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Abstract

Using thirty-one years of data (1990–2020) on U.S. Treasury dealer positions, we find that Treasury issuance is the main driver of dealers' weekly inventory changes. Such inventory fluctuations are only partially offset in adjacent weeks and not significantly hedged with futures. Dealers are compensated for inventory risk by means of subsequent price appreciation of their holdings. Amid increased balance sheet costs attributable to post-crisis regulatory changes, dealers significantly reduce their position taking and layoff inventory faster. Moreover, the increased participation of non-dealers (investment funds) in the primary market contributes to diminishing compensation for inventory risk taken on at auctions.

Key words: treasury market, dealer, positions, inventory, hedging, issuance

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https://www.newyorkfed.org/research/staff_reports/sr299.html.

1 Introduction

This paper examines the inventory dynamics of U.S. government securities dealers and how they manage the intermediation of new Treasury supply. As Madhavan (2000) notes: "...just as physical market places consolidate buyers and sellers in *space*, the market maker can be seen as an institution to bring buyers and sellers together in *time* through the use of inventory." It is well established that intermediaries are critical to the proper functioning of financial markets and that how they manage their inventory has important implications for market liquidity and asset prices.[1]

This importance takes on a new level when it comes to the U.S. Treasury securities market. It is the "single most important financial market in the world" (Group of Thirty, 2021), with $20.9 trillion in marketable securities outstanding as of the end of 2020. Treasury securities fulfill many vital functions, including financing the U.S. government, providing a pricing benchmark for other financial assets, functioning as instruments for monetary policy implementation, and serving as a safe haven for investors. Therefore, having a well-functioning and efficient market for these securities is critical.

The primary government securities dealers are the backbone of the Treasury market. They underwrite issuance of new Treasury security supply, make secondary markets in these securities, including to the Federal Reserve (the Fed) in its implementation of monetary policy, and are key intermediaries in the multi-trillion dollar market for repurchase agreements (repos). Pertinent to the Treasury market is that issuance is frequent and sizable, subjecting dealer inventories to large and frequently repeated shocks. Because dealers' capital is limited, a question of public interest and policy relevance is how dealers manage to absorb such supply shocks in addition to their regular secondary market making activities. This question becomes even more important as the size of the Treasury market continues to grow (from $2.1 trillion outstanding in 1990 to $5.8 trillion in 2008 to

[1] Early and influential papers such as Garman (1976), Stoll (1978), and Amihud and Mendelson (1980) provide models in which dealers adjust prices to control inventory changes. Hendershott and Seasholes (2007) show that liquidity-supplier inventory has significant effects on contemporaneous and future stock returns. Comerton-Forde et al. (2010) show that the time variation in market liquidity is attributable to market makers' inventories with financing constraints. More recent work by Chung and Huh (2016) shows that the inventory-related component of transaction costs is more strongly correlated with stock returns than the adverse-selection component, underscoring the importance of inventory effects on asset prices.

$21 trillion in 2020) while the balance sheets of the intermediaries stagnated following the 2007–09 global financial crisis (see Adrian et al., 2017b; Duffie, 2020). These trends imply that dealer capital constraints become more binding over time, potentially resulting in greater price pressures associated with issuance-related intermediation activities, unless alternative liquidity providers take dealers' place. As Lou et al. (2013) point out, these issuance-related price pressures are costs borne by the U.S. Treasury, and ultimately, taxpayers.

Numerous empirical papers have assessed the inventory management behavior of dealers in equity markets, futures markets, and the foreign exchange market.[2] However, as of the first draft of this paper, there were far fewer studies examining dealer inventory management in fixed income securities despite the size and importance of such markets; the Naik and Yadav (2003b) study of U.K. government bond dealers is one exception. The literature on fixed income market structure flourished only recently, especially following the 2007–09 financial crisis when the role of the intermediary sector came under greater scrutiny (see Adrian et al., 2017b for a review).[3]

Our paper is the first to analyze how dealers in the U.S. Treasury market manage their positions.[4] In particular, we examine how dealer positions respond to issuance and redemption of Treasury securities—factors affecting dealer inventories not yet well studied in the literature. Our analysis thus offers some insights into the key components that drive dealer inventory dynamics. Extant studies also largely ignore how dealers hedge position changes resulting from primary market intermediation.[5] We fill this gap by studying the extent to which dealers engage in intertemporal

[2]See Hasbrouck and Sofianos (1993), Madhavan and Smidt (1993), and Madhavan and Sofianos (1998) for the New York Stock Exchange, Hansch et al. (1998), Reiss and Werner (1998), and Naik and Yadav (2003a) for the London Stock Exchange, Manaster and Mann (1996) for futures markets, and Lyons (1995) and Cao et al. (2006) for the foreign exchange market.

[3]Transaction data in corporate bonds only became publicly available in the early 2000's. Even among studies of corporate bond dealers' inventory, researchers mainly rely on transaction data to arrive at inventory changes over a given time interval rather than direct data on the level of dealers' inventory at any given point in time.

[4]We use the terms "positions" and "inventory" interchangeably throughout the paper.

[5]Naik and Yadav (2003b) find that U.K. gilt dealers use futures to take directional bets and also selectively hedge spot position changes. They also find that dealers offset changes in their spot risk to a greater extent when the cost of hedging is lower, when capital constraint pressures are greater, and when economic uncertainty is higher. When Naik and Yadav (2003b) examine the profitability of dealer trading strategies, they find no evidence that dealer positions appreciate in value.

smoothing and/or use futures to hedge inventory shocks. Lastly, we investigate whether dealers are compensated for taking on inventory risk associated with Treasury issuance.

Our analysis is based on the weekly net positions of the primary dealers over the July 1990 to December 2020 period, published by the Federal Reserve Bank of New York. Given the scarcity of public data on individual dealers' inventories, the aggregate dealer positions data offer valuable information, allowing us to investigate how the dealer sector absorbs Treasury supply shocks and the asset pricing consequences of such intermediation. Furthermore, the long sample period—spanning a variety of market conditions, including the 2007-09 financial crisis and the sweeping post-crisis regulatory reforms—allows us to examine whether and how the role of dealers in the intermediation of Treasuries has changed over time.

We find evidence of a significant role for dealers in intertemporal intermediation. Specifically, dealers absorb a large share of new Treasury supply so that dealer positions increase during auction weeks. The inventory impact seems to be fairly persistent, lasting at least a week. Furthermore, dealer positions decline at redemption of Treasury securities, suggesting that dealers buy and hold many securities from issuance through maturity and/or that redemptions result in increased demand for other Treasuries from customers that need to reinvest the funds. Our analysis shows that Treasury issuance and redemption by themselves explain a large share of the variation in Treasury dealer position changes, far exceeding the explanatory power of other determinants. Even though dealers evidently smooth auction-induced inventory shocks by taking offsetting positions in adjacent weeks, these offsetting positions are small in magnitude compared to activities during auction weeks. These results highlight a key challenge facing Treasury dealers compared to dealers in other markets: absorbing and carrying frequent, sizable supply shocks over extended periods.

Our analysis also considers how dealers manage their Treasury inventory in relation to their activities in the multi-trillion-dollar repo market. As discussed in depth in Yadav and Yadav (2024), primary dealers are the central gatekeepers of the supply of Treasuries as collateral for secured lending transactions. Thus, how they manage their Treasury inventory has crucial implications for the stability of both the cash and repo markets. We find that dealers' Treasury inventory changes are positively correlated with dealers' net financing activity in the repo market. More importantly, our evidence suggests that dealers engage in repo market activities to support their Treasury inventory management, as opposed to repo market activity leading Treasury inventory changes. Our results thus provide some empirical clarity to the discussion in Yadav and Yadav (2024) of whether primary dealers, being intermediaries in both the cash and repo markets, prioritize one market over the other when faced with scarcity.

We next investigate how dealers hedge their inventory exposure taken on at auction. With a shorter but valuable and unique sample of data on dealers' derivatives positions, we uncover several key results. First, dealers are more likely to hedge exposure associated with coupon securities ("coupons") than with bills, which is consistent with the former's higher interest rate risk. Second, dealers appear to engage in selective hedging depending on the nature of the inventory flow. By separating inventory changes into a component driven by auctions and another driven by dealers' other activities (e.g., speculative trading and secondary market making), we find that dealers are less concerned with hedging auction-related inventory changes than with hedging inventory changes driven by other factors. Because the U.S. Treasury Department is committed to regular and predictable auctions, there is little asymmetric information associated with auction-driven inventory flow, whereas adverse selection is potentially present in the inventory flow due to trades with customers or proprietary trading. That dealers use futures to hedge a much smaller share of the former than they do the latter is consistent with dealers wanting to mitigate adverse selection risk (see Naik and Yadav, 2003b for similar evidence concerning U.K. government bond dealers).

Next, we examine whether dealers are compensated for taking on inventory risk, especially that acquired at auction. We find that auction-induced inventory changes are slightly negatively correlated with contemporaneous Treasury returns but strongly positively correlated with Treasury returns the following week. These results suggest that dealers buy Treasuries during auction weeks when prices are depressed and then resell these securities later after prices have appreciated. We therefore identify and explain a microstructure component of Treasury yield predictability surrounding Treasury auctions not previously explored. Moreover, our findings add to the evidence from equity markets (Hendershott and Seasholes, 2007) that maker-maker inventories have significant asset pricing effects at a multi-day horizon, and show that such effects can exist even when the inventory changes are common knowledge.

Subsequent to the first draft of this paper, other authors have provided further evidence on the general asset pricing effects of Treasury auction cycles. Lou et al. (2013) find that U.S. Treasury security prices decrease in the days leading up to Treasury auctions and then recover. Fleming and Liu (2017) document the same pattern at the intraday level on auction dates. Beetsma et al. (2016) find similar evidence around auctions of Italian public debt. The temporary price pressures around auctions documented in these studies and ours point to dealers' limited risk-bearing capacity being the most plausible explanation. Together, our results contribute to the larger literature on the price impact of demand/supply shocks and the role of frictions arising from limited (and slow-moving) capital that are present even in the most liquid and transparent market settings (see Duffie, 2010).

Our paper further contributes new evidence on changes related to dealers' inventory management and inventory risk compensation amid important market developments since the 2007–09 financial crisis. Specifically, dealers' share of purchases at auction, especially for coupon securities, has declined steadily in the post-crisis period, and is roughly offset by the growing role of investment funds (while the collective share of other investor classes remains quite stable). Moreover, dealers lay off inventory faster within the auction week, especially for bills, thereby having to carry less inventory over the subsequent weeks. The reduced position taking and capital commitment are consistent with increased balance sheet costs attributed to post-crisis regulatory changes and more stringent capital requirements (see e.g., Du et al., 2023).

