federal Reserve Bank of New York.[22] Each trading record contains the TBA contract identifier, trading date, settlement date, price, par value, and an identifier of the primary dealer who sells to the Fed. The Fed's trading records are reported in the TRACE data as trades between dealers and (anonymized) customers. We match the Fed trading records with TRACE data and identify the Fed's purchases based on the TBA contract specification, trade date, trading quantity, price, and dealer identity. This matching allows us to separate the Fed's trades from those of regular non-Fed customers.

Measures of price dislocation. We measure price dislocation in the agency MBS market during the COVID-19 crisis using the *price* difference between TBA and SP contracts, as guided by Eq. (A.3) in Appendix A. Specifically, for each TBA contract i on each day t, we compute the

[20] In particular, we correct trade revisions, cancelations, reversals, and duplicated reports. We assign a trade to the dealer who executed this trade rather than the reporting dealer for give-up trades and locked-in trades. We also merge different reporting identities to the same underlying dealer with multiple reporting identities in TRACE for historical reasons. See An and Song (2023) for further details.

[21] Specifically, we exclude the trades of stipulated TBA contracts and dollar rolls, as well as those not qualified for TBA delivery and with non-standard coupon rates. The SP trades of Mega securities, stripped MBS, and collateralized mortgage obligations are also excluded.

[22] These data are available at `https://www.newyorkfed.org/markets/ambs/operations/search`.

transaction-volume-weighted average price of all trades in the TRACE data, denoted as $P^{TBA}_{i,t}$. For each SP trade j that falls under the generic cohort of TBA contract i on day t, we use the reported trade price directly, denoted as $P^{SP}_{j,i,t}$. We then compute trade-level measures of the TBA-SP price difference, $e^{-r\tau_{j,i,t}}P^{TBA}_{i,t} - P^{SP}_{j,i,t}$, where $\tau_{j,i,t}$ is the difference between the time-to-settlement of SP trade j and the transaction-volume-weighed average of time-to-settlement of all TBA trades and r is measured using LIBOR rates corresponding to $\tau_{j,i,t}$. [23]

Because the MBS traded through TBA contracts are CTD ones and may differ from those traded through SP contracts, as discussed in Section 2.1, we need to adjust $e^{-r\tau_{j,i,t}}P^{TBA}_{i,t} - P^{SP}_{j,i,t}$ for the potential value difference. In the Treasury market, the adjustment for the similar CTD feature of futures contracts when computing the cash-futures basis is made by identifying CTD securities and using their cash trading prices (Fleckenstein and Longstaff, 2020); this is relatively straightforward given the small number of Treasury securities and their simple cash flow structure. However, the number of agency MBS is huge and their cash flow is subject to considerable uncertainty due to the prepayment option, which makes the identification of the CTD MBS most demanding. Furthermore, a significant fraction of MBS is not traded in the SP market at all, so that no cash trading prices are available (An, Li, and Song, 2023).

Amid these challenges, we make the CTD adjustment following the approach proposed in An et al. (2023). In particular, we first estimate the CTD effect by regressing TBA-MBS price difference on prepayment characteristics difference of TBA and SP MBS and then adjust $e^{-r\tau_{j,i,t}}P^{TBA}_{j,i,t} - P^{SP}_{i,t}$ based on the estimated CTD effect and its associated prepayment characteristics difference; see Appendix B for details. The resulting adjusted price difference measure conforms to the theoretical measure of price dislocation—the forward-cash basis as discussed in Appendix A—so we denote it by $Basis_{j,i,t}$.

Measures of quantities. To examine quantities of dealers' liquidity provision, we consider the following measures on each day t:

[23] Since June 2019, Fannie Mae and Freddie Mac MBS have been traded through the so-called uniform MBS (UMBS) TBA contracts, while their SP trades continue to be separate. Hence, $P^{TBA}_{i,t}$ is measured using prices of UMBS TBA contracts but $P^{SP}_{j,i,t}$ is measured using prices of SP trades of either Fannie Mae or Freddie Mac MBS.

- Dealers' aggregate net purchase amount with regular customers in the SP market, denoted by $V_t^{cash,C}$.
- Dealers' aggregate net purchase amount with the Fed using t+3 TBA contracts, denoted by $V_t^{cash,Fed}$.
- Dealers' aggregate net purchase amount with regular customers using standard TBA contracts, denoted by $V_t^{forward,C}$.
- Dealers' aggregate net purchase amount with the Fed using standard TBA contracts, denoted by $V_t^{forward,Fed}$.

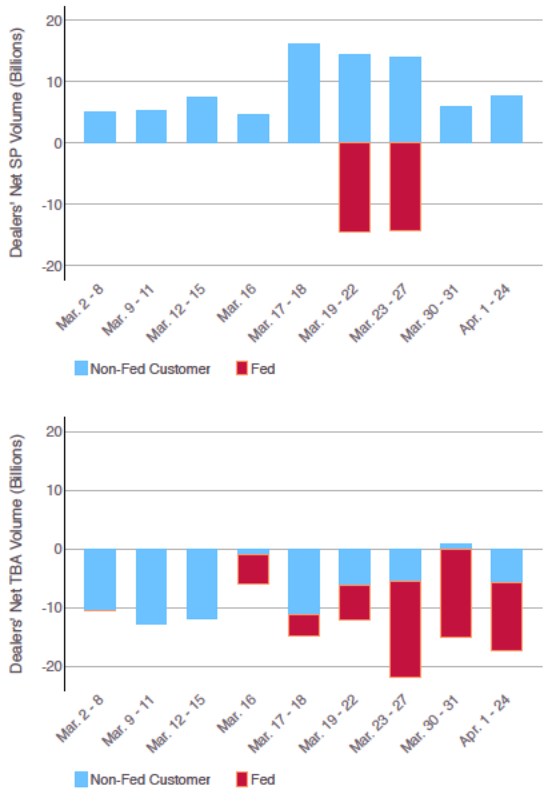
All these measures are computed as the difference between dealers' total purchase and total selling amounts, aggregated across all dealers, with the respective group of counterparties. Note that we denote dealers' aggregate net purchases through the Fed's t+3 TBA operations as cash amount because such TBA contracts settle (almost) as fast as SP contracts. Moreover, as the Fed did not conduct outright sales of agency MBS, both $V_t^{cash,Fed}$ and $V_t^{forward,Fed}$ are equal to the gross amounts. In addition, all these measures are computed using par values rather than market values because using market values is subject to confounding effects related to price changes, especially at the height of the COVID-19 market disruptions.

