Resilience redux in the US Treasury market

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Abstract

The resilience of the US Treasury market is limited by dealer balance sheets that are not sufficiently large and flexible to effectively intermediate this market in a "dash for cash," as when COVID became a global pandemic in March 2020. Since 2007, the total size of primary dealer balance sheets per dollar of Treasuries outstanding has shrunk by a factor of nearly four. This trend continues because of large US fiscal deficits and regulatory capital constraints, which are necessary for financial stability but reduce the flexibility of dealer balance sheets. I review approaches for increasing the intermediation capacity of the market and for backstopping Treasury market liquidity with official-sector market-function purchase programs.

JEL codes: G14, D47, D82

I Introduction

On September 1, 1939, the opening of conflict in World War II triggered a surge of sales of US Treasury securities that threatened the ability of dealers to make orderly markets. New York Fed First Vice President Allan Sproul met with dealers at 9:30am, telling them that the Bank was "prepared to see that no disorder develops" and that "we are willing to clean up the dealers' net positions at a price 1/8 below last night's late closing prices."[1] The Federal Open Market Committee authorized purchases of up to $500 million "toward maintaining orderly market conditions."

In this paper, I describe new empirical evidence, with supporting theory, that the current intermediation capacity of the US Treasury market impairs its resilience. The risks include losses of market efficiency, higher costs for financing US deficits, potential losses of financial stability, and reduced save-haven services to investors.

After investigating these implications, I discuss improvements in Treasury market structure and other measures that could increase the market's intermediation capacity under stress. These include broader central clearing, all-to-all trade, post-trade transaction reporting, substituting the Supplementary Leverage Ratio rule with higher risk-based capital requirements, and official-sector market-function purchase programs.

Central banks have occasionally had to rescue their government securities

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[1]See Garbade (2021) and Menand and Younger (2023).

markets from dysfunction by relieving dealers of some of their inventories so that dealers can intermediate the market more effectively. Notably, on March 12, 2020, when the World Health Organization declared COVID-19 to be a global pandemic, some government securities markets became dysfunctional as investors flooded dealers with demands for liquidity. In the US Treasury market, dealers' gross bond inventories and daily purchases of bonds from customers surged to over ten times their 2017-2022 medians.[2] The Fed responded by offering virtually unlimited Treasury financing to dealers and by purchasing nearly a trillion dollars of Treasury securities from them over the next three weeks, among other major actions.[3] It took several more weeks for normal Treasury market functioning to resume. In the meantime customers of dealers faced bid-offer spreads reaching more than ten times normal and interdealer market depth nearly disappeared at some points.[4] Treasury market prices were unstable and settlement failures soared.[5]

Figure 1 illustrates that normal investors in the US Treasury market trade Treasuries exclusively with dealers. Dealers trade with each other bilaterally

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[2]From FR2004 data and market-implied yield volatilities, Duffie, Fleming, Keane, Nelson, Shachar, and Van Tassel (2023) provide statistics on the time series of gross and net total primary dealer positions and dealer purchases from customers in Treasuries, agency mortgage-backed securities, and corporate bonds. With and without risk-adjustment, total gross inventories and customer-to-dealer daily sales peaked at over ten times their corresponding 2017-2022 sample medians.

[3]See Fleming, Sarkar, and Tassel (2020); Garbade and Keane (2020); Fleming, Liu, Podjasek, and Schurmeier (2022); Getz, Remache, Chen, Stowe, Mithal, Brifu, and Chu (2021). On April 1, the Fed temporarily exempted Treasuries and reserves from the Supplementary Leverage Ratio.

[4]See Figure 3 of Logan (2020), Figure 9 of Duffie (2020), and Fleming and Ruela (2020).

[5]See Barone, Chaboud, Copeland, Kavoussi, Keane, and Searls (2022) and Fleming and Keane (2021).
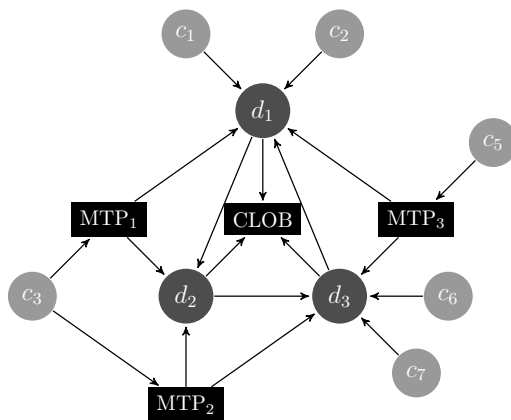
Figure 1: A schematic of the structure of the secondary market for trading US Treasury securities. Light gray represent investors c_1 through c_7. Dark gray dots represent dealers d_1 through d_3. Black rectangles represent trading venues. The Brokertec central limit order book (CLOB) market is for dealers and a selection of high frequency trading firms. Multilateral trade platforms (MTPs) are arranged by firms such as Bloomberg and Tradeweb.

or on a limit-order-book market for on-the-run securities. (High-frequency trading firms also participate on the limit order book market.) Since 2007, as illustrated in the bar chart in Figure 2, the amount of Treasuries outstanding has grown by a factor of nearly four relative to the total size of primary dealer balance sheets. The trend of declining relative market capacity continues because of large US deficits and regulatory capital constraints that keep banks safe but reduce the flexibility of their balance sheets. Entry into the market for providing dealer services is limited.[6] In describing what happened in March 2020, the Federal Reserve Board wrote: "As investors sold less-liquid Treasury securities to obtain cash, dealers absorbed large amounts of these

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[6]The intermediation of trading treasuries a high fixed-cost business with significant additional scale benefits due to the ability to net purchases against sales across customers (Wang, 2017).
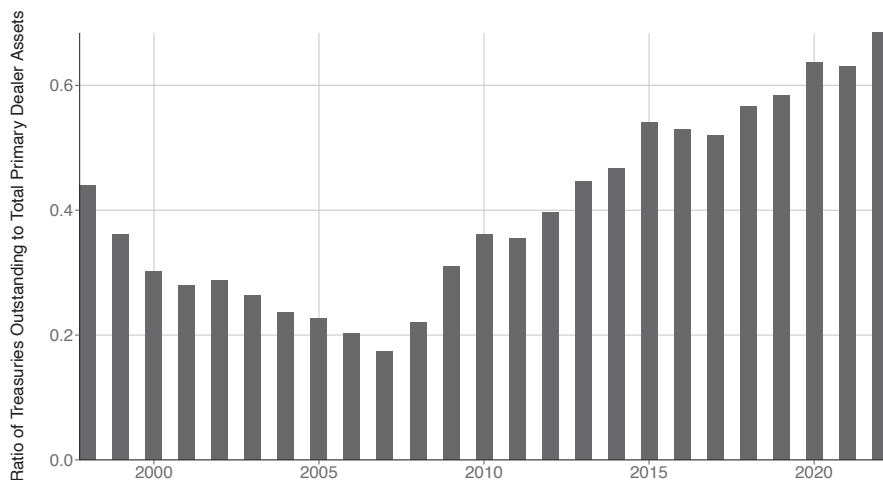
Figure 2: The ratio of US Treasury securities outstanding to primary dealer assets over the period 1998-2022. Data: The Federal Reserve and company filings. Assets are measured at the holding company level.

Treasury securities onto their balance sheets. It is possible that some dealers reached their capacity to absorb these sales, leading to a deterioration in Treasury market functioning."[7] The situation in March 2020 raises concerns over the capacity of dealers to intermediate this market under future stressed economic conditions. Safe-haven investors face a wrong-way risk if Treasury market intermediation capacity limits could plausibly bind just when these investors have an emergency need to liquidate their positions.[8]

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[7]See Board of Governors of the Federal Reserve System (2020). Other accounts of Treasury market dysfunction in March-April 2020 and its implications include those of Brainard (2021), Duffie (2020), Hubbard et al. (2021), Group of Thirty (2021), Government Accounting Office (2021), Board of Governors of the Federal Reserve System (2021), Vissing-Jorgensen (2021), and Committee on Capital Markets Regulation (2021). Fontaine et al. (2021) covers the situation in Canada. Hauser (2020) discusses the situation in the UK gilt market and the actions of the Bank of England.

[8]He and Krishnamurthy (2020) discuss safe-haven services offered by US Treasuries in March 2020.

II Market resilience and safe-haven demands

US Treasury securities are the primary safe haven of global capital markets. A safe-haven asset has two distinct roles. First, in a "flight to quality," many investors sell riskier assets and buy the safe-haven asset. US Treasury security prices therefore tend to rise in a crisis, leading investors to own Treasuries as a crisis hedge.