Surprisingly, compensation for taking on inventory risk at auctions has also declined. We show that the diminished post-auction price appreciation is related to the increasing participation of investment funds in the primary market in the post-crisis period. The greater competition from these new liquidity providers, which traditionally buy securities from dealers in the secondary market, drives down the compensation for intermediation. This helps overcome the decline in dealers' position taking and reduces issuance costs for the Treasury, but increases the primary market's dependence on non-obligatory liquidity providers. Given the current fast growth rate of U.S. borrowing needs, it is prudent to ensure that primary dealers—given their obligations to underwrite Treasury issuance—remain an important part of the primary market.

The paper is organized as follows. In Section 2, we discuss the role of Treasury dealers and institutional features of the market. We detail the data used and variable construction in Section 3. We model dealer inventory dynamics in Section 4 and analyze how dealers hedge inventory shocks in Section 5. We next examine the asset pricing effects of dealer inventory management and evaluate the general auction-cycle price effects in Section 6. In Section 7, we analyze how dealer inventory management and compensation have changed over time. Section 8 concludes.

2 The role of Treasury dealers

U.S. Treasury securities trade in a multiple-dealer over-the-counter market. The predominant market makers are the primary government securities dealers, which are banks and securities broker-dealers that trade with the New York Fed in the course of its open market operations. The dealers also buy securities at auction, make markets for their customers, and take positions for hedging and speculative purposes. In recent years, dealers' roles have evolved with the entry of new participants and tighter regulatory constraints since the 2007–09 financial crisis. We discuss dealers' roles, and how they have changed over time, below.

2.1 Participating in auctions

Certain features of the Treasury market make it a good laboratory for examining how dealers manage their inventory. The primary dealers have a special obligation "to bid on a pro-rata basis in all Treasury auctions at reasonably competitive prices."[6] This underwriting function is somewhat analogous to the "firm commitment" underwriting of an initial public offering, e.g., Ritter (1987). Dealers can consolidate advance customer orders and act as a broker for customer orders at auction

[6]Primary dealers are also expected to "participate in open market operations consistently and competitively," "make markets for the New York Fed on behalf of its official accountholders," and "provide ongoing insight into market developments." Dealer expectations and requirements are posted on the New York Fed's website at `https://www.newyorkfed.org/markets/primarydealers.html`.

(see e.g., Boyarchenko et al., 2021). However, they are expected to place competitive bids for their own account and at a range of prices to ensure that the entire issue is sold at a reasonable price.

Because of this underwriting role, primary dealer inventories are subject to large, predictable changes associated with the Treasury auction cycle. These auction purchases cause dealer positions to deviate from desired levels. While this creates pure inventory risk for dealers, adverse selection risk from trading with counterparties with superior information is small. This is because the Treasury Department commits itself to a "regular and predictable" issuance schedule (Garbade, 2007), explicitly minimizing strategic behavior based on private information. Dealers can hedge the risk of new inventory acquired at auction by selling Treasuries prior to the auction in the when-issued market, selling after the auction in the secondary market, or taking offsetting positions in other Treasury securities or derivatives markets.

2.2 Making markets

Another role of dealers is to make secondary markets, meeting the transaction needs of customers and other dealers by buying and selling securities for their own account. Primary dealers, in particular, are expected to "demonstrate a substantial presence as a market maker that provides two-way liquidity in U.S. government securities" and "maintain a share of Treasury market making activity of at least 0.25 percent." In the last quarter of 2020, primary dealers reported average daily volume (ADV) of $372 billion with customers and $157 billion with other dealers, compared to the $596 billion ADV of the whole market published by SIFMA for 2020.[7] Dealers can hedge positions acquired through market making using the same methods described in the previous section.

2.3 Taking speculative positions

To the extent that dealers have a perceived informational advantage over other market participants, they may take on or maintain interest rate exposure by initiating transactions or by opportunistically hedging positions acquired through market making. For example, a dealer that

[7] Primary dealer statistics are from the Federal Reserve Bank of New York, available at `https://www.newyorkfed.org/markets/counterparties/primary-dealers-statistics`. SIFMA's US Treasury securities statistics are available at `https://www.sifma.org/resources/research/us-treasury-securities-statistics/`. Starting from 2019, SIFMA's ADV statistics are sourced from FINRA TRACE for Treasury data and include trades by dealers (primary and non-primary) that are FINRA members.

expects interest rates to fall in the near future might accumulate a long Treasury securities position. If interest rates do indeed fall, the dealer can sell the securities at a higher price.

Given that there is no asymmetric information about Treasury security cash flows, the ability of market participants to forecast future price changes is probably limited. Nonetheless, it is possible that some market participants are better able to forecast future price changes because they have better information about discount rates. Such information might emanate from fundamentals, such as a superior ability to evaluate the state of the economy, or from technical considerations, such as knowledge of customer order flow or security ownership. Evidence from the literature indicates that order flow of U.S. Treasury dealers is informative for prices (e.g., Fleming, 2003; Brandt and Kavajecz, 2004; Green, 2004; Pasquariello and Vega, 2007).

2.4 New entry and regulatory changes

New entry and regulatory changes since the 2007–08 financial crisis have affected dealers' roles. Even before the crisis, interdealer brokers (IDBs) opened their electronic trading platforms to hedge funds and high-frequency trading firms (HFTs). HFTs employ automated trading strategies in which speed is a key element, usually invest for their own account, employ limited capital, and tend to close the trading day close to flat. The Joint Staff Report (2015) finds that HFTs account for 56% of trading volume in the on-the-run 10-year note compared to bank-dealers' share of 35%, with the remaining 9% split among non-bank dealers and hedge funds.[8]

The effects of new entry by HFTs on primary dealers are likely modest and indirect. In the primary market, HFTs are not active at auction, given the importance of speed to their trading strategies, and their limited capital makes their strategies ill-suited for the inter-day intermediation needed around auctions. In the secondary market, HFTs do not transact with customers given the bifurcated structure of the Treasury market between the interdealer and dealer-to-customer segments. Moreover, even within the interdealer segment, HFTs' participation is limited to the electronic IDBs, which trade only on-the-run coupon securities (Duffie, 2020). HFTs do not trade

[8] On-the-run securities are the most recently auctioned securities of a given maturity. The mentioned statistics are based on trading activity on the BrokerTec platform from April 2–17, 2014.

via the voice-assisted IDBs, which facilitate interdealer trades in all Treasuries, including bills and off-the-run coupon securities (which do not trade electronically).

This is not to say that HFTs do not affect dealer behavior. HFTs likely improve liquidity of the on-the-run coupon securities (which are the Treasuries that do trade electronically). This decreases dealers' costs of trading on-the-run coupons, thereby lowering dealers' costs of making markets (because they can hedge customer trades more cheaply) and taking speculative positions. The effect on dealer position-taking at a weekly level is ambiguous, however, as the improved liquidity lowers dealers' cost of taking offsetting positions, which should decrease their net positions, all else equal, but also increases dealers' incentives to make markets, which could increase their net positions.

In contrast, regulatory changes since the 2007–09 financial crisis and increased participation of investment funds have likely had meaningful direct effects on dealer behavior. Basel III's higher risk-weighted capital requirements and the supplementary leverage ratio, in particular, have reduced dealers' liquidity provision and risk-taking capacity more generally (see e.g., Adrian et al., 2017a). At the same time, increased participation by hedge funds has likely both reduced the demand for dealer liquidity provision and increased the supply of competing liquidity provision. In Section 7, we discuss these changes in more detail and test several hypotheses on how the changes affect the intermediation of primary market issuance and the compensation for providing such intermediation.

3 Data

3.1 Treasury dealer positions

Our data on dealer positions come from the Federal Reserve Bank of New York's FR 2004A statistical release. The Fed collects positions data from the primary dealers on U.S. Treasury securities, agency debt securities, mortgage-backed securities (MBS), corporate debt securities, and municipal debt securities. While our main variable of interest is dealer positions in Treasury securities, positions in the other fixed income securities contribute to a more complete understanding of dealer position management across different fixed income instruments. The data are reported to the Fed on a weekly basis, as of the close of business each Wednesday. The Fed then publishes the data netted and aggregated across dealers with a one-week lag.[9] The data are only available for broad categories of securities (except on-the-run Treasury coupon securities for which security-specific data are available starting from April 3, 2013).[10]

We analyze dealer Treasury positions over the weeks ending July 4, 1990 to December 30, 2020. Spot positions data are available for the full sample period, whereas futures and options data are only available until June 27, 2001.[11] Spot and futures positions are reported in terms of market value.[12] Options positions are reported in terms of the delta-weighted value of the security underlying the option. In our analyses, we combine the options and futures positions and refer to the combined positions as futures positions for brevity.

Summary statistics in Table 1 show that, on average, primary dealers are \$15.86 billion net long in bills but \$9.96 billion net short in coupon securities. Coupon positions also seem to be more volatile than bill positions, with a standard deviation of \$76.6 billion for coupons versus \$17.5 billion for bills. In terms of weekly changes, the average coupon inventory flow exceeds that for bills (\$0.11 billion vs. \$0.04 billion), but both pale in comparison to the corresponding inventory levels.

[9]The positions data were released with a four-week lag until January 15, 2004.

[10]Bills are reported as a distinct category for our entire sample. Coupon securities are reported in several buckets, but bucket definitions change a few times during our sample. The maturity buckets as of the end of our sample period are: 2 years or less, greater than 2 but less than or equal to 3 years, greater than 3 but less than or equal to 6 years, greater than 6 but less than or equal to 7 years, greater than 7 but less than or equal to 11 years, and greater than 11 years. Treasury Inflation-Protected Securities (TIPS) and floating rate notes (FRNs) are each reported in their own buckets and are excluded from the paper (the data we retain reflects positions in TIPS from their introduction in January 1997 until a February 1998 reporting change separated out these positions, and positions in FRNs from their introduction in January 2014 until a January 2015 reporting change separated out these positions).

[11]Spot positions include securities transacted for immediate or forward delivery. For part of our sample, futures and options positions are reported as separate categories, and for part of our sample futures positions are reported together with longer-term forward positions. For Treasuries and agencies, we group longer-term forward positions with futures positions when reported together. Longer-term forwards are a minimal part of the Treasury or agency debt markets, so our processing results in fairly consistent Treasury and agency spot and futures series. For MBS, we group longer-term forward positions with spot positions when forwards and futures are reported together. Longer-term forwards are important in the MBS market, and there has never been a large market for MBS futures, so our processing results in a consistent MBS spot series.

[12]Spot position changes are almost entirely determined by changes in portfolio composition as opposed to valuation effects. For bills and coupon securities, the overall standard deviations of weekly position changes are \$9.49 and \$9.36 billion, respectively, with valuation effects producing standard deviations of \$0.01 billion and \$0.40 billion. The valuation effects are estimated as the weekly price change of the 6-month bill (for bills) or 5-year note (for coupon securities) times dealer positions at the beginning of the week. The paper's findings are essentially unchanged when position changes are adjusted for valuation effects.