3.2 Quantities and Prices of Dealers' Liquidity Provision

Using the measures constructed above, we analyze both the quantities and prices of dealers' liquidity provision in this section.

First of all, we look into quantities. Figure 2 presents bar plots of the daily average of dealers' aggregate net purchase amounts, $V_t^{cash,C}$ and $V_t^{cash,Fed}$ in the top panel and $V_t^{forward,C}$ and $V_t^{forward,Fed}$ in the bottom panel, between two event days (as listed in Table 1). We observe that in the week before the COVID-19 market disruptions started (March 2-8), dealers' net cash purchase amount was positive and their net forward purchase amount was negative, con-

Figure 2: **Dealers' Aggregate Daily Net Purchase Amounts of Agency MBS**



Note: This figure plots dealers' average daily net purchase amounts, between two event days, in the cash (SP) market and in the forward (TBA) market, respectively. For each market, we report dealers' net purchase amounts from non-Fed customers and from the Fed respectively. The sample period is from March 2 to April 24, 2020.

sistent with their regular liquidity provision strategy as discussed in Section 2.2. Dealers maintained this liquidity provision after March 9 when the COVID-19 market disruptions started, even before the Fed started the first intervention on March 12. However, over March 9-11, the magnitudes of dealers' purchase amounts little changed than before, i.e., they did not *increase* their liquidity provision initially.[24]

We then examine how dealers' net purchase amounts change in response to the Fed's different interventions. We find that dealers' average daily net purchase amounts did not change

[24]We also observe that the Fed conducted sporadic MBS purchases over March 2-8. These are due to the Fed's historical MBS programs, like the reinvestment operations.

much after March 12 when the Fed offered term repo funding. The amounts little changed either on March 16 when the Fed started the standard TBA purchases, though dealers began to allocate a large fraction of their standard TBA sales to the Fed. Instead, dealers began to significantly increase their net cash purchase amount (and net forward selling amount), to about $15 billion per day on average, after the PDCF was established on March 17.[25] They continued to conduct this large amount of daily net purchases from March 19 when the Fed started t+3 TBA purchases to March 27 when the Fed executed the last t+3 TBA purchases; in this period, dealers' daily t+3 TBA selling amount is about the same as their daily net cash purchase amount, showing that dealers quickly offloaded their cash purchases to the Fed.[26]

Second, we look into prices. In particular, we examine how the forward-cash basis changes in response to market disruptions and Fed interventions using the following regression:

$$Basis_{j,i,t} = \beta \times D_d + D_i + \varepsilon_{i,t}, \tag{1}$$

where d is the day when an event occurs, D_d is the dummy for the event day, and D_i is the dummy for coupon cohort. We estimate the regression using observations on day d and $d-1$ based on weighted least square (the weight is the volume of the SP trade j). Hence, the coefficient β captures the one-day change of the forward-cash basis from the day before the event to the event day. We cluster standard errors at the coupon cohort level.

Table 2 reports the regression results. We observe that the forward-cash basis increased significantly on March 9, indicating severe price dislocation in the agency MBS market. It continued to increase on March 12 when the Fed established term repo operations and on March 16 when the Fed started standard TBA purchases. On March 17 when the Fed launched the PDCF,

[25] As discussed in Section 2.3, the PDCF has a number of advantages over the term repo operations in supporting dealers' funding liquidity needs, which explain why dealers increased the amount of cash purchases after the PDCF was set up but not after the term repo operations were deployed.

[26] We note that the magnitude of dealers' net forward sales is usually greater than that of their net cash purchases, different from the (almost) equal amounts of cash and forward positions shown in Section 2.2. One important reason is that MBS issuers often use TBA contracts to sell their newly-issued securities through TBA contracts (Gao et al., 2017). For example, Wells Fargo, one of the largest MBS issuers, is a registered broker-dealer, and their sales of newly-issued MBS to investors would be recorded as the dealer's TBA sales to customers in the TRACE data, without a record of SP purchases that occur internally.