The second role of a safe-haven asset is manifest when a crisis induces investors to *sell* the asset in order to raise cash.[9] US Treasuries are expected to provide excellent safe-haven services in a "dash for cash" because of the anticipated depth and liquidity of the market in which they are traded, even during a crisis when many large investors are simultaneously liquidating their Treasuries (Das, Gopinath, Kim, and Stein, 2022). However, this dash-for-cash safe-haven service generates a negative demand complementarity. During normal times, each investor who anticipates a need to raise cash in a future crisis prefers to own *less* of a particular asset as a safe haven, other things equal, to the extent that other safe-haven-seeking investors own more of that asset. Investors don't want to suffer a cost of liquidation that is magnified by the price impact of simultaneous sales of many other investors, especially if the underlying market is not sufficiently resilient to efficiently intermediate a flood of demands for liquidity. Until now, despite this negative

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[9]US Treasuries are also particularly useful to many central banks to hold in their foreign exchange reserves because they can be sold at stable or elevated prices for US dollars, which are often needed in a crisis because of dollar funding stresses (Das, Gopinath, Kim, and Stein, 2022).

complementarity,[10] US Treasury securities remain the world's clear go-to safe haven, not only because they are safe if held to maturity, but also because of the expected depth and liquidity of Treasury markets.

In 2020, both of the safe-haven roles of US Treasuries were tested. With the heightening risk of a global pandemic leading up to March 2020, a flight to quality caused US Treasury yields to decline more than the yields of other developed-market government securities, as shown in Figure 3. Then, once the onset of a severe global pandemic was clear by mid-March, a dash for cash caused severe *selling* of Treasuries. The resulting illiquidity in the US Treasury market was worse than that of most other major government securities markets (Barone et al., 2022). The March 2020 dash for cash also had a significant adverse impact on liquidity in the UK gilt market, out of proportion to the extent to which gilts are held in foreign exchange reserves and perhaps related to the level of stressed demand for liquidity in gilts relative to the intermediation capacity of the underlying market.

In short, for US Treasuries to maintain the high level of safe-haven services that they have normally provided to global investors, the intermediation capabilities of the underlying market must be sufficiently resilient to crisis-level selling.

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[10]Coppola, Krishnamurthy, and Xu (2023) show that the demand for US Treasuries is raised by a *positive* complementarity associated with the ease of finding counterparties.
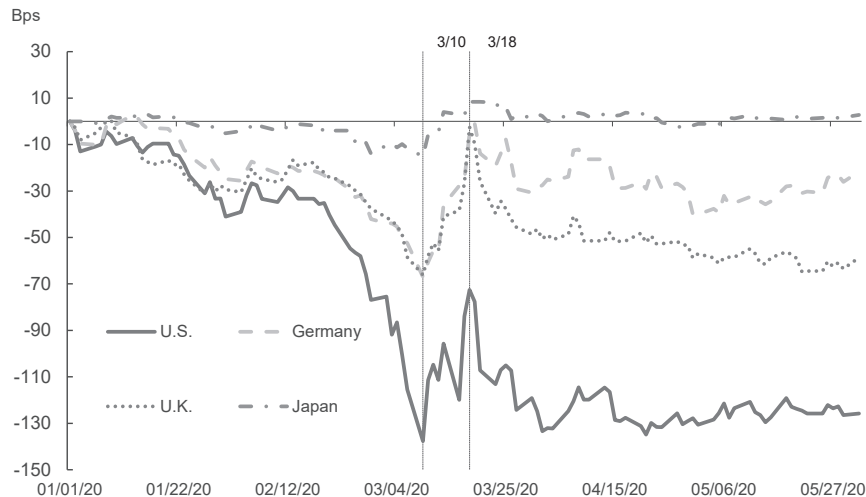
Figure 3: Cumulative changes in 10-year government securities yields, in basis points, from January 1, 2020 to May 30, 2020, for Germany, Japan, the United Kingdom, and the United States. Source: Barone, Chaboud, Copeland, Kavoussi, Keane, and Searls (2022).

III Dealer capacity and liquidity: evidence

The global financial crisis (GFC) led to a major strengthening of capital requirements for large bank holding companies, further tightened in 2014 with the introduction of the enhanced Supplementary Leverage Ratio, followed by requirements under "GSIB scoring" (Tarullo, 2023). While high capital requirements are necessary for financial stability, these capital regulations have reduced the short-run flexibility of liquidity provision to the US Treasury market, given its heavy reliance on bank-affiliated dealers.[11] The long-run rate of growth of the balance sheets of the largest dealers has also

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[11]See Tarullo (2023); Group of Thirty (2021); Adrian, Fleming, Shachar, and Vogt (2017); Breckenfelder and Ivashina (2021); He, Nagel, and Song (2022). Du, Hébert, and Li (2022) provide theory and evidence of a change in the pricing of Treasuries caused by post-GFC capital constraints on dealers.

slowed dramatically since the GFC, especially in comparison with the size of the US Treasury market (Duffie, 2020). The underlying incentive is debt overhang: dealers often refrain from issuing new equity or debt to undertake profitable expansions of their balance sheets because this can adversely impact shareholder return.[12] For example, since the GFC (but not before the GFC), dealers subject to quarter-end capital requirements forego significant profits at quarter ends that could be obtained by arbitraging cross-currency bases in the foreign exchange market (Du, Tepper, and Verdelhan, 2018).

Beyond the impacts of regulation and funding costs on the provision of liquidity by dealers, the flexibility of space on dealer balance sheets for intermediating the Treasury market is also reduced by the complexity of internal capital allocation processes and by agency costs, including the risk aversion and career concerns of their traders and managers.

On typical trading days, Duffie, Fleming, Keane, Nelson, Shachar, and Van Tassel (2023) show that illiquidity in the US Treasury market is well and simply explained by yield volatility. Figure 4 illustrates this nearly linear relationship. The scatter plot shows daily observations of a composite measure of illiquidity versus the average volatility of 2-year, 5-year, and 10-year yields. The yield volatilities are one-month swaption-implied volatilities. The composite illiquidity measure is the first principal component[13] of the

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[12]Beyond higher dealer capital requirements, increased dealer credit spreads induced by other post-crisis reforms imply higher costs for debt and equity financing of dealer inventories, as explained by Andersen, Duffie, and Song (2019) and Berndt, Duffie, and Zhu (2022). Klingler and Sundaresan (2023) analyze dealer balance sheet costs for Treasuries in their Appendix B.4.

[13]The first principal component places significant positive weight on each of the 18
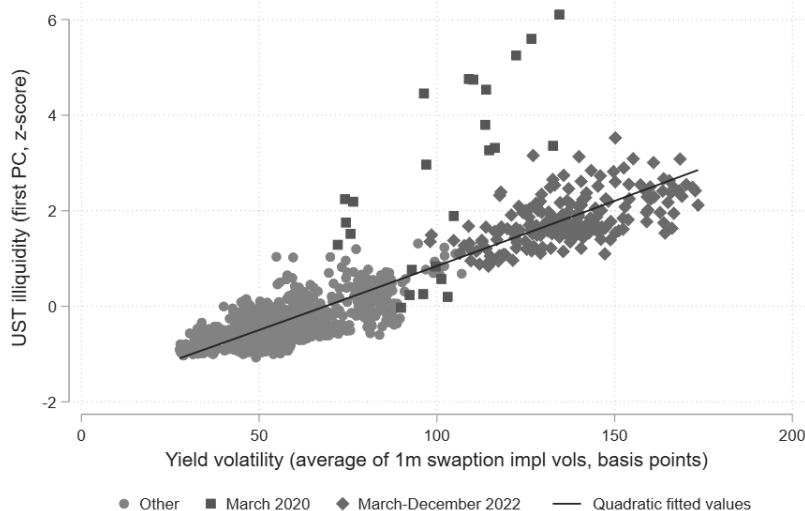
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Figure 4: A scatter plot and estimated relationship between the principal-component composite measure of Treasury market illiquidity and a composite measure of implied volatility, as measured by the average of the standard deviations of benchmark swap rates, in basis points, implied by swaptions on 2-year, 5-year, and 10-year swaps with one-month expirations. The plotted ordinary-least-squares fit, for July 10, 2017 to December 31, 2022 ($T = 1,336$), is the second-order polynomial $y = -1.81 + 0.026x + 0.000005x^2$, where volatility x is in basis points, $R^2 = 79.5\%$. The constant and linear coefficient estimates have p-values of less than 1% under standard assumptions. Source: Duffie, Fleming, Keane, Nelson, Shachar, and Van Tassel (2023).

z-scores of 18 metrics covering, for each of the 2-year, 5-year, and 10-year

maturity sectors of the Treasury market, six different measures of illiquidity.

These illiquidity measures are: interdealer market price impact, lack of inter-

dealer market depth (the negative logarithm of depth),[14] interdealer market

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underlying illiquidity measures, and explains 61% of their variation, in the usual sense of principal component analysis.