These full-sample averages mask drastically different inventory levels over time. As seen in Figure 1, whereas bill positions are mostly positive over the entire sample (fluctuating in the \$0–50 billion range for the most part), net positions in coupons exhibit a structural break around the 2007–09 financial crisis, changing sign from mostly net short to net long. The changed sign of Treasury coupon positions coincides with dealers' declining net long inventory positions in other fixed income securities, most notably corporate bonds, as seen in Figure 2. After the crisis and following post-crisis regulatory changes, dealers significantly cut back their inventory positions in these other fixed income assets (see e.g., Bessembinder et al., 2018), likely lessening the need to hold short positions in Treasury coupon securities as a hedge.

An important consideration in analyzing dealers' inventory fluctuations is whether to scale such fluctuations by the prevailing level of trading activity in the market. Because trading volume fluctuates widely with market conditions, scaling positions by volume would introduce additional variation to weekly changes in dealers' positions and complicate interpretation of results. We thus choose to include trading volume as a control variable in various inventory model specifications. Weekly trading volume data are also from the FR 2004 statistical release.

We also examine dealers' use of Treasury futures in relation to spot Treasury positions. Figure 3 compares dealers' Treasury spot positions with futures positions over the sample period for which futures positions data are available (1990–2001). In both panels of Figure 3, there appears to be a negative correlation between spot and futures positions, with a stronger correlation for coupons (-0.50) than for bills (-0.13). This is consistent with dealers using futures to hedge spot exposures, although the magnitude of futures positions is visibly smaller than that of spot positions (see also Table 1) and the use of bill futures largely fades away after 1995.

3.2 Explanatory variables

3.2.1 Treasury issuance

Our issuance data are from the U.S. Treasury Department.[13] We identify the auction date, issuance size (in terms of par value), and term to maturity of every marketable Treasury security issued over our sample period. Figure 4 plots the average weekly issuance by quarter and shows that bill issuance is about four times greater than coupon issuance, partly due to the fact that bills mature much more quickly than coupons. As reported in Table 1, average weekly issuance amounts to \$82.9 billion for bills but only \$23.2 billion for coupons (the latter includes weeks when there was no coupon issuance). It is also clear from the figure that issuance increases over time, most noticeably in late 2001, mid 2008, and early 2020 corresponding to Treasury's increased borrowing needs following September 11, the 2007–09 financial crisis, and the Covid-19 pandemic.

We also use data on investor class allotment (also from the Treasury Department, starting from August 1, 2001) to compute the specific amounts of Treasury securities purchased at auctions by broker-dealers, of which the primary dealers account for the vast majority.[14] These data allow us to gauge the speed at which dealers lay off their auction-driven inventory, controlling for the variation in the share of issuance purchased by dealers over time.

3.2.2 Treasury redemptions

We collect the maturity date, size, and term to maturity (at auction) of every Treasury security from the same auction history data described above.[15] Most securities are redeemed at maturity, but some were called or bought back in debt buyback operations over our sample period.[16] We collect

[13] The data are available at `http://www.treasurydirect.gov/instit/annceresult/query/query.htm`.

[14] Broker-dealers include both primary and non-primary dealers, but primary dealers account for nearly all broker-dealers' purchases: 87.3% for bills and 89.8% for coupons. These statistics rely on data on primary dealers' purchases at auctions, available from April 23, 2008 onward.

[15] Auction data start from 1980 and thus contain information on only securities issued since 1980. For the 26 securities issued prior to 1980 that matured during our sample period, we manually collect their issue date, maturity date, and outstanding amount as of December 31, 1979 from Table III of the Monthly Statement of Public Debt ("MSPD") for December 1979 (`https://www.treasurydirect.gov/ftp/opd/opdm121979.pdf`).

[16] See Longstaff (1992) for an analysis of callable bonds and Han et al. (2007) for an analysis of debt buyback operations. Our sample also contains five "flower" bonds, which could be effectively redeemed before maturity by being used in lieu of cash to pay estate taxes (see Mayers and Smith, 1987 for an analysis of flower bonds). Maturing

data on calls and buybacks and adjust the weekly redemption amounts accordingly.[17] Over our sample period, 24 bonds with a total par value of $93 billion were called. All of these bonds were originally issued between 1963 and 1984; the Treasury does not currently issue callable securities. Bonds with a market value of $87 billion were bought back in 45 operations between March 9, 2000 and April 25, 2002.[18] Figure 5 plots average weekly redemptions by quarter and shows that called and bought back amounts are dwarfed by maturing amounts. Overall, bill redemptions in our sample average $79.9 billion per week and coupon redemptions $15.4 billion per week.

3.2.3 Central bank purchases

We control for the possible effects of central bank purchases on dealer positions using data on Treasury security holdings of the Federal Reserve and foreign central banks.[19] The holdings data are reported by the Fed on a weekly basis as of the close of business each Wednesday, and thus match the timing of the dealer data. Note that while the Fed data are comprehensive, the foreign central bank data only include holdings held in custody at the Fed and not holdings held through other financial institutions. Over our sample, Fed holdings of bills and coupon securities average $128.9 billion and $930.1 billion, respectively. In the period since the 2007–09 financial crisis, Fed holdings of coupon securities go up significantly (as a result of large-scale asset purchases) from a pre-crisis (1990–2006) average of $274.7 billion to a post-crisis (2007–2020) average of $1,702 billion, while Fed holdings of bills decrease from $193.4 billion to $52.9 billion. Foreign central bank holdings of all Treasuries average $1,496.7 billion (the split between bills and coupons is not reported for foreign central banks), likewise driven by holdings in the post-crisis period (averaging $2,563.6 billion compared to $590.9 billion before the crisis). We use the weekly changes of the

amounts of flower bonds are based on the amounts outstanding at the end of the month preceding maturity (the last of which was in 1998).

[17]Data on called bonds are collected from various MSPDs for bonds issued before 1980, and from the auction history data described above for bonds issued since 1980. Data on buybacks are available at `http://www.treasurydirect.gov/instit/annceresult/buybacks/buybacks.htm`.

[18]Buyback operations resume in October 2014, but these are operational readiness exercises in small amounts. Only $218 million in market value of Treasury coupons and $25 million of Treasury bills were bought back between 2014 and 2020.

[19]The data are available at `http://www.federalreserve.gov/releases/h41/`

Fed's and foreign central banks' holdings to control for central bank purchases in our empirical analysis of dealer Treasury inventory management.

3.2.4 Dealer positions in other fixed income securities

To control for changes in dealer Treasury positions due to activity in other debt securities, we collect data on dealers' positions in agency MBS, agency debt, corporate debt, and municipal debt. These positions are also reported in the FR 2004A release, although data on corporate and municipal debt positions are not available for the full sample period.[20] Over our full sample period, agency MBS positions average $44.9 billion and agency debt positions $50.9 billion. Over the shorter periods for which data on corporate and muni positions are available, corporate debt positions average $96.8 billion and municipal debt positions $17.7 billion. Because of the incomplete data for corporate and muni positions, we instead use data on weekly corporate and muni bond issuance to substitute for positions changes in these instruments. Corporate and muni issuance data are from Mergent. For corporate bonds, we exclude convertible issues, private placements, issues denominated in foreign currencies, and issues of financial institutions. We aggregate issuance amounts by week (ending on Wednesdays) to correspond with our other data. Over our sample, corporate issuance averages $10.5 billion per week and muni issuance $7.2 billion per week.

3.2.5 Dealer repo market activities and financing costs

We collect information on primary dealers' sale and repurchase market ("repo market") activities, also from the FR 2004A statistical release. Specifically, dealers report "Securities In" ("Securities Out") for the amount of funds lent (borrowed) in exchange for receiving (pledging) securities as collateral. Starting with the week ending July 4, 2001, the FR 2004A data also contain "Treasuries In" and "Treasury Out" to reflect lending and borrowing specifically collateralized by Treasury securities, which on average account for about 76% and 65% of "Securities In" and Securities Out" respectively. We use "Securities In/Out" for their long sample coverage, and because they capture more completely dealers' financing as explained in Adrian and Fleming (2005). For ease

[20] Data on corporate debt positions are available from July 4, 2001 and municipal debt positions from April 3, 2013. The corporate debt series includes non-agency MBS from July 2001 to March 2013. Non-agency MBS are split into their own series from April 2013, but we include them with corporate debt for consistency.

of exposition, we refer to such financing as "repo market financing" even though it includes other short-term borrowing and lending activity as well.[21] We measure dealers' net financing ($RepoFin$) as securities out minus securities in.

Data on repo and other relevant rates are from various sources. Daily overnight repo rates and effective fed funds rates for the early part of our sample (from May 21, 1991 to May 29, 2009) are collected from Bloomberg. Because the repo rates are no longer available from Bloomberg, we use repo rates provided by the Depository Trust and Clearing Corporation (available from 2005) for the rest of our sample period.[22] We collect the daily effective fed funds rate for the later part of our sample from the website of the Federal Reserve Bank of New York. We also collect the 3-month Treasury bill and 5-year Treasury rates from the St. Louis Fed's website for the purpose of computing the spreads between the repo rate and the yields on Treasuries held in inventory. Lastly, interest rate volatility as measured by the MOVE index is from Bloomberg. We convert all daily data to the weekly frequency (ending on Wednesdays) by using the last observation for each week.

3.3 Treasury security risk and return

To assess how position changes are related to contemporaneous and future Treasury returns, we use daily Treasury price data from the Center for Research in Securities Prices (CRSP). We extract weekly prices and accrued interest (sampled every Wednesday to correspond with our other data) for the on-the-run 3- and 6-month bills and 2-, 5-, and 10-year notes.[23] We also aggregate any paid interest by week. The weekly returns are then computed as $\frac{P_t+AccInt_t+PaidInt_t}{P_{t-1}+AccInt_{t-1}}-1$, where P_t is the last price of week t, $AccInt_t$ is the accrued interest as of the end of week t, and $PaidInt_t$ is

[21]This slight abuse of terminology is justified by the fact that repos/reverse repos account for the vast majority of collateralized short-term borrowing and lending activities and because the repo/reverse repo terminology is often used to refer to short-term collateralized borrowing/lending arrangements generally, even for financing transactions that are not technically repos/reverse repos. For the period when data on Treasury repo and reverse repo financing are available, starting from the week ending April 3, 2013, such financing accounts for about 94% and nearly 80% of Treasury-collateralized borrowing and lending by dealers.

[22]We verify using the overlap period between the two repo series that they are nearly identical to one another.

[23]When the weekly return for an on-the-run security is missing, we use the return for the first off-the-run security. This is most likely to happen when a security is auctioned on a Wednesday or later in the week (or on a Tuesday before a holiday) and thus the first week's Wednesday-to-Wednesday return is not computable. The data can also be missing as flagged by CRSP. CRSP data are completely missing from September 11-20, 2001, so we exclude from our returns analysis the weeks ending September 12, 19, and 26, 2001.

the amount of paid interest during week t. Weekly excess returns are then calculated as the actual returns minus the expected risk-free returns implied by the secondary market rate on the 3-month Treasury bill prevailing at the beginning of the week.