Table 2: **Changes in the Forward-Cash Basis of Agency MBS**

	One-Day Change of the Forward-Cash Basis	Coupon Cohort FE	Obs.	Adj. R^2
March 9	0.572**	Yes	2774	0.269
	(0.196)			
March 12	0.551***	Yes	2986	0.340
	(0.108)			
March 16	0.234	Yes	3268	0.110
	(0.240)			
March 17	0.094	Yes	3702	0.153
	(0.129)			
March 19	-0.270***	Yes	3212	0.043
	(0.059)			
March 23	0.318	Yes	5018	0.099
	(0.190)			
March 24	-0.196***	Yes	6042	0.159
	(0.075)			
March 30	-0.013	Yes	3416	0.356
	(0.093)			

Note: This table reports the estimated one-day change of the forward-cash basis from the day before an event to the event day based on using the regression (1). The events are those reported in Table 1. We estimate the regression using weighted least squares by trade size and cluster standard errors at the coupon cohort level (reported in parentheses). Significance: $^*p$<0.1, $^{**}p$<0.05, $^{***}p$<0.01.

the forward-cash basis increased further, though both the statistical significance and economic magnitude are tiny. Finally on March 19 when the Fed began its t+3 TBA purchases, the forward-cash basis decreased significantly. It significantly decreased further on March 24, the first day after the first settlement of the Fed's t+3 TBA purchases, and continued to decline thereafter. On March 30, the first business day after the Fed conducted its last t+3 TBA purchases, the forward-cash basis little changed.[27]

Putting the above findings on quantities and prices together, we can infer the importance of dealers' constraints. Specifically, the continued widening of the forward-cash basis on March 17 when the Fed established the PDCF, though dealers began to increase the amount of cash

[27]We also note that the regression R^2 is smaller for the events between March 19 and March 23 than for other events. We compute the standard derivation of intra-day prices and find that it is relatively high in this period. One interpretation is that the Fed's purchases introduced higher intraday price dispersion.

purchases around then, suggests that funding constraints were unlikely the most severe economic force. In contrast, the finding that dealers turned around (almost) all their cash purchases quickly through the Fed's t+3 TBA purchase operations while the forward-cash basis reverted its widening only after the inception of such t+3 TBA purchases implies that balance sheet constraints were likely the major economic force. Moreover, the fact that neither dealers' amount of liquidity provision increased nor the widening forward-cash basis reverted when the Fed started its standard TBA purchases (that can only reduce dealers' carry-inventory time to less than a month) corroborates the severity of balance sheet constraints.[28]

3.3 Drivers of Dealers' Balance Sheet Constraints

Given the major role that balance sheet constraints played during the COVID-19 crisis, as documented above, we conduct further analyses to understand the drivers of dealers' balance sheets in this section.

One type of balance sheet constraints often discussed in the literature is the supplemental leverage ratio (SLR) requirements introduced in the post-GFC regulatory reforms (Duffie, 2018). Specifically, to strengthen the resilience of the global banking system in the wake of the 2008 financial crisis, the Basel III regulatory framework proposed a new leverage ratio rule as a backstop to risk-based capital regulation. In general, this supplemental leverage ratio is computed as the Tier I capital divided by total leverage exposure irrespective of its riskiness, which is distinct from the conventional risk-weighted–asset capital requirement. The Basel Committee proposed a 3% minimum leverage ratio, which US banks subject to the SLR rule must maintain. Furthermore, US regulators require US-domiciled global systemically important banks (GSIBs) to maintain an SLR of at least 5% on a consolidated basis and at least 6% for their depository subsidiaries, known as the enhanced SLR requirement. This enhanced SLR rule was finalized

[28] Although the Fed's standard TBA purchases were not able to reduce dealers' balance sheet constraints quickly, they served to uphold dealers' inventory risk hedging in the very short horizon (up to three weeks) of the COVID-19 crisis. This provides additional support for using the price wedge between cash and forward markets to capture dealers' constraints.

in September 2014, its mandated disclosure started in January 2015, and the final implementations were mostly finished in January 2018.

The leverage exposure in the SLR includes the total notional of all cash transactions, which "increases 'rental cost' for the space on a bank's balance sheet" (Duffie, 2018). Compared with the constraint on cash positions, the constraint imposed by the SLR on standard derivatives like TBA forward contracts is minor. As discussed in He et al. (2021), the constraint imposed by SLR on standard interest rate derivatives is about two orders of magnitude smaller than that on the cash positions. In consequence, when dealers face SLR constraints that disproportionately affect cash positions, a wedge between forward and cash prices would arise and dealers would be unwilling to expand their balance sheet.