[14]Fleming and Ruela (2020) and Fleming and Ruela (2020) find large losses in market depth and increases in price impacts in March 2020. They estimate price impact as the slope coefficient associated with a regression of one-minute price changes on net order flow (buyer-initiated trades less seller-initiated trades). According to JP Morgan analysis by Henry St. John, Joshua Younger, and Sejal Aggarwal, "Total depth at the top 20 levels on both sides of the market collapsed, with a fairly staggering peak-to-trough decline of 92%." (The Life Aquatic: Deeper Depth in the Treasury Market Infrastructure, JP

bid-ask spreads,[15] the yield spread between off-the-run and on-the-run Treasuries, the within-security dispersion of off-the-run transaction yields,[16] and the root mean squared error (RMSE) of yield-curve fitting noise.[17]

Volatility alone explains about 80% of the variation in Treasury market illiquidity. When volatility is higher, dealers tend to reduce their provision of liquidity for a range of reasons unrelated to capacity limits, including the typical risk-versus-return incentives of their traders and the fear of having their quotes adversely selected by informed counterparties, which tends to rise with volatility. The total demand by investors for liquidity provision from dealers, and by dealers for liquidity provision from other dealers, is expected to rise with volatility. As volatility rises, higher demands for liquidity and a reduced supply of liquidity at any given level of dealer compensation imply that the cost or ease of obtaining liquidity rises.[18]

Although yield volatility explains most of the variation in Treasury market illiquidity, Duffie, Fleming, Keane, Nelson, Shachar, and Van Tassel (2023) also show that dealer balance-sheet loading plays an important role,

Morgan Fixed Income Strategy, June 5, 2020.)

[15]The interdealer data are from BrokerTec. The dealer-to-customer transaction data are from TRACE.

[16]See Jankowitsch et al. (2011).

[17]The Hu, Pan, and Wang (2013) noise measure of Treasury market illiquidity is the square root of the mean squared error (RMSE) obtained when fitting the prices of Treasury securities to a smooth mathematical model of the yield curve. The yield-curve fitting model used in this case is the non-parametric model of Filipović et al. (2022), derived from CRSP end-of-day quotes. Using data from 1990 to 2017, Goldberg (2020b) shows that the supply of liquidity by dealers to the US Treasury market goes down as RMSE rises, along with a decline in dealer gross positions.

[18]Bogouslaslavsky and Collin-Dufresne (2023) provide related evidence regarding the relationship between liquidity, volume, and volatility in equity markets.

but only when balance sheets are heavily loaded–a highly nonlinear effect. This supports the proposition that dealer balance-sheet capacity constrains Treasury market intermediation during a dash for cash. When dealer balance sheets are sufficiently loaded, the propensity of dealers to supply liquidity is reduced and the demand for liquidity that dealers request from other dealers rises. Both effects increase illiquidity, and this is consistent with the data. Figure 4 shows that during March 2020 Treasury market illiquidity was at times over three standard deviations worse than predicted by volatility. Figure 5 shows that a significant fraction of this excess illiquidity can be explained by much heavier-than-normal loading of dealer balance sheets. Duffie et al. (2023) estimate dealer capacity utilization based on dealer gross positions, dealer net positions, gross dealer-customer volume, and net dealer-customer volume, all adjusted for risk. When the estimated capacity utilization of dealers is around 20%, Figure 5 shows little estimated marginal impact of increases in capacity utilization on Treasury market illiquidity. However, when dealer capacity utilization rises from 40% to 80%, Treasury market illiquidity is estimated to increase by roughly three standard deviations beyond the level of illiquidity predicted by volatility. The scatter plot reveals a striking nonlinear relationship between balance sheet utilization and market liquidity.

Volatility is likely to be the primary driver of illiquidity in most financial markets, under normal operating conditions. One might therefore view illiquidity that is significantly in excess of the level predicted by volatility
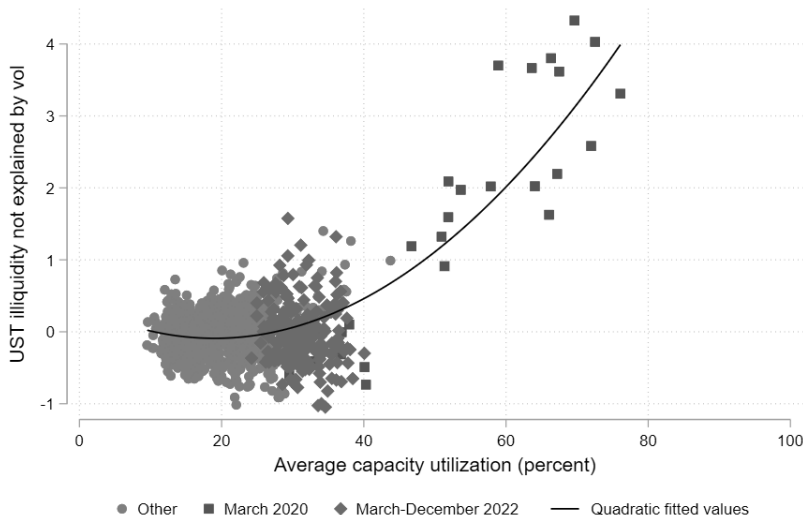
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Figure 5: The relationship between the average dealer capacity utilization and the residual component of Treasury market illiquidity that remains after controlling for average swaption-implied volatility (the residuals associated with the fitted relationship in Figure 4). The average capacity utilization is the average of the dealer capacity utilization measures based on dealer gross positions, dealer net positions, gross dealer-customer volume, and net dealer-customer volume. The plotted ordinary-least-squares fit, for July 10, 2017 to December 31, 2022, is the second-order polynomial $y = 0.363 - 0.048x + 0.0013x^2$, with $R^2 = 43.6\%$. All three coefficient estimates have p-values of less than 1% using Newey-West standard errors. Source: Duffie, Fleming, Keane, Nelson, Shachar, and Van Tassel (2023).

to be a sign of market dysfunction. Despite some limitations, this "excess illiquidity" may be viewed as a index of market dysfunction.

Using quantile regressions, Duffie et al. (2023) also show that extreme levels of illiquidity are predicted to depend heavily on dealer capacity utilization, before or after controlling for volatility. For example, in a univariate quantile regression, the 99th percentile of daily Treasury market illiquidity is predicted to rise 1.2 standard deviations[19] for each one-standard-deviation increase in

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[19]Based on 1336 observations, the estimated standard error of this coefficient is 0.038.

estimated utilization of dealer capacity, as measured by risk-adjusted gross positions. The pseudo-R^2 measure of this fit is 70%. The 50th percentile of Treasury market illiquidity, on the other hand, has a much more muted dependence on dealer capacity utilization, especially after controlling for yield volatility. This again supports the concept of capacity constraints. Marginal changes in balance-sheet loading have only small effects on Treasury market liquidity on normal days, but the same marginal changes in balance-sheet loading have large predicted effects when illiquidity is very high.

Some of the increase in Treasury market illiquidity in March-April 2020 can likely be ascribed to the increased willingness of investors to pay for immediacy from dealers. This increase in the demand for liquidity could be caused not only by a heightened need for cash but also heightened yield volatility or by macroeconomic factors that increase with volatility, consistent with the evidence in Figure 4. An additional increase in illiquidity can be caused by a change in the propensity of dealers to supply immediacy. Some of that change in dealers' supply of liquidity is likely to be related to heightened costs of taking or holding customer positions, which increase with yield volatility, again consistent with the evidence in Figure 4. Additional shifts in the supply of immediacy by dealers could be caused by higher likelihoods of hitting balance-sheet limits in the near future, consistent with the effects shown in Figure 5.

In his analysis of Treasury market liquidity during March and April of 2020, Goldberg (2020a) estimates both an outward shift in the investor de-

mand curve for liquidity and an inward shift in dealers' supply of liquidity.[20] A shift in the supply curve is assumed to lead to opposite-sign changes in price and quantity, proxied by weekly changes in dealer gross positions (FR2004 data). A shift in the demand curve is assumed to lead to same-sign changes in the same two variables. The increase in demand for liquidity in March 2020 is estimated at about 26%, the largest such shift in the sample period, 1990 to 2020. The estimated 17% reduction in the supply of liquidity is the fifth largest of the sample period, the largest being the 29% estimated reduction in liquidity supply that occurred in October 2008, following the Lehman bankruptcy.

Huang et al. (2023) find that transactions costs in the foreign exchange market rise when variables that are correlated with the cost of dealer balance sheet space rise, after controlling for dealer-provided volume.

The implications of dealer capacity limits for Treasury market resilience may worsen in future years because the quantity of Treasury securities that investors may wish to liquidate in a crisis is growing far more rapidly than the size of dealer balance sheets. In 2020 alone, the stock of marketable US Treasuries held by the public increased from about $17 trillion to about $21 trillion. In July 2023, The US Congressional Budget Office (2023) projected that the total amount of Treasury security debt will rise from 98% of US gross domestic product (GDP) in 2023 to 177% of GDP in 2052, far above

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[20]This is based on the vector autoregressive modeling approach developed in Goldberg (2020b).

the previous peak of 106% of GDP in 1946. Yet the dealer balance sheets are not even keeping up with GDP. For example, from 2010 to 2022, the ratio of total primary-dealer assets, at the holding company level, to GDP went down by 18.5%.[21] The stress on dealer balance sheets of handling future surges in trade demands could also be magnified by increases in the volatility of Treasury prices.