For our analysis of Treasury returns, we also control for the Treasury return forecasting factor in the spirit of Cochrane and Piazzesi (2005). The Cochrane-Piazzesi factor is derived from a predictive regression of monthly Treasury bond excess returns (at the one-year horizon) on five forward rates. Because our study examines one-week returns, the Cochrane-Piazzesi return forecasting factor is not directly applicable; instead, we control for the return predictability by including lagged forward rates directly in our regression models of excess returns. As in Cochrane-Piazzesi, we use the five forward rates corresponding to years 1 through 5. We compute these forward rates from continuously compounded zero yields provided by Gurkaynak et al. (2007).

Lastly, in our analysis of auction cycle effects, we use daily yield changes around auctions. Daily Treasury yields are from the same CRSP data. Auction date, security term, and other security pertinent information are from the Treasury auction history data described earlier.

4 Treasury dealer inventory management

To study what drives dealer inventory fluctuations, we build on the basic inventory adjustment model that is standard in the literature (see e.g., Naik and Yadav, 2003b or Schultz, 2017):

$$\Delta Inv_t = \alpha + \beta_1 \, Inv_{t-1} + \epsilon_t, \tag{1}$$

where ΔInv_t is the change in net positions over week t and Inv_{t-1} is the net positions at the end of the previous week $t-1$. The coefficient β_1 captures the extent to which dealers adjust their inventory in a given week based on the beginning-of-week inventory level. A negative coefficient indicates that an elevated inventory level prompts a subsequent decrease in inventory, reflecting inventory management around some target level.

From this baseline model, we then consider the effects of Treasury auctions and redemptions. Unique to the primary dealers is the obligation "to bid on a pro-rata basis in all Treasury auctions at reasonably competitive prices." This means that primary dealers have to absorb sizable Treasury supply shocks on a regular basis, and conversely, have their inventory significantly reduced when the securities in their inventories mature. Adding Treasury issuance and redemptions to Equation (1) allows us to quantify the effects of dealers' primary market activity on their net positions. One key advantage of our empirical setting is the exogeneity of these supply shocks: Treasury issuance and redemption are exogenous to dealers' existing positions and risk preferences. Thus, the effects we document truly reflect the extent to which these supply shocks cause the dealers' inventory to change.

In addition to supply shocks related to Treasury securities' life cycle, we also examine several other important drivers of Treasury dealer inventory. First, due to primary dealers' role as counterparties to the Federal Reserve in monetary policy implementation (or in making markets on behalf of its official accountholders), changes in the Fed's Treasury holdings (and those of foreign central banks) can contribute to dealers' inventory changes. After the 2007–09 financial crisis, the Fed conducted large-scale asset purchases as part of its quantitative easing (QE). It unwound many of these purchases in subsequent years, but then initiated market functioning purchases in March 2020 in response to Covid-related disruptions. Quantifying the effects of these actions on dealer inventory enable a better understanding of the role dealers play in facilitating monetary policy actions.

Second, intertwined with their outright Treasury market activities are dealers' activities in the repo market. Specifically, dealers can finance long Treasury positions by borrowing the funds through a repo, using the securities as collateral. Likewise, to take short positions, dealers can borrow the securities through a reverse repo, using cash as collateral. Thus, it is natural to expect dealer repo activities to have some bearing on their Treasury inventory. In particular, the amount of collateralized borrowing net of lending reflects the funding available to support Treasury inventory and is thus expected to be positively correlated with the latter. Coupled with the amount of financing available, we also consider the role of the relevant Treasury/repo spread. The spread is a proxy for the return on inventory holdings net of financing costs, and is expected to be positively correlated with dealer inventory. In this analysis, we also account for changes in interest rates (the fed funds rate) and interest rate volatility.

Finally, it is important to control for other variables that are potentially related to Treasury inventory fluctuations in any given week. To the extent that dealers also trade and make markets in other fixed income securities, it is possible that fluctuations in these other securities' positions also help explain Treasury inventory changes (due to hedging or arbitrage trading motives, or because inventory is managed at the portfolio level). For this reason, we include in the model changes in dealers' agency debt positions, changes in dealers' agency MBS positions, and the weekly amounts of corporate and municipal bond issuance. In addition, we control for the level of dealer trading activity, although the relationship between trading volume and inventory changes is ambiguous (as it depends on whether the trade flow is balanced or one-sided).

The expanded regression model is thus:

$$\Delta Inv_t = \alpha + \beta_1\, Inv_{t-1} + \beta_2\, Issuance_t + \beta_3\, Redemption_t + \gamma'\, Z_t + \epsilon_t, \tag{2}$$

where Z_t denotes the variables discussed above.

We estimate the above regression separately for bills and coupons because the dynamics of bill inventory are likely different from those of coupons. Bill auctions occur every week, with an average weekly issuance amount of roughly \$83 billion. In contrast, there are no coupon auctions in nearly 40% of the weeks in our sample and the average weekly issuance amount conditional on an auction taking place is only about half of the average weekly bill issuance amount. Moreover, as short-dated securities with minimal interest rate risk, bills are not actively traded like coupons for hedging and speculative purposes.[24]

For estimation, some variables are specific to each security type (i.e., issuance, redemptions, changes in Federal Reserve holdings, trading volume, and the Treasury/repo spread variables).[25]

[24] Brain et al. (2018) report average daily trading volume in the on-the-run 2-, 5-, and 10-year Treasury notes of \$52 billion, \$115 billion, and \$93 billion, respectively, but only \$8 billion and \$6 billion in the on-the-run 3- and 6-month bills over the August 2017–July 2018 sample period.

[25] For the Treasury/repo spread, we use the 3-month Treasury bill rate in regressions for bill inventory changes and the 5-year Treasury yield in regressions for coupon inventory changes.

All other variables are only defined in aggregate (e.g., changes in foreign central bank holdings, changes in other fixed income positions, and net financing) or reflect overall market conditions (e.g., the fed funds rate and interest rate volatility) and thus do not vary between the bill and coupon regressions. We report various specifications in Table 2 and discuss our key findings below.

4.1 Inventory mean reversion

The baseline inventory adjustment model presented in Table 2 (column (1) for bills and column (4) for coupons) shows that dealer inventory is mean-reverting and that this mean reversion is stronger for bills (-0.146) than coupons (-0.006). Furthermore, such mean-reverting adjustment explains a far greater fraction of bill inventory fluctuations than coupon inventory fluctuations (based on the R^2 of 7.1% in the bill regression in column (1) compared to 0.2% in the coupon regression in column (4)). Evidence from other securities markets shows that there is substantial variability in dealer willingness to hold new inventory.[26] Here, even among the same class of securities (Treasuries), dealers' inventory strategy differs markedly between bills and coupons.

What can explain the difference in mean reverting behavior of bill and coupon inventory? On the one hand, bills are much less risky than coupons, so dealers should be more willing to hold them. On the other hand, bills are primarily traded by dealers for market making purposes and not speculative or hedging purposes. In contrast, coupons are traded by dealers for all three purposes. As a result, when bill positions deviate significantly from their average level, it is likely because dealers are making markets (primary or secondary) and they naturally want to subsequently close out or offset those positions. When coupon inventory deviates, however, it might reflect dealer market making, or it might reflect a deliberate shift for hedging/speculative reasons, resulting in weaker mean reversion behavior. Nevertheless, the low explanatory power on weekly inventory changes observed for both bills and coupons indicate that the mean-reverting adjustment is only a small part of Treasury dealer inventory management.

[26] For example, in the foreign exchange and futures markets, dealers typically close out their positions by the end of the trading day (Lyons, 1995; Manaster and Mann, 1996). In contrast, inventory adjustment of NYSE specialists seems to be much slower, lasting from several days to as long as one or two months (Hasbrouck and Sofianos, 1993; Madhavan and Smidt, 1993).

4.2 The role of Treasury auctions and redemptions

Adding Treasury issuance and redemptions markedly increases the ability of the models to explain the variation in dealer inventory fluctuations from week to week. As seen in columns (2) and (5) of Table 2, the R^2 jumps to about 26% for bills and 28% for coupons. More importantly, when adding other control variables (reported in columns (3) and (6)), the R^2 further increases only marginally to around 29% and 32%, respectively. The changes in explanatory power across different specifications clearly point to issuance and redemptions as the main drivers of Treasury dealer inventory fluctuations.

The issuance and redemption coefficients indicate the average change in dealer positions over the week relative to the total amount of issuance and redemptions during the week. Using the estimates from the most comprehensive specification (shown in columns 3 and 6), dealers on average finish the week with an extra \$126 million in bill inventory and \$165 million in coupon inventory per \$1 billion of bill and coupon issuance, respectively. Conversely, bill positions decline by an average of \$84 million and coupon positions by an average of \$79 million per \$1 billion of redemptions of these securities. As Treasury securities mature, it is natural to see a reduction in dealers' inventory, because either the dealers themselves hold some securities through maturity (most likely the case with bills) or investors buy other securities from dealer inventory to replace the redeemed ones.

The above estimates quantify the overall effects of Treasury auctions on dealer inventory at the end of the week. We also estimate the model using the actual amount dealers purchase at auction in place of the total issuance amount so that the coefficient on this variable reflects the portion of auction purchases that still remains on dealer balance sheets at the end of the week. As shown in Internet Appendix Table A1, the coefficient estimate is 0.286 for bills and 0.331 for coupons, implying that dealers shed roughly 71% and 67%, respectively, of inventory acquired at auction within the same week.

Still, roughly 29% and 33% of auction purchases remain on dealer balance sheets at the end of the week, requiring considerable capital commitment.[27] Given that broker-dealers purchase about \$70 billion of newly issued bills and over \$13 billion of newly issued coupons per week, on average, Treasury auctions cause dealer inventory to swell, with about \$20 billion in bills and nearly \$5 billion in coupons carried over to the following week. These estimates underscore the important role of primary dealers and the significant capital they commit in underwriting Treasury issuance.

4.3 The effects of monetary policy actions

The inventory model in Equation (2) also enables us to assess how dealer inventory changes due to dealers' obligation to serve as counterparties to the Federal Reserve and make markets on behalf of its official accountholders. Similar to issuance and redemptions, central bank purchases are also exogenous to dealer inventory changes (for the most part), thereby allowing a causal interpretation of the coefficients of these variables. The coefficients reported in columns (3) and (6) of Table 2 indicate that purchases by both the Fed and foreign central banks significantly reduce dealers' coupon inventory, but unsurprisingly not bill inventory. This is consistent with central banks' post-crisis large-scale asset purchases (and the subsequent unwinding of such purchases) being primarily focused on longer-term Treasuries. For every \$1 billion increase in the Fed's (foreign central banks') holdings of Treasury coupon securities, dealer inventory at the end of the week is lower by about \$91 million (\$59 million) (and vice versa).