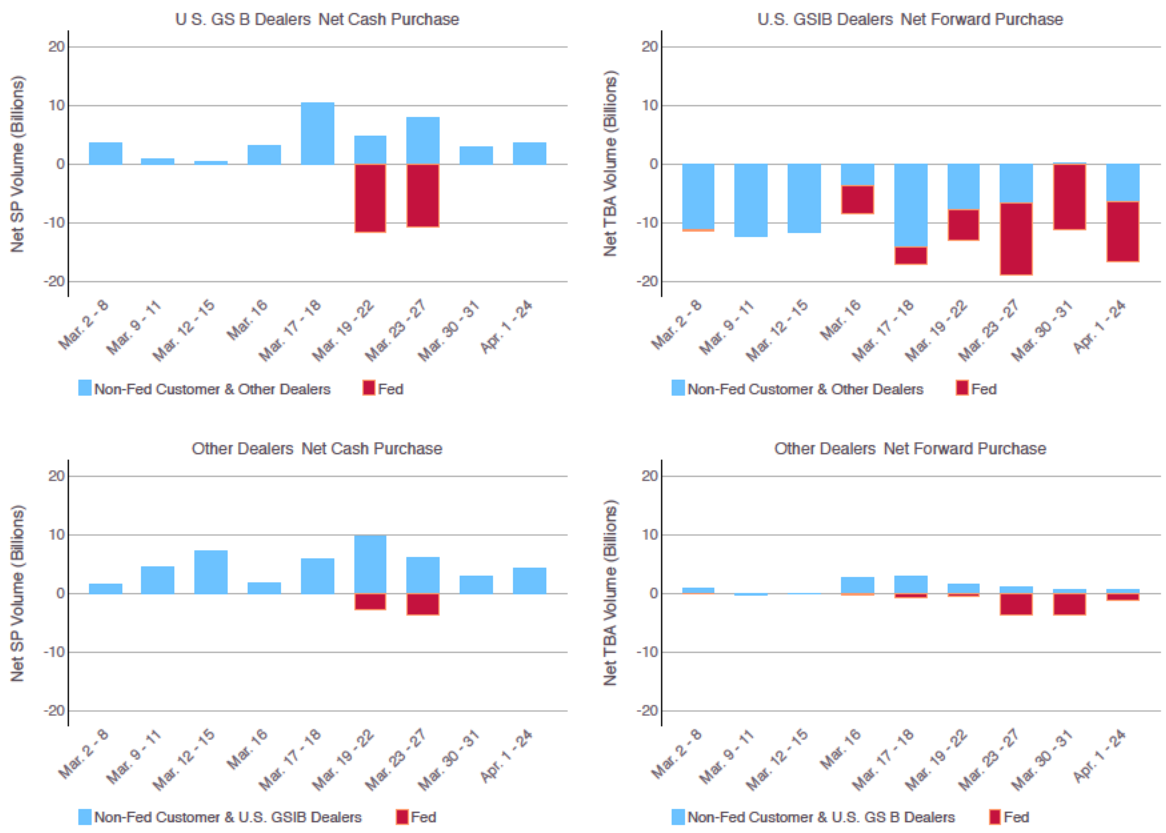
Taking advantage of the availability of dealer identities in the supervisory TRACE data, we divide all dealers into two groups: the group associated with the eight US-domiciled GSIBs subject to the enhanced SLR requirements and the group of all other dealers.[29] We then compute the four quantity variables ($V_t^{cash,C}$, $V_t^{cash,Fed}$, $V_t^{forward,C}$, and $V_t^{forward,Fed}$) for the two groups of dealers respectively. The left two panels of Figure 3 provide bar plots of the average daily net purchase amounts between two event days in the SP market by US GSIBs dealers and by other dealers, respectively, while the right two panels provide those in the TBA market.

From the right two panels, we observe that US GSIBs dealers' forward selling amounts are larger than those of other dealers, consistent with the larger size of the former than the latter. In fact, US GSIBs dealers are on the short side of forward contracts but other dealers are on the long side from March 16 to 22. Moreover, both groups of dealers began allocating forward sales to the Fed after March 16.

Importantly, from the left two panels, we find that relative to March 2-8, US GSIBs dealers slightly *decreased* their daily net cash purchase amounts over March 9-17 but other dealers moderately *increased* their daily net cash purchase amounts. That is, dealers subject to less stringent SLR requirements increased their liquidity provision but those subject to more

[29]The eight US GSIBs dealers are Bank of America, Bank of New York Mellon, Citigroup, Goldman Sachs, JP Morgan, Morgan Stanley, State Street, and Wells Fargo.

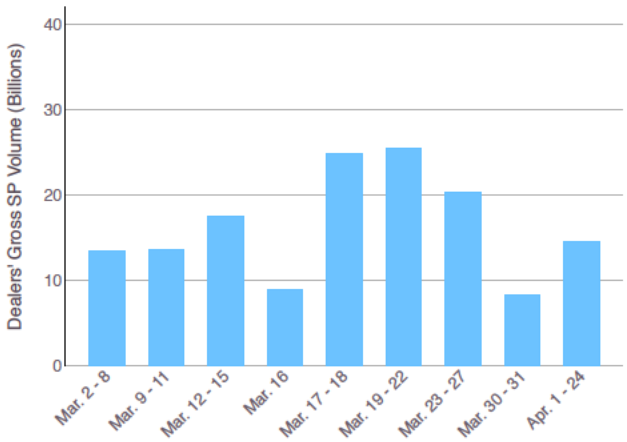
Figure 3: **SLR Constraints and Dealers' Liquidity Provision**



Note: This figure provides bar plots of the average daily net purchase amounts between two event days in the SP market by US GSIBs dealers (top left panel) and by other dealers (bottom left panel), as well as in the TBA market by US GSIBs dealers (top right panel) and by other dealers (bottom right panel). For each panel, we consider dealers' net purchase amounts from non-Fed traders and from the Fed respectively. The sample period is from March 2 to April 24, 2020.

stringent SLR requirements decreased their liquidity provision before the Fed's PDCF alleviated dealers' funding constraints. Moreover, after the Fed started t+3 TBA purchases, US GSIBs dealers offloaded a much higher amount of MBS to the Fed through the t+3 TBA operations than other dealers; that is, relative to other dealers, GSIBs dealers mainly engaged in "broker" trades that would not expand their balance sheet. Both of these two findings provide support for the importance of SLR requirements as dealers' balance sheet constraints in the COVID-19 crisis.

Figure 4: **Customers' Gross Cash Selling Amounts of Agency MBS**



Note: This figure presents bar plots of customers' average daily gross SP selling amount of agency MBS. The sample period is from March 2 through April 24, 2020.

3.4 Customers' Selling Pressure

So far, all our empirical findings consistently point to dealers' balance sheet constraints as the major economic force for the COVID-19 market disruptions. In this section, we provide evidence to rule out an alternative channel—customers' selling pressure.