IV   Dealer capacity and liquidity: theory

As the basis for a theoretical exploration of the impact of dealer capacity limits on market liquidity and the benefits of a "buyer of last resort," this section extends the dealership model of Amihud and Mendelson (1980).[22] The main theoretical findings are: (1) a dealer's bid and offer prices "bend down" sharply when their bond inventories near capacity; (2) simultaneously, the rate at which the dealer purchases bonds from customers suffers a

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[21]In 2010, based on holding company public filings and FRED (for GDP), this ratio was $26.05 trillion in dealer assets divided by $15.05 trillion of GDP, which is 1.73. By the end of 2022, this ratio had declined by 18.5% to $35.88 trillion divided by $25.46 trillion.

[22]Here, the dealer's objective is maximization of the present value of dealing profits. In Amihud and Mendelson (1980) the dealer's objective is maximization of the steady-state expected net rate of dealer revenue. Amihud and Mendelson (1980) illustrate a solution for the case of linear demand and supply schedules. This model is also in the spirit of those of Garman (1976) and Ho and Stoll (1981). Eisenbach and Phelan (2022) provide a model in which a safe asset market functions well if deep enough, but can break down, with prices falling precipitously, if intermediated by dealers subject to balance sheet constraints. Kalsi, Vause, and Wegner (2023) go beyond the buyer-of-last-resort benefit of creating more dealer balance-sheet space by modeling the ability of a buyer of last resort to reduce self-fulfilling firesale equilibria. Other models of the impact of limited dealer intermediation capabilities or incentives for market liquidity include those of Gromb and Vayanos (2010), Geromichalos, Herrenbrueck, and Lee (2023), Weill (2007), and He and Krishnamurthy (2020).

sharp decline as inventory limits approach; and (3) both of these effects are mitigated by an official-sector market-function purchase program.

The time discount rate is $r > 0$. A dealer's inventory x of a given asset must remain below some integer capacity $\overline{x} > 0$ and above some minimum level, which is taken to be zero without loss of generality for our purposes. With an inventory of x, the total dividend paid to the dealer, net of dealer holding costs, is $d(x)$. For example, if the asset is a perpetual bond that pays one per unit of time, then $d(x) = x$, unless the dealer has holding costs.

At each ask price a, the intensity (mean arrival rate) at which customers arrive and agree to sell a unit to the dealer is $A(a)$. At each bid price b, the intensity at which customers arrive and agree to buy a unit from the dealer is $B(b)$. These intensity functions A and B, which are assumed to be differentiable, reflect trading motives that can arise from investor liquidity shocks, changes in risk preferences, and frictions such as attention and search costs. This setup is illustrated in Figure 6. This model does not incorporate general-equilibrium effects stemming from dealer competition[23] and endogenous changes in the asset holdings of each type of non-dealer investor.

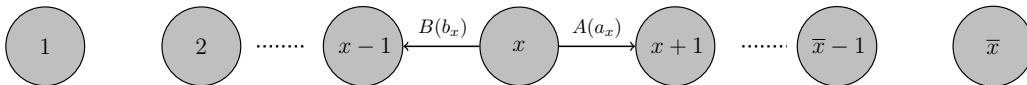Figure 6: Mean dealer purchase rate $A(a_x)$ and sale rate $B(b_x)$ from the current inventory level x at the dealer's chosen ask price a_x and bid price b_x. The dealer's upper bound on inventory is $\bar{x}$. The lower bound of zero, chosen for simplicity, could be replaced with any integer less than $\bar{x}$, including a negative lower bound.

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[23]Ho and Stoll (1983) analyze a related model of dealer competition.

Some of the price elasticity embedded in the mean supply and demand rates, $A(a)$ and $B(b)$, could arise from the cross-sectional distribution of willingness-to-pay of investors and some could stem from the ability of investors to trade with other dealers under imperfect competition (Ho and Stoll, 1983). For example, suppose that investors hoping to buy contact the dealer at some mean frequency $\lambda(b)$ that could depend on the dealer's posted bid b. For any such investor, let ρ be the larger of *(i)* the investor's preference-based value of owning the asset and *(ii)* the lowest alternative bid quote available (or prospectively available) to the investor from other intermediaries. The cumulative probability distribution function of this reservation price ρ is denoted by F. In this example, investors accept a bid b with probability $F(b)$, so the mean frequency of investor purchases is $B(b) = \lambda(b)F(b)$.

At each initial inventory level x, the dealer's maximum expected present value $V(x)$ of future discounted cash flow is achieved by an optimal price quotation policy.[24] At any inventory level x other than the boundary points[25] 0 and $\overline{x}$, the dealer's optimal present value $V(x)$ of inventory and intermediation profits satisfies the Hamilton-Jacobi-Bellman (HJB) optimality

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[24]A complete mathematical specification of the dealer's problem is stated in the Appendix.

[25]For the boundary cases: $\max_a\{-V(0)(r + A(a)) + d(0) + A(a)(V(1) - a)\} = 0$ and $\max_b\{-V(n)(r + B(b)) + d(n) + B(b)(b + V(n - 1))\} = 0$.

condition[26]

$$\max_{a,b}\{-rV(x)+d(x)+B(b)(b+V(x-1)-V(x))+A(a)(V(x+1)-V(x)-a)\} = 0.$$

The first-order necessary condition for an interior optimal ask price a is

$$A'(a)(V(x + 1) - V(x) - a) - A(a) = 0, \quad 0 \le x < \overline{x}, \tag{1}$$

Similarly, an optimal interior bid price b satisfies

$$B'(b)(V(x - 1) - V(x) + b) + B(b) = 0, \quad 0 < x \le \overline{x}. \tag{2}$$

Example 1. Exponential supply and demand. Suppose

$$A(a) = ke^{\alpha a}, \qquad B(b) = ce^{-\beta b}, \tag{3}$$

for positive parameters k, α, c, and β. In this case, we can verify optimality

and compute optimal dealer quotes given a solution V of the HJB equation.

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[26]The condition is that dealer's optimal expected net rate of gain is equal to the "required return" $rV(x)$. At given quotes (a, b), the expected net rate of gain in value is the sum (i) of the dividend payout $d(x)$ net of holding cost, (ii) the mean rate of gain from selling, which is the product of the selling rate $B(b)$ and the gain in value $b+V(x-1)-V(x)$ from a sale, and (iii) the mean rate of gain from buying, which is the product of the buying rate $A(a)$ and the gain $V(x + 1) - V(x) - a$ from a purchase. That a function V solving the HJB equation is in fact the optimal present value of future profits is verified by a standard martingale argument.

The optimal bid and ask at inventory level x are

$$b = V(x) - V(x-1) + \frac{1}{\beta}, \qquad a = V(x+1) - V(x) - \frac{1}{\alpha}. \qquad (4)$$

The bid b is the sum of the dealer's indifference price $V(x) - V(x-1)$ and the direct markup β^{-1}. The indifference price $V(x) - V(x-1)$ embeds the present value of future markups from other investors and future dividends (net of dealer holding costs). Similarly, the optimal offer a reflects the direct rent α^{-1} taken from a seller. The bid-ask spread is

$$\alpha^{-1} + \beta^{-1} + 2V(x) - V(x+1) - V(x-1). \qquad (5)$$

The first two terms of the bid-ask spread are the rents taken directly from sellers and buyers, respectively. The remainder of the bid-ask spread, $2V(x) - V(x+1) - V(x-1)$, is the concavity of the value function V at inventory level x, in a discrete sense. The concavity of the dealer's value for inventory naturally increases as the inventory x nears the capacity $\overline{x}$ because of the increasing marginal cost to the dealer of using up its shrinking balance-sheet space. This is consistent with the empirical results of Duffie, Fleming, Keane, Nelson, Shachar, and Van Tassel (2023) summarized in Section III and with solved numerical examples found below.[27]

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[27]For example, consider the parameters $r = 0.10$, $n = 50$, $c = e^{40}$, $k = e^{-20}$, $\alpha = \beta = 3$, and $d(x) = x$ for all x. At the efficient-market bid price of $b = 1/r = 10$, the dealer buys at the mean arrival rate of $B(10) = e^{-20}e^{3\times10} = e^{10}$ units per year. If the dealer reduces its bid price by 0.1% from 10 to 9.99, the mean purchase rate declines to $B(9.99) = e^{9.97}$. Similarly, at an ask price of $a = 10$, the mean arrival rate of sales is $A(10) = e^{40}e^{-3\times10} =$

Example 2. Isoleastic supply and demand. An alternative special case is isoelastic demand and supply,

$$A(a) = ka^\nu, \qquad B(b) = cb^{-\gamma}, \tag{6}$$

for positive constants c, k, ν, and γ. In this case, the dealer quotes are proportional to the dealer's indifference prices, in that

$$a = \frac{\nu}{\nu + 1}(V(x+1) - V(x)), \qquad b = \frac{\gamma}{\gamma - 1}(V(x) - V(x-1)). \tag{7}$$

For example, with $\nu = \gamma = 400$ and at the median inventory level, the bid-ask spread is about 50 basis points of the dealer's indifference price. Because actual bid-ask spreads in the Treasury market are even smaller, higher elasticities would be needed to calibrate the model to the relatively high degree of competition that normally obtains in the wholesale Treasury market. A large investor's decision to trade with a particular dealer is highly sensitive to the dealer's quotes because of the investor's outside option to search for a better price from another dealer. For the 10-year customer-to-dealer sector of the US Treasury market, for example, Duffie et al. (2023) estimate yield dispersion, a proxy for bid-ask spread in the off-the-run market, at roughly 0.5 basis points on average across days during their sample period, July 2017 to December 2022, and about 1.2 basis points at the 95th percentile. For large

e^{10}. For the present purposes, the model is solved by "value iteration," meaning iterative solution of HJB equation.

elasticities, the bid-ask spread of the isoelastic model is approximately[28] to the concavity of the value function, as for the exponential model.