It is important to note that the above estimates reflect average effects over the whole sample period. However, QE purchases by the Fed (and the subsequent unwinding of such purchases) occurred mainly during and following the 2007–09 financial crisis. Thus, to have a more precise estimate of the effects of the Fed's monetary policy actions on dealers' balance sheets, we re-estimate the regression in Equation (2) using data only from 2009 (when QE purchases of Treasury securities started) to 2019, carefully excluding 2020 because the Fed's intervention at the height of the Covid-19 pandemic is of a different nature (an issue we will discuss below). As reported in

[27] These estimates may be overstated to the extent that dealers pre-hedge auction shocks by shedding inventory in the preceding week. We study dealers' activities in adjacent weeks in subsection 5.1.

Internet Appendix Table A2, the coefficient on changes in Fed holdings is -0.166, meaning that for each $1 billion increase (decrease) in the Fed's holdings during a week, dealers' positions are $166 million lower (higher) at the end of the week.

Does the effect differ when the Fed implemented its QE purchases from when the Fed unwound its balance sheet? To answer this question, we estimate the coefficient on the Fed's actions separately for positive changes (purchases) and negative changes (sales or redemption) and find that the former has a strong negative effect on dealer balance sheets whereas the effect of the latter is insignificant (see column (2) of Internet Appendix Table A2). Specifically, for every $1 billion of Fed purchases, dealers have to carry on their balance sheets a $241 million short position over the following week. Given that the average weekly purchases by the Fed over this 2009–2019 period are about $4.6 billion, such operations require substantial dealer capital commitment to intermediate. On the other hand, the unwinding of the Fed's balance sheet has no effect on dealers' inventory. This is because the QE unwinding occurs exclusively through the natural run-off of securities in the Fed's portfolio, rather than through the sale of such securities. Indeed, data on the Fed's open market transactions in the 2009–2019 period show that there are no Fed sales, except for a short period from October 2011 to November 2012 during which the Fed conducted its Maturity Extension Program (selling shorter-term securities and replacing them with longer-term securities).[28]

The Fed's purchases in March 2020 deserve a separate discussion, because such transactions are not exogenous to dealers' net positions, unlike earlier QE-related transactions. As shown in studies of the Covid crisis (see Duffie, 2023 for a review of the evidence), dealers were overwhelmed by extraordinary customer selling pressure in Treasuries, threatening market functionality and prompting the Fed to step in as "dealer of last resort". The Fed purchased nearly $1 *trillion* of Treasuries in late March – early April of 2020, in addition to providing new financing facilities, to relieve the pressure on the dealer sector and help restore market functioning. For this episode only, the Fed's purchases are endogeneous to and in the same direction as dealers' positions.

[28]This data is available at `https://www.newyorkfed.org/markets/desk-operations/treasury-securities`.

Including 2020 in the full sample estimation thus underestimates the role dealers normally play as counterparties to the Fed in its implementation of monetary policy.

4.4 The link between repo market activity and Treasury inventory

The results reported in Table 2 for the inventory model in Equation (2) also offer a first look into the contemporaneous correlation between dealer repo market activity and Treasury inventory fluctuations, holding all else constant. Changes in the amount of net financing dealers obtain through repo market activities are positively correlated with changes in Treasury positions. The coefficient estimates are 0.038 and 0.049 in the bill and coupon regressions, respectively, with both statistically significant at the 1% level. Notably, we observe no significant contemporaneous relationship between dealer inventory fluctuations and the changes in the interest rate level, the spreads between relevant Treasury yields and repo rates, nor interest rate volatility. It is possible that the amount of net financing dealers can raise already reflects these market movements. Thus, once we control for net financing, these variables do not have incremental explanatory power for dealer inventory.

It is important to emphasize that we do not ascribe a causal interpretation to the net financing coefficients, because the amount of net financing is not exogenous to dealer Treasury holdings. It is entirely possible that an increase in inventory requires financing to carry, or that the increased supply of collateral enables dealers to borrow more in the repo market. Such dynamics would not be satisfactorily captured by the inventory adjustment model specified in Equation (2). Instead, we employ a bivariate vector autogression (VAR) of changes in Treasury inventory holdings and repo financing to gain a better understanding of the dynamic interrelationship of dealer activity in the two markets:

$$\mathbf{y}_t = \boldsymbol{\alpha} + \sum_{j=1}^{p} \boldsymbol{\phi}_j \, \mathbf{y}_{t-j} + \boldsymbol{\eta} \, \mathbf{z}_t + \boldsymbol{\epsilon}_t, \tag{3}$$

where $\mathbf{y}_t$ is a vector variable consisting of changes in Treasury inventory (ΔInv) and net financing (ΔFin), and $\mathbf{z}_t$ includes important variables exogeneous to both Inv and Fin, namely Treasury issuance, redemptions, and changes in central banks' holdings. We rely on the Bayesian Information

Criterion (BIC) to select the optimal lag length p for the VAR model. It is 13 for the VAR of bill positions and net financing and 14 for the VAR of coupon positions and net financing (see Internet Appendix Tables A3 and A4 for parameter estimates of these models).

The estimated VAR model provides important evidence on the direction of effects between dealers' Treasury inventory changes and the financing obtained through the repo market. Do fluctuations in dealer inventory predict subsequent changes in net financing? If so, that would suggest that dealers' repo activity is undertaken to support Treasury inventory management by providing the needed financing. On the other hand, if net financing changes lead dealer inventory fluctuations, that would be consistent with the idea that changes to Treasury inventory are undertaken to provide collateral to support repo market activities.

We formally test the above hypotheses by employing Granger causality tests. We tabulate the F-test statistics in Table 3, which indicate whether the lagged values of one variable can significantly predict the value of the other variable over and above the latter's own lags and other control variables. The evidence strongly suggests a one-way direction of Granger causality: changes to net Treasury inventory (for both bills and coupons) significantly predict subsequent changes to net repo financing, but not vice versa. This result is further corroborated by visual inspection of the generalized impulse response functions, shown in Figure 6. Plots in the left column reveal an increase in net financing in the same week (week 0) and the following week (week 1) after a shock to Treasury inventory in week 0. In contrast, as shown in the right-hand-side plots, following a one-standard-deviation shock to net financing, Treasury inventory increases only mildly (despite the much larger standard deviation of net financing shocks) and only in the same week (week 0) without any further response thereafter.[29]

The lack of response of dealers' Treasury inventory to fluctuations in dealers' repo market activity could be partly due to the common practice of collateral reuse in the repo market. That is, the same collateral can be used in multiple secured financing transactions. Infante et al. (2018) estimate that 85% of primary dealers' incoming collateral immediately flows out, and that a Treasury

[29]Unreported impulse responses per unitary shock expose even greater contrast in the responses of Treasury inventory and net financing to shocks in the other.

security can be re-used between six and nine times, on average. This implies that repo market activity can contract or expand without necessitating commensurate changes in the available amount of collateral. Nevertheless, to the extent that our analysis focuses on the net financing amount (securities out minus securities in), the collateral re-use phenomenon is not of first order importance in driving our results.

In sum, our evidence on the positive relationship between dealer Treasury inventory and dealer repo market financing supports the view that dealers use the repo market to support their market making and other activities (and the resultant inventory) in the Treasury market. In contrast, shocks in dealer repo market financing are far less consequential to Treasury inventory fluctuations, especially in comparison to the much more influential drivers of Treasury inventory documented earlier (i.e., auctions and redemptions).

4.5 Managing inventory interest rate risk

Thus far, our analysis of dealer inventory management is based on the dollar market value of inventory and its determinants. Recognizing that the most significant risks associated with Treasury dealer inventory are the changes in the level and the slope of the yield curve, we also model the inventory adjustment process through the lens of these risk exposures. We measure the risk to yield curve *level* changes by DV01 (i.e., the change in security value due to a one basis point change in yield, or modified duration $\times$ 0.0001). We measure the risk to yield curve *slope* changes by computing the change in security value in response to a one basis point increase in the yield curve slope (defined as the difference between the 2- and 10-year yields), similar to the "Twist" factor in Chaumeton et al. (1996).[30]

We then compute inventory, inventory changes, and issuance in these risk terms, while redemptions become largely irrelevant with respect to interest rate risk. It is important to note that while we can accurately compute duration and twist risks of auctioned securities for the $Issuance$ variable,

[30]We compute this "twist" risk for a given representative bond as follows. We price a bond's cash flows where the yield applicable to each specific cashflow equals a level component plus a prorated term premium based on the prevailing slope. Using the market price of the bond, we solve for the level component of the yield for the bond. We then increase the slope by one basis point and compute the new price, and hence the change in price of the bond.

we do not have security-level positions data to precisely compute these risks for dealer inventory (nor any other variables). The available positions data are aggregated to broadly defined maturity buckets, thereby requiring us to make assumptions on the representative security for each bucket with which to approximate the interest rate risk exposure of the bucket.[31]

Using the above risk measures, we estimate the following regression:

$$\Delta InvRisk_t = \alpha + \beta_1\, InvRisk_{t-1} + \beta_2\, IssuanceRisk_t\, + \gamma'\, Z_t + \epsilon_t, \tag{4}$$

where $InvRisk$ is dealers' inventory risk and $IssuanceRisk$ is the total amount of risk supplied at the auctions in a given week. In this regression, all relevant variables combine bills and coupons, after their respective market values have been weighted by the corresponding appropriate risk measure. The control variables are as in Equation (2). We estimate the regression separately for level change risk and slope change risk and report the results in Table 4.

The results here are largely consistent with the main results in Table 2. Treasury issuance results in a significant increase in the interest rate risk exposure of dealers' inventory. On average, 19% of total level change risk and roughly 31% of total slope change risk supplied at auction remains on dealers' balance sheets at the end of the week. This sizable warehousing of risk once again underscores the important role of dealers in intermediating new Treasury supply.

5 Hedging repeated supply shocks

Evidence from the main inventory model in Equation (2) discussed above suggests that supply shocks due to Treasury issuance weigh heavily on dealer inventory. In this subsection, we investigate the question of how dealers hedge such shocks. We examine two specific channels: 1) intertemporal

[31]For bills, we use the average duration of the on-the-run 3- and 6-month bills, while the twist risk of bills is negligible. For coupons, the maturity bucket definitions change over time. To reduce the effects of measurement error, we use positions data only for the period from July 4, 2001, when coupons are reported in four or more maturity buckets (versus just two before this time). When coupons are reported in four maturity buckets, we multiply the market value of each bucket by the DV01 or twist measure of the corresponding representative on-the-run security, be it the 2-, 5-, 10-, or 30-year security. Lately, coupons are reported in six maturity buckets, so we use the risk measures of the corresponding on-the-run 2-, 3-, 5-, 7-, 10-, and 30-year security accordingly.

smoothing (e.g., selling the to-be-auctioned securities in the when-issued market or similar securities in the secondary market) and 2) using derivatives.