As discussed in Section 2.3, by providing an anchor for investors' price expectations, the Fed's purchase announcements alone can reduce customers' selling pressure and mitigate price dislocation. In fact, because of the strong effects of purchase announcements in the corporate bond market, Haddad et al. (2020) and Vissing-Jorgensen (2020) conjecture that the Fed contained market disruptions not by mitigating dealers' constraints but by reducing customers' selling. For example, Haddad et al. (2020) reason that "if the issue leading to the disruptions was a temporary lack of capacity to intermediate short-term trades, merely announcing bond purchases would not solve the issue," while Vissing-Jorgensen (2020) state that "corporate announcements improved perceived corporate fundamentals enough to stop the selling."

Using the TRACE data, we compute customers' gross cash selling amount of agency MBS. As reported in Figure 4, we observe that customers' gross cash selling amount *increased* on March 19 when the forward-cash basis began to narrow. Similarly, as shown in the top panel of Fig-

ure 2 above, customers' net cash selling amount (equal to dealers' net cash purchase amount) of agency MBS also *increased* on March 19. These findings go directly against the conjecture that the Fed's interventions mitigated market disruptions by *reducing* customers' selling.

3.5 Comparison with the Corporate Bond Market Disruptions

The COVID-19 liquidity disruptions took effect not only in the agency MBS market but also in other important fixed-income markets. Distinct features of different markets make it challenging to analyze them all at once. Nevertheless, in this section, we conduct an additional analysis to compare dealers' liquidity provision in the agency MBS and corporate bond markets to garner a further understanding of the economic forces of market disruptions.

Toward this goal, we obtain daily series of the CDS-bond basis of investment-grade corporate bonds from J.P. Morgan and also compute dealers' aggregate net purchase amounts in the cash market using the TRACE data of corporate bond transactions (all with regular customers in our sample because the Fed did not purchase until late May). Unfortunately, the data availability of CDS transactions is very limited, so we do not have a measure of dealers' CDS trading.[30]

The top panel of Figure 5 presents bar plots of the daily average of dealers' net cash purchase amounts of corporate bonds. Consistent with O'Hara and Zhou (2021), and Kargar et al. (2020), we find that dealers' net cash purchase amounts slightly decreased entering the COVID-19 market disruptions, began to increase only after the establishment of the PDCF, and further increased after the announcements of the PMCCF and SMCCF. Moreover, the middle panel of Figure 5 plots the daily series of the CDS-Bond basis. Consistent with Haddad et al. (2020), we find that the CDS-Bond basis was stable until early March and then widened notably around March 9. It kept widening through March 12 (when the Fed deployed term repo operations), March 16 (when the Fed began to purchase Treasury securities and agency MBS), and March 17 (when the Fed set up the PDCF), and began to narrow around March 23 (when the Fed an-

[30] The availability of Treasury transactions is even more limited. For example, the TRACE data of Treasury transactions were collected starting from July 2017 but its use for research has been very restrictive.

nounced the PMCCF and SMCCF). Finally, the bottom panel of Figure 5 presents bar plots of customers' average daily gross cash selling amount of corporate bonds. We observe that customers' gross cash selling amounts of corporate bonds *increased* when price divergence began to revert on March 23, similar to the pattern in the agency MBS market.[31]

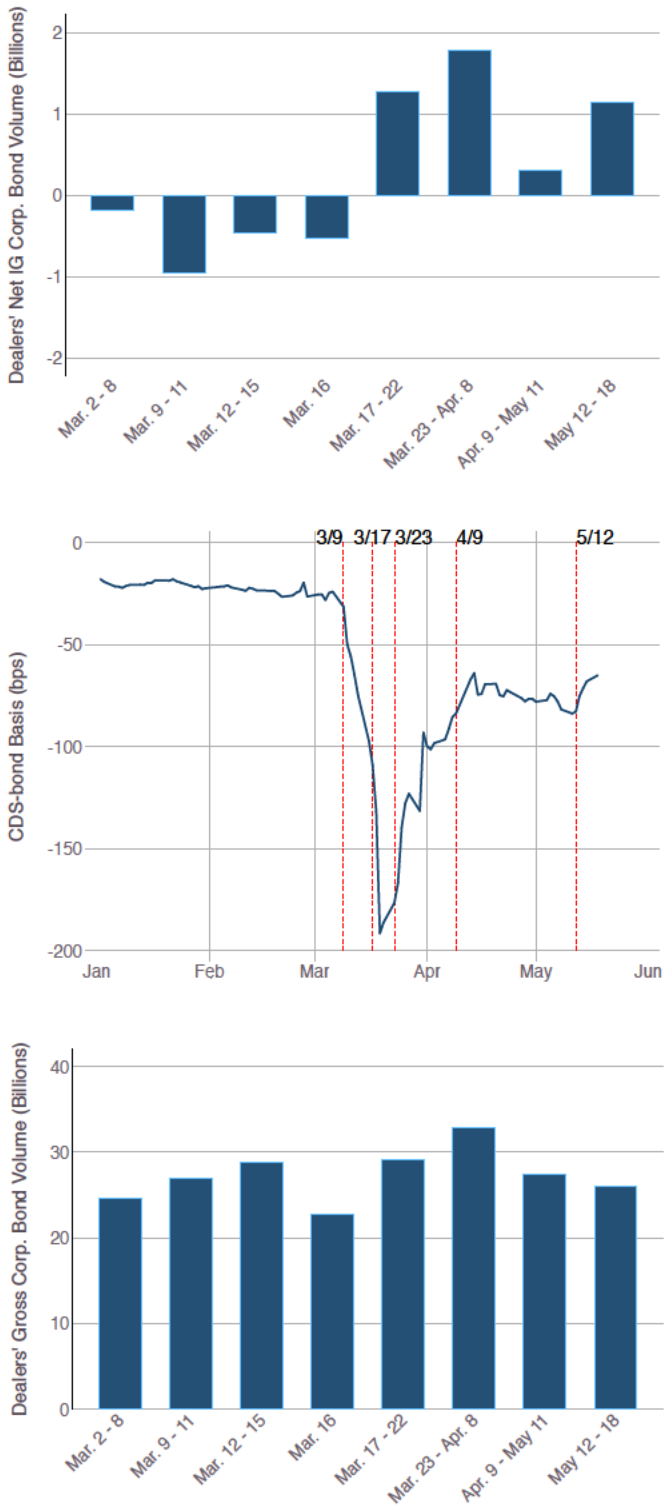
Among these observations, we first highlight the similar pattern that customers' selling increased when the price divergence began to narrow. This pattern corroborates the central role of dealer frictions in both markets and goes against a reduction in customer selling pressure, as discussed above in Section 3.4.