Panel of Figure 7 illustrates the solution of the optimal quotation policy for a completely specified isoelastic model. Consistent with the empirical results of Du, Hébert, and Li (2022), bid and offer prices are declining in dealer inventory. Moreover, when the dealer's inventory nears its capacity $\bar{x}$, bids and offers decline more rapidly, as the dealer's marginal value of remaining balance sheet space rises, discouraging investor sales and encouraging investor purchases. As inventory rises toward the boundary, the bid-ask spread also widens as a reflection of the increasing marginal indirect cost to the dealer of balance-sheet space.

Consumer surplus is reduced in this setting by dealer pricing power, captured by the elasticity-dependent markups relative to the dealer's indifference price $V'(x)$. Surplus is also reduced by the effect of dealer rationing of balance-sheet space through pricing, reflected in the concavity of the value function. Figure 8 illustrates expected investor surpluses added by trades.

For example, suppose the value u to a potential buyer of owning the asset is distributed exponentially with parameter μ, identically and independently across buyers. At a dealer bid b, the expected surplus of a buyer conditional on a trade is $E(u - b \mid u > b) = 1/\mu$. The expected time rate of buyer surplus at inventory level x is $B(b_x)E(u - b_x \mid u > b_x)$. The case of a selling investors

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[28]For large ν and γ, the formulas shown for a and b imply that $b - a$ is approximately $2V(x) - V(x+1) - V(x-1)$.
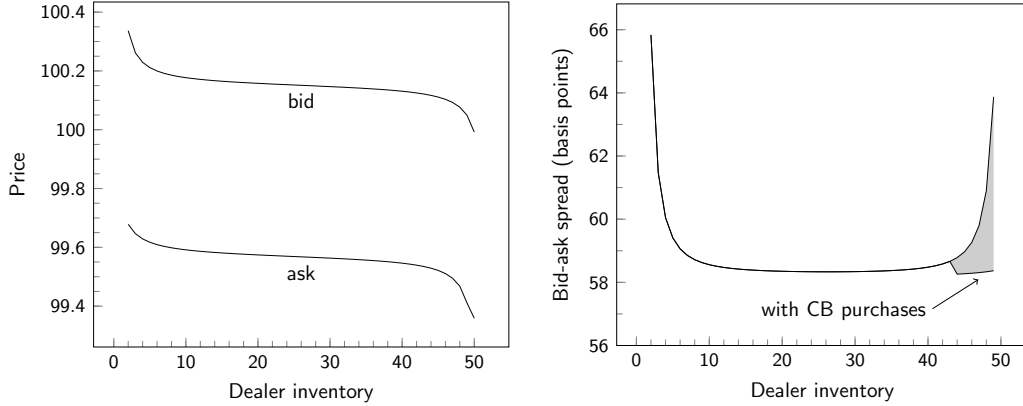
(a) Bid and ask prices for an isoelastic model. Buyer elasticity is $\gamma = 400$. Seller elasticity is $\nu = 300$. The trade-rate constants are $c = 100,000$ and $k = 50,000$. The discount rate is $r = 0.1$. The bond dividend rate is $d(x) = 0.1x$, implying a perfect-markets bond price of $0.1/r = 1$. The prices shown are scaled by 100.

(b) Bid-ask spreads for the isoelastic model shown in Panel (a), with and without a central-bank market-function purchase program. The height of the blue shaded area is the reduction in bid-offer spread caused by the central-bank market-function purchase program through its impact on the shape of the dealer's value function V.

Figure 7: Dealer pricing for an isoelastic model. The central-bank market-function purchase program whose effect on bid-ask spread is shown in Panel (b) is active whenever the inventory level x is at or above $\underline{x} = 45$. Central bank purchases from the dealer are at the mean rate $\lambda(x) = 0.1B(b_x)$ and executed at the mid-price $(a_x + b_x)/2$.

is analogous.[29]

The value to a buyer of owning the asset may be much higher than the trade reservation price of the buyer when facing a given dealer because the buyer's reservation value reflects not only the value of owning the asset, but also expected cost of obtaining the asset from an alternative dealer, including delay and search costs (Duffie, Dworczak, and Zhu, 2017).

To illustrate how a buyer of last resort can increase the dealer's capacity to absorb customer sales, suppose the central bank purchases units of the

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[29]Suppose the value of owning the bond for a randomly chosen potential seller is π. Then the expected time rate of seller surplus is $A(a_x)E(a_x - \pi \,|\, \pi < a_x)$.
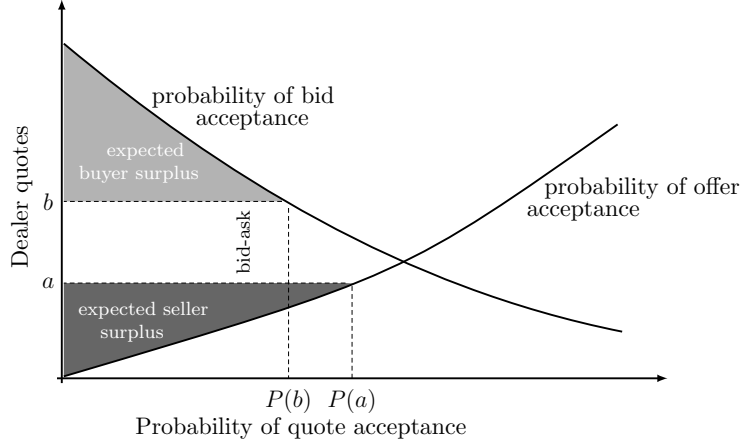
Figure 8: An illustration of the expected buyer surplus (the light shaded area) and expected seller surplus (the dark shaded area) at dealer bid b and ask a quotes, respectively.

asset from the dealer at mean frequency $\lambda(x)$, paying the mid-price $m(x) = (a_x + b_x)/2$. When facing the central bank, the dealer takes $m(x)$ as given, not influenced by dealer quotes.[30]

The theoretical impact of a central bank market-function purchase program on dealer pricing at high inventory levels is illustrated in Panel (b) of Figure 7 and in Figure 9. For this parametric example, the central bank purchases a unit from the dealer at the mean frequency $\lambda(x) = KB(b_x)$, for some constant K, whenever the dealer's inventory x exceeds some threshold

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[30]The modified HJB equation is

$$\begin{aligned} 0 &= \sup_{a,b}\{-V(x)(r + A(a) + B(b) + \lambda(x)) + d(x) + A(a)(V(x+1) - a) \\ &\quad + \lambda(x)\,(m(x) + V(x-1)) + B(b)(V(x-1) + b)\}, \end{aligned}$$

with the obvious elimination of b at $x = \bar{x}$ and a at $x = 0$.

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$\underline{x}$. The central bank's purchases liberate space on dealer balance sheets to handle more customer sales. That is, with the prospect of these central-bank purchases, the dealer expects to be less constrained in the future by balance-sheet space. The concavity of the dealer's value function therefore declines, and at high levels of inventory the dealer optimally raises its quotes to more socially efficient levels than would apply without the market-function purchase program. (I am ignoring the welfare effect of increasing the size of the central bank's balance sheet.) For the illustrated example, the central bank purchases at a mean rate equal to $K = 10\%$ of the rate of purchases of other investors whenever the dealer's inventory is within 90% of its capacity. Although buyers pay a higher price than would be the case without a buyer of last resort, the total surplus is improved whenever the mean rate of gain from trade of sellers is raised sufficiently relative to the lost mean rate of gain from trade of buyers, which is to be expected when prices would otherwise be depressed by elevated inventory levels.