5.1 Intertemporal inventory adjustment

One way for dealers to reduce the impact of supply shocks on their inventory is to engage in intertemporal smoothing of their inventory around Treasury auctions. If they do this, we should observe a decrease of inventory prior to the auction week and likewise, a downward adjustment of inventory after the auction week. To explore this question, we add to the inventory adjustment model in Equation (2) the previous-week and next-week issuance amounts as follows:

$$\begin{aligned}\Delta Inv_t &= \alpha + \beta_1 Inv^*_{t-1} + \beta_2\, Issuance_t + \beta_{2a}\, Issuance_{t-1} + \beta_{2b}\, Issuance_{t+1} \\ &\quad + \beta_3\, Redemption_t + \gamma'\, Z_t + \epsilon_t. \end{aligned} \tag{5}$$

The model contains the same set of control variables previously discussed, except that the starting inventory level Inv^*_{t-1} excludes the effects of $Issuance_{t-1}$. That is, $Inv^*_{t-1} = Inv_{t-1} - \hat{\beta}_2 \times Issuance_{t-1}$, where $\hat{\beta}_2$ is estimated from the main inventory model in Equation (2) (reported in column 3 and column 6 of Table 2 for bills and coupons, respectively). This way, we can isolate the effects of $Issuance_{t-1}$ on inventory changes in week t without it being subsumed by the starting inventory level. Thus, β_{2a} reflects the extent to which dealers continue to sell the inventory acquired at the previous week's auctions and β_{2b} reflects the extent to which dealers preemptively adjust their inventory in preparation for auctions in the upcoming week (or pre-hedge).[32] We run the regression using two alternative $Issuance$ variables. The first is the total issuance amount, while the second is just the portion of total issuance purchased by broker-dealers. We report β_2, β_{2a}, and β_{2b} of the former in Panel A and of the latter in Panel B of Table 5.

Panel A indicates that dealers indeed engage in intertemporal smoothing of their auction-driven inventory shocks, with positions declining in both the week before and the week after a given auction

[32]Dealers can pre-hedge by selling from inventory securities similar to those expected to be acquired at auction or by selling securities in the when-issued market. FR 2004A data includes when-issued positions. Because auction schedules and offering amounts are announced well in advance, the amount of next-week's issuance $Issuance_{t+1}$ is known during week t and therefore can be included in the regression to explain dealers' position changes in week t.

week. Specifically, dealers' bill positions decline by about \$78 million in the week before and about \$42 million in the week after, partially offsetting the auction-week inventory increase, per each \$1 billion of bill auction amount. Intertemporal inventory adjustment of coupons appears weaker, with significant effects observed only in the week after the auction week (a decrease of \$29 million). Consistent across bills and coupons, the adjacent weeks' inventory adjustment pales in comparison to the increase in inventory in the auction week, indicating that these inventory shocks take time (more than three weeks starting from the week before) to fade from dealers' inventory. Adding these coefficients together, we approximate that for each \$1 billion of new Treasury issuance, roughly \$75 million in bill inventory and \$130 million in coupon inventory remain on dealer balance sheets a full week following the auction week. With average weekly bill and coupon issuance amounts of \$82.9 billion and \$23.2 billion respectively, our estimates indicate that Treasury dealers carry roughly \$9.2 billion additional inventory on their balance sheets beyond the studied horizon. These results illustrate significant capital commitments by primary dealers over multiple-week horizons in underwriting newly issued Treasury securities.

Panel B zooms in on the issuance amounts purchased by dealers (as opposed to the total issuance amounts) and shows a qualitatively similar but statistically much stronger pattern than that in Panel A. Panel B affords us a more accurate estimate of the speed at which dealers lay off their auction-driven inventory. The same-week coefficient of 0.34 (0.31) for bills (coupons) indicates that dealers are able to immediately lay off about 66% (69%) of their auction purchases within the same week. The 34% (31%) unsold inventory at the end of the auction week is partially offset by preemptive selling in the preceding week (8.7% for bills and 4.7% for coupons) and by continued selling in the week after (7.2% for bills and 8.4% for coupons), leaving roughly 18% of dealers' auction purchases being intermediated over a longer time frame.

5.2 Hedging with derivatives

Another way to hedge inventory shocks is through the use of derivatives. Naik and Yadav (2003b) find that U.K. government bond dealers hedge spot positions with futures. Do U.S. primary dealers similarly hedge their inventory shocks by taking offsetting positions in Treasury futures? If so, there should be a negative relationship between changes in dealers' spot and futures positions. Furthermore, because hedging reduces risk, we should observe greater hedging for positions deemed riskier. More specifically, we expect the correlation between futures and spot position changes to be more negative for coupons compared to bills, and more negative for inventory changes that are subject to greater adverse selection.

We shed light on this question using the subsample of FR 2004 data on dealers' futures and options positions (1990–2001), with the obvious caveat that dealers' use of derivatives for managing inventory shocks might have changed since 2001. To proceed, we first regress weekly changes in futures positions on changes in spot positions, separately for bills and coupons, and report the results in columns (1) and (3) of Table 6. Supporting our hypothesis, we find that Treasury futures and spot position changes indeed tend to move in opposite directions. The coefficient on bill spot position changes is small and marginally significant: bill futures positions decrease (increase) by \$15 million for every \$1 billion increase (decrease) in bill spot positions. In contrast, the coefficient for coupon positions is both sizable in magnitude and highly significant. On average, coupon futures positions decrease (increase) by \$232 million for every \$1 billion increase (decrease) in coupon spot positions. The R^2 in columns (1) and (4) (0% and 19% for bills and coupons respectively) clearly show that dealers use futures to hedge mainly coupon spot positions. Nevertheless, even for coupons, the hedge ratio is significantly less than one, suggesting that dealers still leave a significant amount of risk unhedged.

Next, we examine whether dealers selectively hedge certain components of their inventory flow. Naik and Yadav (2003b) find that U.K. gilt dealers hedge more when perceived informational asymmetry is high, such as on days before major macroeconomic announcements. Thus, we expect to see greater hedging from the component of inventory flow with greater adverse selection. Using our inventory model, we separate position changes into components attributable to issuance, redemptions, and other factors (which may reflect speculative, hedging, or customer flows). Because auctions are designed to have minimal adverse selection (e.g., due to Treasury's commitment to a regular and predictable auction schedule), the auction-driven inventory flow should have little adverse selection risk. In contrast, position changes due to market-making activities or speculative trading might emanate from trades that are based on private information. These are the types of inventory changes that a dealer would prefer to hedge. Therefore, we hypothesize that the use of derivatives to hedge auction-related inventory changes is lower than that to hedge inventory changes driven by other factors. We also predict no hedging need for position changes due to redemptions, because securities that are about to mature have very low price risk and high redemption liquidity (they are about to be turned into cash), obviating the need for hedging.

For the decomposition of inventory changes, we first estimate the regression model specified in Equation (2) (again separately for bills and coupons) using data over the shorter sample period used in this section. Thus, the auction-driven component of inventory changes is computed as $\Delta Inv_{issuance} = \beta_2 \times Issuance$ and the redemption-driven component as $\Delta Inv_{redemption} = \beta_3 \times Redemption$. Position changes due to other factors are thus $\Delta Inv_{other} = \Delta Inv - \Delta Inv_{issuance} - \Delta Inv_{redemption}$. To test for selective hedging, we regress futures position changes on all three components of spot position changes and report the results in columns (2) and (4) of Table 6:

$$\Delta Fut_t = \alpha + \beta_1 \Delta Inv_{issuance} + \beta_2 \Delta Inv_{redemption} + \beta_3 \Delta Inv_{other} + \epsilon_t. \quad (6)$$

The results reveal that futures are mainly used to hedge spot position changes driven by other factors, not issuance nor redemptions, consistent with our hypothesis of selective hedging to mitigate adverse selection risk. For bills, the coefficient on spot position changes due to other factors is a significant -0.042, while the ones due to issuance and redemptions are not significant. Bills have low duration risk, which likely explains the lack of hedging for inventory changes due to their issuance. For coupons, the coefficient on position changes due to issuance is significantly negative (-0.140), but much smaller in magnitude than the coefficient on position changes due to other factors (-0.282).

Overall, the results show that dealers use futures to hedge their Treasury spot position changes only to a limited extent, and mainly for coupons rather than bills. Even for coupons, the focus of hedging is on position changes that are susceptible to adverse selection risk rather than position changes related to the auction-redemption cycle. We conclude that even though issuance is the main driver of dealers' weekly inventory changes, dealers appear to leave issuance-driven inventory changes largely unhedged.

6 Compensation for intermediating Treasury supply shocks

In their underwriting and market-making roles, dealers accumulate undesired inventory. This inventory is costly to dealers, because it generates both price risk (i.e., the risk that the value of inventory holdings fluctuates with price changes) and asymmetric information risk (i.e., the risk that dealers are stuck with informationally undesirable holdings). In this section, we investigate whether and how much dealers are compensated for taking on such inventory risk, specifically in the form of price appreciation following inventory acquisition. For this, we conduct two complementary analyses. First, we specifically examine the link between dealer inventory flow and Treasury excess returns. Second, we study the general price patterns around Treasury auctions following the approach of Lou et al. (2013) by testing for systematic price depreciation in advance of auctions and price appreciation following auctions. The idea is that compensation for risk need not only be received by dealers. Other market participants who provide liquidity services (e.g., hedge funds and proprietary trading desks) would also receive such compensation.

6.1 Dealer compensation for inventory risk

The existing literature addresses several closely related questions. First, a number of studies have shown that dealers are compensated for participating in the primary market in that Treasuries tend to be auctioned at prices lower than those in the secondary market; e.g., Cammack (1991), Spindt and Stolz (1992), and Simon (1994). These analyses of auction underpricing focus on contemporaneous differentials between primary and secondary market prices. In contrast, we examine changes in secondary market prices around auctions. If such prices systematically increase following auctions, dealers gain through the appreciating value of their inventory, which serves as compensation for holding such positions. Thus, the compensation we document is separate and *in addition to* any underpricing dealers obtain at auctions.

Second, many studies have documented a negative relationship between Treasury supply and prices. Simon (1991), Simon (1994), Duffee (1996), and Fleming (2002) examine the effects of individual issue sizes. Greenwood and Vayanos (2014) study the effects of long- versus short-term supply, while Krishnamurthy and Vissing-Jorgensen (2012) analyze overall outstanding Treasury supply. Different from these studies, which identify permanent price effects of Treasury supply, we examine the transitory price impact associated with frequent and publicly known supply shocks and the reallocation of such shocks from a small group of intermediaries to a broader set of market participants.