We further highlight two contrasting patterns. First, dealers stopped providing liquidity for corporate bonds when market disruptions started, in contrast to their maintaining of liquidity provision in the agency MBS market. Second, the widening of the CDS-Bond basis began to revert mainly from March 23 when the Fed *announced* corporate bond purchases, long before the actual purchases started on May 12. In contrast, the widening of the forward-cash basis began to revert mainly after the Fed *promptly took* MBS off dealers' balance sheets using nonstandard purchase operations.

These two contrasting patterns indicate that in addition to SLR constraints (which had been relaxed since March 19 as shown in Section 3.2), other frictions were also constraining dealers in the corporate bond market. One such type of dealer frictions is fragile dealer coordination in liquidity provision theoretically analyzed in Yang and Zeng (2021); they show that the market can switch between the equilibrium with high coordination among dealers in providing liquidity and the equilibrium with low coordination. Specifically, the lack of liquidity provision by dealers for corporate bonds when market disruptions started is consistent with the low-coordination equilibrium; around then, dealers' expectation of future Fed purchases was likely negligible because corporate bond purchases had never occurred before. And the restor-

[31] There are also other similar patterns across the two markets. For example, dealers began to increase their net cash purchases both in the corporate bond market and in the agency MBS market on March 17 when the PDCF was introduced, and for both markets, price dislocations continued to worsen on March 17. This finding confirms the interpretation we drew in Section 2.2 that funding constraints affected dealers' liquidity provision but were not the major economic force.

Figure 5: **COVID-19 Disruptions in the Corporate Bond Market**



Note: The top panel presents bar plots of dealers' average daily net cash purchase amount of corporate bonds, between two event days, from March 2 to May 18, 2020. The middle panel plots the daily series of the CDS-Bond basis from January 1 to May 18, 2020. The bottom panel presents bar plots of customers' average daily gross cash selling amount of corporate bonds from March 2 through April 24, 2020.

ing of market functioning after March 23 is consistent with a switching to the high-coordination equilibrium prompted by the mere change in the expectation of future Fed purchases. In contrast, given that agency MBS purchases have been regularly conducted by the Fed since 2008, the expectation of future Fed purchases of agency MBS was likely high in the very beginning of market disruptions; hence, a change in the expectation of future Fed purchases is unlikely the key channel through which agency MBS market functioning was restored.[32]

4 Conclusion

In this paper, we contribute novel facts and analyses on understanding what were the key economic forces in the COVID-19 disruptions of U.S. fixed-income markets. The novelty of our results derives from the (1) granularity of available data and (2) unique features of Fed interventions in the agency MBS market. Specifically, using agency MBS transactions data, we examine high-frequency changes in both prices and quantities of dealers' liquidity provision. Furthermore, the Fed conducted agency MBS purchases using standard forward contracts that settle on a monthly cycle and nonstandard forward contracts that settle almost on the spot; comparing them reveals the severity of dealers' balance sheet constraints directly.

We find that amid customers' selling to "scramble-for-cash" since early March, dealers maintained the usual liquidity provision in the agency MBS market by taking cash inventory and hedging inventory risk with forward contracts. However, dealers only increased their cash purchases after the Fed established the PDCF. The cash and forward prices significantly diverged and mainly converged after the Fed deployed nonstandard operations to take MBS from dealers promptly. These findings imply that dealers' balance sheet constraints played a major role in market disruptions. Further cross-dealer analyses point to SLR requirements as important drivers of dealers' balance sheet constraints, while comparisons with the corporate bond mar-

[32] Dealers' holdings of agency MBS were way larger than their holdings of corporate bonds entering the COVID-19 period. For example, according to the FR2004 data, Primary Dealers' aggregate net holding amount is about $45 billion for agency MBS and only about $6 billion for corporate bonds in the week before March 9. This finding is consistent with the higher expectation of Fed purchases of agency MBS than Fed purchases of corporate bonds.

ket disruptions uncover additional dealer frictions. Finally, we find that customers' selling increased when price divergence reverted, inconsistent with a reduction in their liquidity needs.

Our results not only shed light on COVID-19 market disruptions *per se* but also provide the basic facts for the evaluation and design of the Fed's new "dealer of last resort" policy—using asset purchases to address market functioning problems. A rigorous theoretical framework that models the interactions between dealers and the Fed's liquidity provision would be an important next step.