V   Market-function purchase programs

Consistent with the theory in Section IV, empirical research supports the effectiveness of central-bank government-securities purchases in March-April 2020 in support of market functionality.[31] These official-sector purchases reduced the inventories of dealers, liberating space on dealer balance sheets

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[31]See Vissing-Jorgensen (2021); Bernardini and De Nicola (2020), and Fleming et al. (2022).
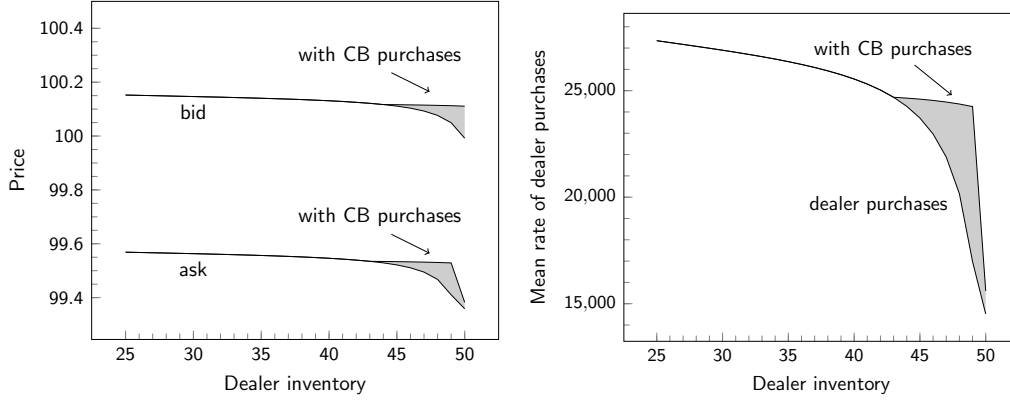
(a) Bid and ask prices for the isoelastic model described in the caption of Figure 7. The between the quotes with a central-bank market-function purchase program and without are the height of the shaded area.

(b) Mean time rate of dealer purchases from customers for the isoelastic model. The difference between the dealer purchase rate with a central-bank market-function purchase program and without is the height of the shaded area.

Figure 9: Dealer quotes and purchase rates for the isoelastic model described in the caption of Figure 7. The central-bank purchase program is active whenever the inventory level x is at or above $\underline{x} = 45$. Central bank purchases from the dealer are at the mean rate $\lambda(x) = 0.1B(b_x)$ and at the mid-price $(a_x + b_x)/2$.

to handle more investor demands for liquidity. For example, Boneva et al. (2020) show that in reverse auctions conducted by the Bank of England, dealers sell gilts more aggressively when they have unwanted inventory, or when they took additional gilt positions just before the reverse auctions, or when they are more constrained by the leverage-ratio rule. They find that "by acting as a backstop in the secondary market for gilts, the BoE's QE purchases have played a role in helping to alleviate market dysfunction and reducing price volatility."

In his Presidential address to the American Economics Association, Bernanke (2020) said: "A possible interpretation is that the initial [2008-2009] rounds

of QE were particularly effective because they were introduced, and provided critical liquidity, in a period of exceptional dysfunction in financial markets." Busetto et al. (2022) write that "In exceptionally stressed circumstances, when dealers' capacity to intermediate trades is limited, large-scale asset purchases can improve wider market liquidity and mitigate the risk of a broader tightening in financial conditions that might disrupt the monetary transmission mechanism. The strength of this channel therefore depends on the degree of market dysfunction and the amount of gilts held by dealers."

Buiter et al. (2023) offer a policy discussion of emergency market-function programs, including both lending of last resort and buying of last resort. A market-function purchase program would naturally be triggered only if lending of last resort by the central bank is insufficient, as was the case in March 2020. Within the first few days of Treasury market dysfunction in mid March, the Fed had saturated dealers with virtually unlimited repo financing of their Treasuries, quickly returning repo rates to normal levels (Copeland et al., 2021). However, in the "cash" market for trading Treasury securities, extreme illiquidity persisted for several more weeks. In response, the Fed purchased an enormous quantity of Treasuries, nearly $1 trillion in the first three weeks of the crisis, as depicted in Figure 10, in addition to large quantities of mortgage-backed securities.

For the largest dealers, those affiliated with US bank holding companies, these purchases failed to liberate as much balance-sheet space as one might have hoped because the Fed paid dealers for its purchases with new reserve

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balances, which have the same capital requirement under the Supplementary Leverage Ratio Rule (SLR) as any other asset, including the Treasuries that the Fed purchased. On April 1, 2020, the Fed temporarily exempted both Treasuries and reserves from the SLR for bank holding companies, although it was not until the middle of May that the Fed, the Office of the Comptroller of the Currency, and the Federal Deposit Insurance Corporation adopted a similar SLR exemption for commercial bank subsidiaries. Treasuries held by bank-affiliated dealers remained subject to risk-based capital requirements, given their obvious re-pricing risk.

He, Nagel, and Song (2020) and Breckenfelder, Grimm, and Hoerova (2022) analyze the implications of bank leverage constraints on market liquidity during the COVID-19 crisis. He, Nagel, and Song (2020) estimate significant "inconvenience yields" for Treasuries associated with the SLR and "find that during the two weeks of turmoil, Treasury yields rose substantially above maturity-matched OIS rates, reflecting the inconvenience yield." The SLR exemptions expired on April 1, 2021.

The Fed's March 2020 program of market-function purchases eventually became a quantitative-easing (QE) program. Market participants may not have had a clear perception at each point of time of how much of current purchases would have sufficed for monetary policy objectives alone. This suggests the transparency value to monetary policy transmission of a clearly demarcated market-function purchase program (Duffie and Keane, 2023). Purchases that are designated to cure a market dysfunction would be ex-

pected have the same monetary-policy impact as concurrent QE purchases, dollar for dollar, but the opposite conclusion applies only to the extent that markets are actually dysfunctional.

Moreover, market-function purchases may be needed just when monetary policy objectives imply tightening, thus sales of government securities! For example, on September 22, 2022, the Monetary Policy Committee of the Bank of England voted to begin selling gilts for the purpose of quantitative tightening. Within a day of this announcement, a UK fiscal policy shock triggered fire sales of gilts by liability-driven investors that destabilized the gilt market. On September 28, the Financial Policy Committee of the Bank of England instituted a program of gilt purchases that restored market stability. On October 22, Bank of England Governor Andrew Bailey stated that "There may appear to be a tension here between tightening monetary policy as we must, including so-called Quantitative Tightening, and buying government debt to ease a critical threat to financial stability. This explains why we have been clear that our interventions are strictly temporary and have been designed to do the minimum necessary."[32]

Hauser (2021) proposed that central banks need "new tools" such as market-function purchase programs to deal with dysfunction in government securities markets. Duffie and Keane (2023) provide a cross-jurisdictional discussion of market-function purchase programs, covering their objectives, effectiveness, and design. They emphasize that the transparency of these pro-
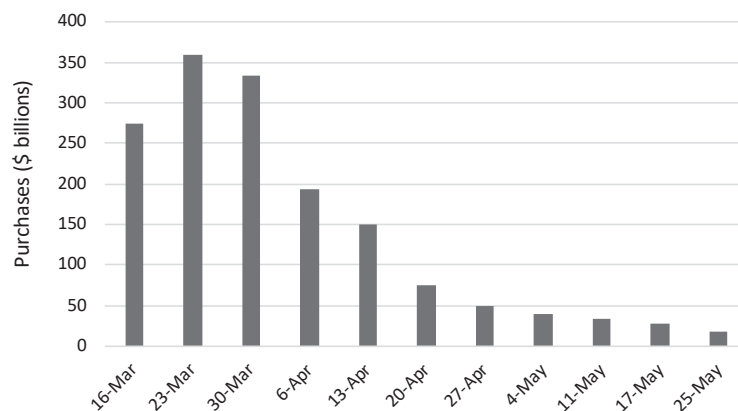
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[32]See Bailey (2022).

Figure 10: Total weekly purchases of Treasuries by the Fed from the week of March 16, 2020. Data: Federal Reserve. Source: Duffie (2020).

grams and the intent to use them in a market-function emergency supports financial stability, the transparency of monetary policy, and the safe-haven quality of government securities. At the point of issuance of government securities, investors will treat the existence of market-function programs that can be activated in a future liquidity crisis as a feature of the securities for which they are willing to pay a premium. Governments would then benefit from stronger primary-market demand, lowering the cost to taxpayers of financing government deficits. The extra price premium associated with improved future safe-haven services would also lead to a more efficient allocation of the securities across investors, given the heterogeneity of investor preference for safe-haven services.

Knowledge of the existence of a liquidity backstop from a buyer of last resort could, however, lead some investors to take additional leverage. This moral hazard can be addressed with improvements in regulation and mar-

ket structure, discussed in the next section, that promote increased market capacity and stability.

Duffie and Keane (2023) note that, at least in some jurisdictions and in some situations, a fiscal authority can conduct market-function purchases in the form of buybacks. As for the United States, where buybacks are likely to be reinitiated, the Treasury Borrowing Advisory Committee stated that "Treasury buybacks are intended to support healthy market functioning but not mitigate episodes of acute stress in markets."[33]

Depending on the setting, fiscal-authority market-function purchase programs might reduce potential tensions over monetary policy communication and in extreme cases could mitigate fiscal dominance concerns. However, there are limits on the speed with which the fiscal authority can conduct purchases, relative to the central bank, which has the ability to immediately fund its purchases by creating reserve balances.