Our analysis is most similar to Hendershott and Seasholes (2007) in that we explore whether there is a transitory but somewhat persistent price effect of shocks to market-maker inventories. However, an interesting difference is that Hendershott and Seasholes (2007) focus on price effects of private-knowledge inventory shocks measured using individual NYSE specialist inventories. In contrast, our analysis measures price effects of predictable, publicly known inventory changes; namely, those due to Treasury issuance. The fact that the size and timing of the issuance inventory changes is common knowledge does not preclude a price effect to the extent that such an effect is fair compensation for bearing inventory risk.[33] The existence of a price effect around known and repeated supply shocks is also consistent with the idea that investor capital is not mobile enough to immediately absorb these sizable supply shocks (as in Duffie, 2010).

Thus, the main hypothesis we seek to test in this section is whether dealers acquire positions at prices below their long-run expected value, implying that such positions should subsequently appreciate in value.[34] However, it is also important to recognize that dealers' order flow might contain information that moves prices, especially for the order flow originating from the dealers themselves (e.g., due to proprietary trading). Earlier studies (e.g., Fleming, 2003; Brandt and Kavajecz, 2004) show that dealer order flow is informative for U.S. Treasury security prices.

[33] As noted, since the first draft of this paper, Lou et al. (2013) find that U.S. Treasury security prices decrease in the days leading up to Treasury auctions and then recover.

[34] As explained in Hendershott and Seasholes (2007, p. 210), "Empirical studies linking liquidity provision to asset prices follow naturally from inventory models... [L]iquidity suppliers/arbitrageurs are willing to accommodate trades — and, therefore, hold suboptimal portfolios — only if they are able to buy (sell) at a discount (premium) relative to future prices."

Thus, an increase in dealer positions—implying dealers are buying—might be accompanied by a contemporaneous price increase, which is opposite to the prediction of a negative contemporaneous relationship under the inventory risk compensation channel discussed above.

Without detailed data on different types of order flow in and out of dealers' inventory, it is challenging to separate the inventory risk compensation effects of order flow from the informational price impact of order flow. However, our empirical analysis allows us to distinguish between these competing channels. Specifically, based on our inventory adjustment model in Equation (2), we decompose dealers' position changes into a component driven by Treasury auctions and a component due to other factors. This decomposition is important because of the very different informational content of the components. The first component—an important part of dealer inventory fluctuations as demonstrated by our earlier results—is arguably free from information. This is because Treasury auctions are on a regular schedule and details are announced in advance, intentionally designed to minimize any adverse selection. Thus, any price effects observed for issuance-driven inventory changes can be cleanly attributed to compensation for bearing inventory risk, free of informational effects.

On the other hand, the second component of dealers' inventory changes captures dealers' order flow due to their trading with customers in the secondary market, as well as any hedging and speculative trading activity by the dealers. As a result, this component is likely informative, based on evidence from the literature discussed above. Thus, a contemporaneous and positive relationship between this component of dealer inventory flow with price (without reversal) would provide supporting evidence for the informational content of dealer order flow separately from the inventory risk compensation channel.

To formally test the above hypotheses, we regress weekly excess returns on contemporaneous and lagged values of the two components of dealer inventory changes. To control for the Treasury return predictability documented by Cochrane and Piazzesi (2005), we include five forward rates as in their model. Thus, the regression model is:

$$
\begin{aligned}
r_t \;=\;& \alpha + \beta_1 \Delta Inv_{issuance,t} + \beta_2 \Delta Inv_{others,t} + \beta_3 \Delta Inv_{issuance,t-1} + \beta_4 \Delta Inv_{others,t-1} \\
& + \gamma_1 f_{t-1}^{(1)} + ... + \gamma_5 f_{t-1}^{(5)} + \epsilon_t, \qquad (7)
\end{aligned}
$$

where r_t is the weekly excess return on a given Treasury security. $\Delta Inv_{issuance}$ is dealers' weekly position change due to Treasury auctions, ΔInv_{others} is dealers' weekly position change due to other factors, and $f^{(i)}$ are forward rates for years 1 through 5.[35] We estimate this regression using excess returns for the on-the-run 3- and 6-month bills, and the 2-, 5-, and 10-year notes. Bill returns are regressed on changes in bill positions and coupon returns on changes in coupon positions. To assess the incremental predictive power of dealers' position changes, we also report the increases in R^2 relative to Cochrane-Piazzesi styled regressions with just the five forward rates.

Based on the hypotheses outlined above, a negative β_1 and positive β_3 would provide support for the idea that dealers are compensated for taking on inventory risk. The negative β_1 would imply that dealers are taking on long positions when the price is declining. The positive β_3 would imply that the price subsequently increases the week after the inventory acquisition. On the other hand, a positive β_2 would indicate that dealer inventory flow due to non-issuance factors is informative, consistent with the literature. If this information content takes time to be incorporated into prices (beyond the current week), we should observe a positive β_4 as well.

We tabulate the results in Table 7. We first discuss the results pertaining to the inventory risk compensation channel. β_1 is not significant for most securities, but β_3 is positive and significant across all of them. These results support the hypothesis that dealers are compensated for taking on informationally-free inventory risk. Moreover, this compensation manifests mainly through the subsequent appreciation of the acquired inventory, rather than through price cheapening at the time

[35] The decomposition of dealers' weekly position changes into an issuance- and non-issuance-driven components is based on our coefficient estimates from the regression in Equation (2) as reported in columns (3) and (6) in Table 2. For bills, $\Delta Inv_{issuance,t} = 0.126 \times Issuance_t$. For coupons, $\Delta Inv_{issuance,t} = 0.165 \times Issuance_t$. The non-issuance component is then computed as $\Delta Inv_{others,t} = \Delta Inv_t - \Delta Inv_{issuance,t}$ respectively for bills and coupons.

of taking on inventory positions. The compensation appears to scale up with the duration of the securities, consistent with the increasing risk associated with holding longer maturities. For example, a \$1 billion increase in issuance-driven inventory changes predicts a 0.18 bps increase in the 6-month bill's excess return, but a 3.23 bps increase in the 10-year note's excess return the following week. For comparison, studies of underpricing in Treasury auctions using data over the 1990's and 2000's identify a primary versus secondary market yield differential of about 1/2 to 1 basis point (Simon, 1994; Nyborg and Sundaresan, 1996; and Goldreich, 2007). This yield differential—when adjusted for duration—is similar in magnitude to our estimates of return attributable to auction-driven price pressures. Our results thus imply that a good portion of the return to dealers from underwriting Treasury auctions comes from dealers' intertemporal intermediation of supply across weeks.

Turning to the pricing effects of non-issuance-driven inventory changes, we find evidence supporting the conjecture that dealers' order flow due to their secondary market and proprietary trading activities is informative for Treasury security returns, especially among coupon securities. In particular, β_2 is significant and positive for all Treasury notes. For example, a \$1 billion increase in dealers' non-issuance-related order flow is accompanied by a contemporaneous 1.74 basis point increase in excess returns for the 10-year note. The fact that this informational effect shows up significantly and positively in the coupon securities is consistent with the idea that coupons are more likely to be used for speculation and proprietary trading than bills. Notably, this information appears to be incorporated on a timely basis, with no significant effect after the current week (as shown by the insignificant β_4 across all securities). This result further corroborates the conclusion that non-issuance order flow has an immediate price impact due to adverse selection and that such price impact does not subsequently revert.

Lastly, we find that dealers' position changes add considerable power to explaining Treasury excess returns. Without dealers' position changes, the Cochrane-Piazzesi-styled regression models explain between 0.1% to 3.4% of the variation in excess returns.[36] Adding dealer position changes

[36] In Treasury return predictability regressions, Cochrane and Piazzesi (2005) document explanatory power ranging from 9% to 16% for forward versus spot spreads, from 22% to 26% for slope, level, and curvature factors, from 15% to 33% for combinations of one-, four-, and five-year spot yields, and from 36% to 39% for one- to five-year forward

increases the regression R^2s by 2.1%–3.2%. The incremental R^2s are generally higher for coupons than for bills, consistent with our earlier finding that dealers' coupon inventory changes are slightly more informative for future Treasury excess returns than dealers' bill inventory changes.

In sum, we uncover evidence that dealers are compensated for inventory risk associated with Treasury supply changes via subsequent appreciation of the positions they hold. Despite the Treasury market's liquidity, new Treasury issues are large enough to temporarily depress prices. Dealers absorb these large supply shocks into their inventory and then resell them to other market participants over time. Such intertemporal intermediation is facilitated by the Treasury's commitment to not use private information, but also by the compensation dealers receive through the subsequent price appreciation of securities bought at auction.

6.2 Auction-cycle pricing effects

Our results so far focus on the pricing effects of dealers' position changes driven by Treasury issuance and other factors. To the extent that the compensation for absorbing supply shocks is obtainable not only by the primary dealers studied in this paper but also by other liquidity providers who participate in the primary market, we should observe similar price patterns in general and not just in relation to primary dealers' inventory flow.

Following Lou et al. (2013), we track the changes in the secondary market yields of three key on-the-run notes (2-, 5-, and 10-year) starting from 10 trading days before the auction date of the next issue (in the same maturity term) to 10 days after. That is, we capture the evolution of the yield of the same security as it transitions from being an on-the-run security to being the first off-the-run following the auction date of the next issue (except when the auction is a reopening, in which case the security continues to be on-the-run after the reopening). An important advantage of this analysis is that we can zoom in on the price behavior at the daily interval, allowing a more granular look into how prices change around auctions.

rates. Our regressions have much lower R^2 because they predict one-week returns, which are much less predictable than annual returns.

One important consideration in designing our analysis of auction-cycle effects is that the benchmark Treasury securities we examine are auctioned once per month at around the same time of month. As shown in Internet Appendix Figure A1, the 2- and 5-year notes are mostly auctioned toward the end of the month whereas the 10-year note is auctioned early in the month. Thus, the evolution of yields around these auctions might be confounded by the general patterns of Treasury returns around the turn of the month due to factors such as institutional cash needs (documented in Etula et al., 2020) or investor demand for specific securities due to window dressing and portfolio rebalancing (documented in Hartley and Schwarz, 2019). Accordingly, we adjust yields for day-of-month effects before quantifying the auction-cycle effects.

Specifically, we regress daily yields on day-of-month dummies and collect the residuals, which reflect the component of yields not predicted by the day-of-month effects.[37] This is the adjusted yield $y(t)$ that we use in our analysis of auction-cycle effects. For each day in the auction cycle (ranging from -10 to 10, with 0 representing the auction date), we compute the difference in adjusted yield between that given day and the auction date, i.e., $\Delta y(t) = y(t) - y(0)$. We then take the average of $\Delta y(t)$ across all auctions in the relevant sample and compute the standard errors for these averages using Newey-West adjustment with 12 lags (as in Lou et al., 2013).