Appendices

A Economic Framework

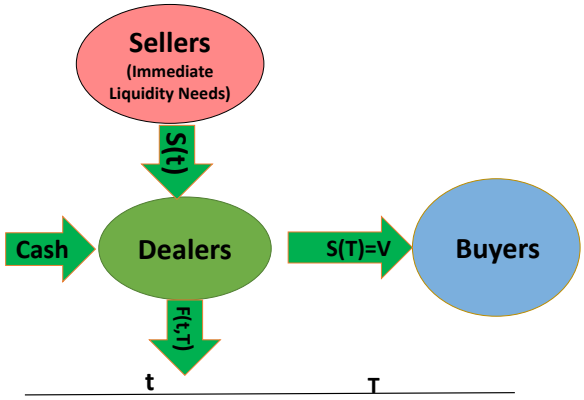
In this appendix, we provide a simple economic framework, without delving into modeling details, to guide the empirical analysis.

The framework adapts the Grossman and Miller (1988) model to the agency MBS market with both cash and forward trading. In particular, Figure A.1 presents a diagram of the framework. There are two periods, t and T. At time t, MBS holders who experience liquidity shocks sell q units of MBS in the cash market to raise cash immediately. However, MBS buyers deploy capital slowly and arrive in the market only at time T. Dealers bridge the gap by taking the MBS sold in the cash market into inventory at time t and carrying them until time T when they unload the inventory to buyers. In doing so, dealers provide immediacy to customers.

Taking inventory requires funding. Dealers usually use the security they purchase as collateral and borrow cash against it (e.g., through repo contracts), known as "funding liquidity" (Brunnermeier and Pedersen, 2009). Moreover, dealers bear inventory risk associated with price variation from time t to T. They often hedge inventory risk by taking opposite positions in the related derivative market, e.g., forward contracts in the agency MBS market, as shown in Section 2.2. Finally, even though price risk is offloaded through hedging, dealers can still bear balance sheet costs in carrying inventory. For example, post-crisis capital regulations like the supplementary leverage ratio (SLR) requirements of Basel III can constrain dealers' balance sheet capacity, especially for liquid safe assets (Duffie, 2018). Moreover, as emphasized by Andersen, Duffie, and Song (2019) recently, debt overhang issues can also impose balance sheet costs on financial intermediaries.

To see how the funding liquidity, inventory risk, and balance sheet cost affect dealers' liquidity provision, we examine prices of both cash and forward trading. In particular, suppose

Figure A.1: **Diagram of the Economic Framework**



Notes: This figure presents a diagram of the economic framework.

that the cash price at time T equals V. Then the cash price at time t equals

$$SP(t) = E[V] - RP - \gamma(q,\tau) - f(q,\tau), \tag{A.1}$$

where $\tau = T - t$ is the inventory-carrying time, $E[V]$ is the time$-t$ expectation of the security value at time T, RP is the risk premium associated with dealers' effective "risk-aversion", $\gamma(q,\tau)$ is the (marginal) funding cost, and $f(q,\tau)$ is the (marginal) balance sheet cost. That is, not only the fundamental value $(E[V]+RP)$ but also the funding and balance sheet costs affect the cash price at which investors with immediacy liquidity needs can sell at time t.

In contrast, dealers do not carry inventory from time t to T by entering a forward contract, so neither funding costs or balance sheet costs would be incurred.[33] As a result, the time-t present value of the forward price only equals the fundamental value:

$$e^{-r\tau}F(t,T) = E[V] - RP. \tag{A.2}$$

Though very stylized, this economic framework demonstrates dealer frictions that can lead to market disruptions. In particular, given that dealers hedge inventory risk (as shown in Sec-

[33] Margins need to be posted for trading forward contracts, but are much lower than the capital needed for cash purchases. We hence assume that no balance sheet cost is incurred by forward trading for simplicity.

tion 2.2), funding and balance sheet constraints are the major forces that can hinder dealers' liquidity provision. To capture them, we take the difference between forward and cash prices

$$e^{-r\tau}F(t,T) - S(t) = \gamma(q,\tau) + f(q,\tau), \tag{A.3}$$

which we denote by forward-cash basis, similar to the cash-futures basis of Treasury securities and CDS-bond basis of corporate bonds (Fleckenstein and Longstaff, 2020; Bai and Collin-Dufresne, 2019). This forward-cash basis would increase if funding or balance sheet constraints prevent dealers from taking the MBS that investors sell in the cash market.

It is worth noting that, for simplicity, we assume buyers would arrive in the market at time (T); hence dealers' inventory-carrying time (τ) is known. In practice, dealers could face large uncertainty regarding when buyers would arrive. Such uncertainty would exacerbate dealers' constraints and price dislocation.

B Adjustment for the CTD Effect

As discussed in Section 3.1, we empirically measure the forward-cash basis in Eq. (A.3) using the price difference between TBA and SP contracts. However, the MBS traded in TBA contracts are usually the CTD ones that may differ from MBS traded in SP contracts (as mentioned in Section 2.1). Hence, we need to adjust the raw TBA and SP price difference for this so-called CTD effect (Fusari et al., 2022).

We follow the approach proposed by An et al. (2023) to make this adjustment. Specifically, we first estimate the CTD effect by regressing the raw TBA-SP price difference on value difference measures of outstanding MBS:

$$e^{-r\tau_{i,t}}P_{i,t}^{TBA} - P_{i,t}^{SP} = \alpha + \beta_i \times D_i \times h_{i,t} + \epsilon_{i,t}, \tag{B.1}$$

where $P_{i,t}^{TBA}$ is the transaction-volume-weighted average price of all trades of TBA contract i

on day t, $P^{SP}_{i,t}$ is the transaction-volume-weighted average price of all SP trades that fall under the generic cohort of TBA contract i on day t (it is equal to the weighed average of $P^{SP}_{j,i,t}$ as discussed in Section 3.1), $\tau_{i,t}$ is the difference between the transaction-volume-weighed average of time-to-settlement of all TBA trades and the transaction-volume-weighed average of time-to-settlement of SP trades of cohort i on day t, r is measured using LIBOR rates corresponding to $\tau_{i,t}$, D_i is the coupon cohort dummy, and $h_{i,t}$ captures the value difference between the MBS traded in TBA contracts and the MBS traded in SP contracts.