VI   Market structure and capacity

Over time, reforms to the structure of the US Treasury market have been considered primarily for their potential to improve market efficiency and stabil-

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[33]See Treasury Borrowing Advisory Committee (2023). In his May 2023 Quarterly refunding statement, Assistant Treasury Secretary Josh Frost stated that "Based on feedback from a broad variety of market participants, including the Treasury Borrowing Advisory Committee and primary dealers, Treasury believes it would be beneficial to conduct regular buyback operations for cash management and liquidity support purposes. Treasury anticipates designing a buyback program that will be conducted in a regular and predictable manner, initially sized conservatively, and not intended to meaningfully change the overall maturity profile of marketable debt outstanding." See Frost (2023).

ity.[34] Some key potential improvements in market structure may also increase the intermediation capacity of the market, which is my main focus here. These include, especially, broad central clearing and all-to-all trade, which are the main focus of this section. Central clearing increases the amount of trade that can be effectively intermediated on existing dealer balance sheets. All-to-all trade adds intermediation capacity to the market through better matching efficiency for some types of trade and by allowing some trade that does not necessarily require dealer intermediation.

Improving post-trade price transparency with the real-time publication of Treasuries transactions[35] would also improve market intermediation capacity through a more efficient matching of specific types of trades to specific dealer balance sheets (Duffie, Dworczak, and Zhu, 2017). The Fed's new Treasury financing facilities, the Standing Repo Facility (SRF), the Bank Term Funding Program (BTFP), and the Foreign and International Monetary Authorities (FIMA) Repo Facility,[36] could also reduce the likelihood of stressing the intermediation capacity of the US Treasury market by making

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[34]See, for example, US Department of the Treasury and Federal Reserve (1969), US Department of the Treasury, Board of Governors of the Federal Reserve System, Federal Reserve Bank of New York, US Securities and Exchange Commission, and US Commodity Futures Trading Commission (2015), US Department of the Treasury (2017), and Adrian, Fleming, Goldberg, Lewis, Natalucci, and Wu (2013). The most recent broad US official-sector discussions of reforms, Interagency Working Group for Treasury Market Surveillance (2021) and Interagency Working Group for Treasury Market Surveillance (2022), were triggered by the market dysfunction in March 2020.

[35]See Brain et al. (2018).

[36]The BTFP provides financing for banks. FIMA was also established as a special repo facility that allows foreign monetary authorities with a custodial account at the Federal Reserve Bank of New York to obtain repo financing for the securities held in their custodial accounts.

it easier for some investors that need cash, and do not necessarily need to sell their securities, to instead obtain financing for their Treasuries from the Fed. Group of Thirty (2021) and Hubbard et al. (2021) recommend broadening access to the SRF.

VI.A Central clearing

Broad central clearing in the US Treasury market, recently proposed by the Securities and Exchange Commission,[37] could increase the intermediation capacity of the market through several different channels that I outline here. The main purpose of central clearing, however, is to lower counterparty risk and, from that, improve financial stability.[38]

When a trade is centrally cleared, the original buyer and seller are no longer exposed to each other for the settlement of their trade—they instead face the central counterparty (CCP). In case of a default, the surviving clearing members of the CCP are mutually responsible for covering most of ultimate losses.[39] US Treasuries transactions between primary dealers are

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[37]See "SEC Proposes Rules to Improve Risk Management in Clearance and Settlement and to Facilitate Additional Central Clearing for the US Treasury Market," Securities and Exchange Commission, press release, September 14, 2022.

[38]See Duffie (2020), Hubbard, Kohn, Goodman, Judge, Kashyap, Koijen, Masters, O'Connor, and Stein (2021), Group of Thirty (2021), Liang and Parkinson (2020), and relevant reports of The Treasury Markets Practices Group (TMPG) (Treasury Markets Practices Group, 2018, 2019; Treasury Market Practices Group, 2021a,b). The TMPG states at its web site that "The TPMG is composed of senior business managers and legal and compliance professionals from a variety of institutions–including securities dealers, banks, buy side firms, market utilities, and others and is sponsored by the Federal Reserve Bank of New York."

[39]Typically, a CCP operator contributes a comparatively small amount of capital.

centrally cleared by the Fixed Income Clearing Corporation (FICC).[40]

On average, a participant in the US Treasuries market is protected by FICC on about 22% of market transactions.[41] By comparison, central clearing covers virtually 100% of exchange traded derivatives and equities, and the majority of swap-market transactions. In the bilateral non-centrally-cleared Treasury repo market, which is larger than the centrally cleared component of the market, Hempel, Kahn, Mann, and Paddrik (2022) found that a majority of repos have no "haircut" to cover default losses. The lack of central clearing in this market therefore increases both counterparty credit risk and leverage.

Figure 11, from Fleming and Keane (2021), shows a comparison between the daily settlement commitments of Treasuries dealers in the opening months of 2020 and the much smaller settlement commitments that would have applied in a counterfactual market with broad central clearing. As the figure shows, for the same set of trades, central clearing of the entire market would have reduced peak daily settlements in March 2020 from about $1 trillion to about $300 billion, a vast reduction of dealer balance-sheet commitments. Baranova et al. (2023) conduct an analogous study for the UK

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[40]In the current market structure, transactions by principal trading firms (PTFs) in the interdealer market are not cleared by the CCP, but rather are cleared on the balance sheets of interdealer brokers. Customer-to-dealer Treasuries securities trades are not centrally cleared. Some Treasury repos are cleared by "sponsors." FICC clearing members are also responsible for covering the liquidity needs of the CCP, through the Capped Contingent Liquidity Facility.

[41]This is from a simple calculation (Duffie, 2020), based on data from Treasury Markets Practices Group (2018).
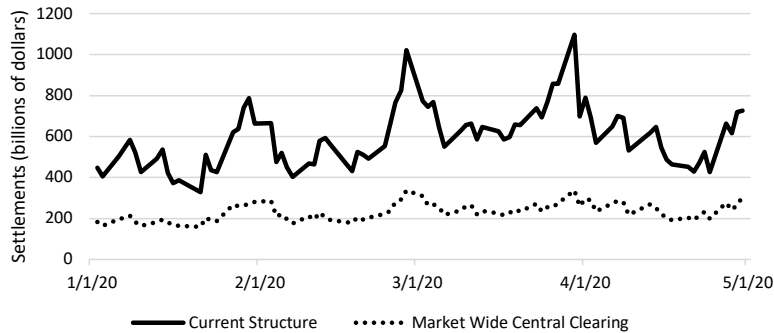
Figure 11: Total daily settlements of US Treasury securities transactions under the current market structure and in a counterfactual market structure with market-wide central clearing. Source: Fleming and Keane (2021).

gilt market, with directionally similar but not as dramatic balance-sheet efficiency gains from central clearing. Chen et al. (2022) show the significant netting benefits of clearing in Canada's government securities market.

In addition to benefiting financial stability, the netting of purchases against sales that is achieved by central clearing also improves the efficiency with which dealers use their balance sheets.[42] Broader central clearing of Treasuries could also, depending on its design, promote the introduction of all-to-all trade of Treasuries by making it simpler for trade platform operators and investors to arrange for safe and efficient trade settlement, without necessarily requiring the intermediation of a dealer. All-to-all trade would further

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[42]In current accounting practice for the determination of US regulatory capital under the SLR requirement, commitments to settle a cash-market Treasuries transaction do not count toward assets, unless the settlement fails. This is not consistent with the regulatory capital accounting treatment for the closing leg of a Treasury repo, which is economically identical, but does count toward assets. Because of this accounting inconsistency, the shareholders of large dealer banks have a regulatory-capital incentive in favor of broader central clearing in the repo market that does not apply to the market for cash Treasuries trading.

increase the capacity and resilience of US Treasury markets, as I discuss in the next subsection.

Central clearing also improves market safety and economizes on dealer balance-sheet commitments by reducing settlement delivery failures, which rose significantly during the most stressful days in March 2020. Fleming and Keane (2021) show that broad central clearing would dramatically reduce delivery failures, which reached $85 billion per week in March 2020, finding that "nearly three-fourths (74%) of fails in specific issues are effectively "daisy-chain" fails, which could be paired off and hence eliminated with increased central clearing. Moreover, the percentage of fails that pair off tends to be higher when fails are higher and in issues where they are higher. It follows that expanded central clearing not only reduces the balance sheet resources needed for intermediation overall through reduced settlement fails, but that the benefits are greatest when they are most needed and for the securities for which they are most needed."