Because no data on values of all MBS are available, as discussed in Section 3.1, we follow An et al. (2023) to calculate the measure $h_{i,t}$ based on prepayment characteristics. Specifically, from eMBS, we obtain prepayment characteristics for each outstanding standard TBA-eligible MBS in each month (m), including the weighted-average original FICO score (FICO) and the weighted-average original loan size (Size). These characteristics are key inputs for prepayment models, with the appealing feature that their effects on prepayment risk are largely monotonic (Fabozzi and Mann, 2011). In particular, mortgage borrowers with larger loans or higher FICO are more likely to prepay when it is beneficial to do so, implying higher prepayment risk and lower MBS value.[34] As shown in An et al. (2023) (Appendix B.1), both FICO and Size have statistically significant and economically large effects on MBS values.

We measure the prepayment characteristics of SP MBS using the transaction-volume-weighted average Size and FICO of the MBS associated with SP trades that fall under cohort i on day t, denoted as $Size^{SP}_{i,t}$ and $FICO^{SP}_{i,t}$. To measure prepayment characteristics of TBA MBS, we use the 80th percentile of Size and FICO of all MBS within cohort i in month m (that day t belongs to), denoted as $Size^{TBA}_{i,m}$ and $FICO^{TBA}_{i,m}$, because prepayment characteristics are available at the monthly frequency. We then take the difference between TBA and SP MBS characterizes to capture the difference of TBA and SP MBS prepayment characteristics, in particular, $h^{Size}_{i,t} = Size^{TBA}_{i,m} - Size^{SP}_{i,t}$ and $h^{FICO}_{i,t} = FICO^{TBA}_{i,m} - FICO^{SP}_{i,t}$.[35]

[34] An et al. (2023) also use loan-to-value ratio (LTV). We do not include this characteristic because in stressful times like COVID-19 market disruptions, the positive effects of LTV on default might outweigh its negative effects on prepayment (Fabozzi and Mann, 2011).

[35] Note that although the value measure of TBA MBS is constant within a month, $h_{i,t}$ can vary at the daily level

With the measure $h_{i,t} = \left(h_{i,t}^{FICO}, h_{i,t}^{Size}\right)$ for the difference in prepayment characteristics between TBA and SP MBS, we estimate the regression (B.1) using weighted least squares (by the log of total gross trading volume for cohort i on day t) in the sample period from May 2011 to December 2018, and obtain the coefficient estimates $\hat{\beta}_i$. We choose this sample period before 2020 as the *estimation period* to avoid including confounding effects of COVID-19 market disruptions.[36] Like for our main analyses, we limit the sample to actively-traded coupon cohorts with moneyness in the range of $[-1\%, 4\%]$ (see Section 3.1).

To check the performance, we use $\hat{\beta}_i$ and the associated value difference measures to compute the forward-cash basis for the estimation period as

$$Basis_{i,t} = e^{-r\tau_{i,t}} P_{i,t}^{TBA} - P_{i,t}^{SP} - \hat{\beta}_i \times D_i \times h_{i,t}. \tag{B.2}$$

Then for each month (t), we compute the average across days (t) and coupon cohorts (i). Table B.1 reports summary statistics of these monthly measures of the raw TBA-SP price difference and the forward-cash basis. We observe that the average raw TBA-SP price difference is about -34 cents per \$100 par value while the average forward-cash basis is about -16 cents. That is, the CTD adjustment procedure based on prepayment characteristics does have a large effect in removing the value difference component of the raw TBA-SP price difference.

We finally compute the forward-cash basis at the SP-trade level for the COVID-19 crisis period as

$$Basis_{j,i,t} = e^{-r\tau_{j,i,t}} P_{i,t}^{TBA} - P_{j,i,t}^{SP} - \hat{\beta}_i \times D_i \times h_{j,i,t}, \tag{B.3}$$

where $h_{j,i,t} = \left(h_{j,i,t}^{FICO}, h_{j,i,t}^{Size}\right)$ is computed as the difference between the prepayment characteristics of the MBS of SP trade j within cohort i on day t ($FICO_{j,i,t}^{SP}$ and $Size_{j,i,t}^{SP}$) and the prepayment characteristics of TBA MBS ($FICO_{i,m}^{TBA}$ and $Size_{i,m}^{TBA}$) as computed above.

for a cohort i because potentially different MBS are traded through SP contracts on different days.

[36] We end the estimation period in December 2018 to exclude 2019 particularly because it is the transition period during which the UMBS reform occurred and there might be potential measurement issues.(Liu, Song, and Vickery, 2023).

Table B.1: **Summary Statistics of the CTD Adjustment**

	N	Mean	SD	P25	Median	P75
Raw TBA-SP Price	92	-0.338	0.114	-0.395	-0.326	-0.279
Forward-cash Basis	92	-0.158	0.103	-0.236	-0.165	-0.083

Note: We first calculate monthly series of the cross-cohort (i) volume-weighted averages of the raw TBA-SP price difference ($e^{-r\tau_{i,t}}P_{i,t}^{TBA} - P_{i,t}^{SP}$) and the forward-cash basis in Eq. (B.2). We then compute the summary statistics of the monthly series. We consider the estimation period from May 2011 to December 2018.

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