Central clearing comes with some costs. The Brattle Group (2022) collected a range of views of market participants regarding the costs and benefits of central clearing in US Treasury markets. Among the concerns expressed in this survey is the risk of concentrating settlement at a central counterparty. A CCP like FICC is systemically important and, effectively, too big to fail. Because of these concerns, large US CCPs are designated by the Financial Stability Oversight Council as systemically important, which implies a heightened level of supervision by US regulators. Without careful regulation,

supervision,[43] and failure resolution planning, CCPs risk financial instability (Powell, 2017). Market participants also expressed concern over their participation costs for central clearing, which include fees, operational costs, and the cost of funding margin requirements. These costs reduce the incentives of individual firms to participate in central clearing. In effect, each participant is incurring costs to insure other market participants against its own default. Central clearing costs are likely to be more tangible and internalized by market participants than are the broader public benefits of increased financial stability and intermediation capacity. The promotion of public goods is more easily addressed by the official sector.[44]

VI.B   All-to-all trade

The advent of all-to-all trade in the US Treasury market could significantly increase the intermediation capacity of the market, among other benefits such as improved competition and market efficiency.

All-to-all trade means that a broad set of market participants, dealers and non-dealers alike, are able to trade at quotes supplied by each other. This can be achieved on a continuous limit order book, or via all-to-all requests for quotes on an electronic trade platform, or with occasional batch auctions, or by size-discovery trading on dark pools, among other trade pro-

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[43]Hubbard et al. (2021) and Group of Thirty (2021) offer policy recommendations for the case of FICC.

[44]Treasury Markets Practices Group (2019) wrote that "the TMPG believes that to the extent that public policy interests are served by moving to more widespread utilization of central clearing, that is something best addressed by the official sector."

tocols. Analysis of the benefits of all-to-all trade in government securities markets has usually focused on the associated improvements in competition and allocative efficiency (Allen and Wittwer, 2023; Kutai et al., 2022). Like Chaboud et al. (2022), my main focus here is the impact of all-to-all trade on market intermediation capacity and resilience.

In 2022, the Securities and Exchange Commission (2022) discussed reforms that may encourage all-to-all trade in the US Treasuries market, including the removal of exemptions for Treasuries securities to fair-access rules.[45] As I mentioned earlier, central clearing also lowers barriers to all-to-all trade by making it simpler for trade platform operators and investors to arrange for safe and efficient trade settlement without necessarily trading directly with a dealer.

Currently, there is a "done-with" norm in the US Treasury market, meaning that an investor who arranges with a dealer for the central clearing of a trade must also conduct the trade with that same dealer. This done-with practice, among other disadvantages such as reducing competition, also lowers the ability or incentives to conduct all-to-all trade. Anonymous central clearing and a greater flexibility for done-away trades would promote the introduction and adoption of all-to-all trade and thus a likelihood of increased market capacity.

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[45]The SEC proposed a new definition of "exchange" that would have the effect of covering the principal interdealer and multidealer-to-client platforms for Treasury securities and therefore require them to comply with Regulations ATS and SCI. Group of Thirty (2021) and Group of Thirty (2022) explain the implications.

In a future US Treasury market that includes all-to-all trade, investors would continue to conduct some trades directly with dealers but could also expose some of their trading interests simultaneously to many non-dealers and dealers at all-to-all trade venues. Although some all-to-all trade has emerged in the corporate bond market, bilateral trade with dealers retains the dominant share of market intermediation. The option to source liquidity either way would increase market efficiency and the total intermediation capacity of the market (Allen and Wittwer, 2023). I conjecture that market illiquidity on all-to-all trade venues in March 2020 did not significantly exceed levels that are predicted by contemporaneous price volatility. Illiquidity could be measured by bid-ask spread, price impact, and negative log depth. Like a pure dealership market, an all-to-all market has capacity limits related to the willingness of investors to commit capital to the provision of liquidity. However, coupling a dealership market with all-to-all trade venues increases the sources of potential capital commitments to the provision of immediacy by including dealers and many non-dealers. Beyond the wider sourcing of capital, the capacity of all-to-all venues benefits from matching efficiency, relative to pure dealership markets, which have lower pre-trade price transparency and limited bilateral trade relationships. Matching efficiency can be especially impaired if some dealers are nearing their capacity for intermediation. Duffie, Fleming, Keane, Nelson, Shachar, and Van Tassel (2023) provide evidence of high excess illiquidity for the US Treasury market in March 2020 (Section III), and also at the failure of Lehman Brothers in

2008. They show that this excess illiquidity is predicted by the unusually heavy loading of dealer balance sheets at these times.

VII Final remarks

Volatility is likely to explain the majority of variation in illiquidity in many financial markets, except when a market becomes dysfunctional. The extent of illiquidity in excess of that predicted by volatility could be viewed as an index of market dysfunction, despite some limitations of this measure. In the US Treasury market, this dysfunction index is reasonably well explained by heavy loading of dealer balance sheets, which places the resilience of the Treasury market at risk just when safe-haven investors are most dependent on intermediation.

A resilient US Treasury market supports financial stability, dollar dominance, effective monetary policy, capital market efficiency, and the provision of safe-haven services to global investors.

The total amount of Treasuries outstanding will continue to grow rapidly relative to the intermediation capacity of the market because of large and persistent US fiscal deficits and the limited flexibility of dealer balance sheets, unless there are significant improvements in market structure. Broad central clearing and all-to-all trade have the potential to add importantly to market capacity and resilience. Additional improvements in intermediation capacity can likely be achieved with real-time post-trade transaction reporting and

improvements in the form of capital regulation, especially the Supplementary Leverage Ratio. Backstopping the liquidity of this market with transparent official-sector purchase programs will further buttress market resilience.

Appendix: The dealer model and its solution

The dealer problem described in Section IV is more completely formulated as follows. We fix a probability space and an information filtration satisfying the usual conditions. Because A and B are differentiable, for each pair (a, b) in the space $\mathcal{C}$ of bounded and predictable ask and bid processes there is a non-explosive counting process M^a of dealer purchases with integrable intensity process $\{A(a_t) : t \geq 0\}$ (Brémaud, 1981) and a non-explosive dealer-sales counting process N^b with integrable stochastic intensity $\{B(b_t) : t \geq 0\}$. For each initial inventory x in $\mathcal{S} = \{0, 1, \ldots, \bar{x}\}$ and each pair (a, b) of ask and bid processes, a unique dealer inventory process $X^{(a,b)}$ is defined by

$$X_t^{(a,b)} = x + \int_0^t 1_{\{X_s^{(a,b)} < \bar{x}\}} \, dM_s^a - \int_0^t 1_{\{X_s^{(a,b)} > 0\}} \, dN_s^b.$$

The dealer's optimal expected present value of future cash flows is well defined by

$$
\begin{aligned}
V(x) &= \sup_{(a,b) \in \mathcal{C}} E\left[\sum_{j=1}^{\infty} e^{-rS_j} b(S_j) - \sum_{i=1}^{\infty} e^{-rT_i} a(T_i) + \int_0^{\infty} e^{-rt} d\left(X_t^{(a,b)}\right) dt \right] \\
&= \sup_{(a,b) \in \mathcal{C}} E\left[\int_0^{\infty} e^{-rt} \left[b_t B(b_t) - a_t A(a_t) + d\left(X_t^{(a,b)}\right) \right] dt \right],
\end{aligned}
$$

where $T_i = \inf\{t : M_t^a = i\}$ is the time of the i-th dealer purchase and $S_j = \inf\{t : N_t^b = j\}$ the time of the j-the dealer sale. By the usual martingale verification method, any solution of the HJB equation shown in Section can be verified as the value function V and the associated Markov quotation policy $x \mapsto (a_x, b_x)$ can be verified as optimal.

The model is solved by value iteration, as follows. We begin with some initial "guess" $V_0(0), ..., V_0(\bar{x})$ of the solution of the HJB equation, and the bid and ask policies $b_1, ..., b_{\bar{x}}$ and $a_0, ..., a_{\bar{x}-1}$ that solve the associated optimization problems in the HJB equation, after replacing V with V_0. By algebraic rearrangement of the HJB equation, we can update our guess to $V_1(0), ..., V_1(\bar{x})$, where

$$
\begin{aligned}
V_1(0) &= \frac{d(0) + A(a_0)(V_0(1) - a_0)}{r + A(a_0)} \\
V_1(x) &= \frac{d(x) + B(b_x)(b_x + V_0(x-1)) + A(a_x)(V_0(x+1) - a_x)}{r + A(a_x) + B(b_x)}, \quad 0 < x < \bar{x}, \\
V_1(\bar{x}) &= \frac{d(\bar{x}) + B(b_{\bar{x}})(b_{\bar{x}} + V_0(\bar{x}-1))}{r + B(b_{\bar{x}})}.
\end{aligned}
$$

Following this update method, successive iterations $V_0, V_1, V_2, \ldots$ are generated until $\max_x |V_n(x) - V_{n-1}(x)|$ is within a given error tolerance. Any limit of $V_0, V_1, V_2, \ldots$ is the unique solution of the HJB equation.

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