As shown in Table 8, we find significant auction-cycle effects (especially in the 2- and 5-year notes), qualitatively similar to the results in Lou et al. (2013) even though we adjust for day-of-month effects in yields.[38] Yields exhibit an inverted V-shaped patterns, with the yields both before and after the auction day being lower than the yields on the auction day. This is equivalent to a V-shaped pattern in prices, indicating that Treasury securities tend to cheapen in the run up to auctions and then appreciate in value after the auctions. This general price pattern is consistent

[37]The day of month ranges from -9 to N-10, where N is the number of days in a given month. Negative values are for the last ten days of the month, while positive values indicate the number of days into the month. For example, for a month with 22 trading days, the day of month goes from 1 to 12 for the first 12 days of the month then switches to -9, -8, ..., 0 for the last 10 days of the month. Our day-of-month assignment ensures that the day of month is properly anchored to either the first or last day of the month with no double counting of the days in the middle of the month despite varying month lengths.

[38]The pattern around the 10-year note's auctions is weak even in Lou et al. (2013) using raw yields. Once we control for day-of-month effects, the 10-year note does not exhibit any significant effects in advance of auctions. The expected post-auction effects (a decrease in yield, or a price appreciation) only start to become significant after five days.

with our earlier evidence of dealers' inventory positions appreciating in value following auctions. Together, the results point to price appreciation as a means of compensating intermediaries who absorb a large supply shock and redistribute supply to investors over time.

7 The evolution of inventory management and compensation

As Figures 1 and 2 show, there appear to be structural changes in dealers' positions over time, especially with respect to Treasury coupons and other fixed income securities and especially after the 2007–09 financial crisis. In this section, we provide a time series perspective on dealer inventory management and compensation for inventory risk in the broader context of significant market developments, especially the crisis and the sweeping regulatory reforms thereafter.[39] As discussed in Adrian et al. (2017b), regulations affecting the dealer sector tightened markedly after the crisis. These regulations are intended to make the global financial system more resilient to shocks, but also increase the cost of market making by raising the cost of capital and restricting dealer risk taking.

The literature has focused primarily on how these trends affect market liquidity, especially in the corporate bond market (see Adrian et al., 2017a for a review). We contribute to this literature by investigating how inventory management of Treasury dealers changes with the regulatory environment and whether increased balance sheet costs and restricted position taking adversely affect dealers' ability to fulfill their critical underwriting function in the primary market. The U.S. public debt has grown rapidly in recent years (and will continue to do so in the foreseeable future). Whether new Treasury securities can be issued at competitive rates and intermediated smoothly depends on the primary dealers and how they handle these sizable and repeated supply shocks in light of their more constrained capacity.

7.1 Regulatory changes

Following the 2007–09 financial crisis, which exposed solvency and liquidity problems in the global financial system, extensive regulatory reforms took place in the U.S. and internationally. In the U.S., Congress passed the Dodd-Frank Act in July 2010 to strengthen the regulation of financial

[39] We also examine how the rise of HFTs in the secondary market has affected dealer inventory dynamics but find that their impact is statistically insignificant. See Internet Appendix Table A5 for detailed results.

institutions and make the financial system safer. Internationally, the Basel Committee on Banking Supervision finalized Basel III in December 2010, which is a new set of standards on capital and liquidity levels that are applicable to internationally active banks. The implementation of both the Dodd-Frank Act and Basel III standards occurred over a period of several years following their passage, with specific rules concerning various provisions being written and adopted.

Altogether, the Dodd-Frank Act and Basel III form a new regulatory framework for banking institutions, that now includes tighter bank capital requirements, leverage ratios, and liquidity requirements. In response, dealer banks cut back their trading-related exposures, reduced the willingness and/or scope of their liquidity provision, and scaled down their risk-taking capacity (see CGFS, 2016). According to a survey of market participants conducted by CGFS (2016), Basel III's higher risk-weighted capital requirements and the supplemental leverage ratio (SLR, finalized in September 2014) have the largest impact on government bond dealers' profits and are therefore the most likely drivers of changes to their business models. One such business model change, as suggested by the majority of survey respondents, is an increase in inventory turnover and a shift away from principal trading toward agency trading, with the goal of sustaining trading activities on a more constrained balance sheet.

7.2 Changes to intermediation of primary market issuance?

Amid the broad trends brought about by the post-crisis regulatory framework, a key question is whether primary dealers have changed the way they intermediate primary market issuance. As committed underwriters of Treasury auctions, primary dealers absorb issuance supply shocks using their balance sheets and redistribute supply to investors over time. How they manage this important function amid tighter balance sheets and the fast growing U.S. public debt has important implications for the ability of the U.S. Treasury to issue new debt at the lowest possible cost going forward. Indeed, Duffie (2020) expresses the concern that tighter regulations, combined with the rapid growth in Treasury debt outstanding, mean that the market's size may have outgrown the capacity of dealers to safely intermediate the market on their own.

In this section, we investigate two important aspects of dealer intermediation in the primary market. First, are dealers reducing their position taking at auction? Second, given the amount purchased at auction, how fast are dealers laying off such inventory? Based on the perspective of market participants discussed in CGFS (2016) and the vast literature on the effects of post-crisis regulations on fixed income markets (reviewed in Adrian et al., 2017a), we expect the following: 1) dealers are reducing their purchases at auction (in line with the reduction in risk-taking capacity and more constrained balance sheets), and 2) dealers are laying off acquired inventory faster (consistent with the new reality of having to make do with reduced capital commitments).

To formally test the above hypotheses, an event study empirical design would be ideal. However, the literature devoted to studying the effects of post-crisis regulation has recognized that this approach is not feasible (see Trebbi and Xiao, 2019 for an in-depth discussion of the issues). The key challenge is that regulatory changes occur over an extended period of time. This makes it unclear when dealers might have changed their business models as a result and hence difficult, if not impossible, to determine the correct "event date." For example, financial system reform was first proposed by President Obama in 2009, passed by Congress as the Dodd-Frank Act in 2010, then followed by several years of rule making to formalize the implementation of various provisions of the Act before these rules were finally adopted. An additional consideration is that different rules come into effect at different times, and affect different entities differently, making it challenging to cleanly identify the effects of any particular rule.

We thus follow the standard approach in the literature in our empirical investigation (see e.g., Schultz, 2017; Bessembinder et al., 2018; Adrian et al., 2017a). That is, we compare the outcome variables of interest across subsamples defined by key regulatory milestones and test whether they differ significantly across subsamples and in the hypothesized direction. We adopt the same cutoff dates as in Adrian et al. (2017a) except that we start the rule implementation period from January 1, 2015. This is because the SLR, which is most consequential for Treasury dealers, was not finalized until the last quarter of 2014. Thus, the four subsample periods are: 1) pre-crisis period (start of sample period to December 31, 2006), 2) crisis period (from January 1, 2007 to December

31, 2009), 3) rule development period (from January 1, 2010 to December 31, 2014), and 4) rule implementation period (from January 1, 2015 to the end of the sample).

We construct three measures of dealers' intermediation of new issuance. First, we use the amounts purchased by broker-dealers at auction to capture the extent of position taking by primary dealers. Second, we compute the fraction of new issuance purchased by broker-dealers as a proxy for the importance of primary dealers in the primary market. Third, we estimate the fraction of dealers' auction purchases that remains unsold at the end of the auction week by using the inventory model specified in Equation (2) in which the issuance variable is the issuance amount purchased by dealers. Thus, the obtained coefficient β_2 directly reflects how fast dealers lay off auction inventory within the same week and is not affected by the changing share of dealers' purchases at auction.

Table 9 reports our estimates of the three outcome variables across the four subsample periods. We provide the tests of significant change between any two subsample periods in the lower panel of the table. The reduction in position-taking after regulatory changes shows up most strongly in the intermediation of coupon issuance. For example, dealers buy nearly \$21 billion of coupon securities weekly at auctions during the rule making period, but only around \$13 billion after the applicable rules have been implemented despite the fast growth in coupon issuance. Their share of coupon auction purchases plummets to about 30%, whereas they had consistently taken in more than 50% prior to the implementation of tighter regulations.

We also observe a somewhat reduced importance of primary dealers at bill auctions in the post-regulatory change period, although dealers still purchase a large fraction of bill issuance (over 60%). Because bill issuance grows faster than the drop in dealers' purchase share, the dollar value of dealers' bill positions taken on at auction still increases over time. Given the large quantity of weekly bill purchases compared to coupon purchases (e.g., \$99 billion versus \$13 billion in the latest subsample period), it is not surprising to find that dealers manage to unload their bill auction inventory faster compared to coupons (with only 22% remaining unsold compared to 39%) and also compared to the pre-rule implementation period (22% versus 43%). Meanwhile, the rate of coupon inventory layoff does not exhibit significant change when the rules go into effect.

We supplement the findings in Table 9 with a time series plot of the position taking at auction and the fraction of auction inventory that remains unsold at the end of the auction week in Internet Appendix Figure A2. For each year, the auction purchases amount (share) is the average weekly amount (share) for the year, whereas the effect on dealer inventory is estimated using data from the noted year and the two preceding years. Consistent with the subsample analysis above, dealers have substantially curtailed their position taking in coupon securities since the 2007–09 crisis (in both dollar amount and share of auction purchases, especially the latter), whereas the decrease in bills position taking is only modest (as shown by the slight decline in the share of purchases and even an increase in the dollar amount). However, the acceleration of bill inventory unloading is notable.

Overall, the results reveal significant differences in dealers' intermediation of Treasury supply shocks across the subsample periods, with the changes also differing between bills and coupons. It appears that dealers cope with tighter balance sheets by drastically cutting position taking at auctions for coupons but by speeding up the unloading of acquired auction inventory for bills.

7.3 Compensation for intermediating new issuance

With stricter capital and liquidity requirements raising the cost of using balance sheet to warehouse new issuance, it is not surprising to observe evidence of reduced position taking at auctions. How does this affect the compensation for intermediating new issuance? Given that investor capital is not perfectly mobile (Duffie, 2010) and that issuance supply shocks keep growing, dealers' reduced willingness to intermediate these supply shocks should increase intermediary compensation. However, that is not what we observe. We tabulate in Table 10 our subsample analysis of the price effects of issuance-driven inventory flow based on the regression specified in Equation (7). Similar to the full sample results in Table 7, there is no clear evidence of dealers being compensated through declining prices during inventory acquisition, as shown in the upper panel of the table. The more important source of intermediary compensation—the post-auction appreciation of acquired inventory reported in the lower panel of the table—is significant in the earlier periods (mainly for the coupon securities) but dissipates after the crisis.

What explains the attenuation of compensation for intermediating new issuance precisely when key underwriters play a progressively reduced role at auctions? The literature on the effects of regulations on fixed income markets has documented the emergence of new liquidity providers amid the contraction of dealers' balance sheets and market making capacity. For example, Choi et al. (forthcoming) find that customers (likely big asset managers) increasingly provide liquidity to other customers in the corporate bond markets. Likewise, evidence from Kruttli et al. (2021) and Barth and Kahn (2021) suggests that hedge funds now provide significant liquidity in the Treasury market. If these players increasingly participate in the primary market, they can fill the void left by the primary dealers in absorbing new supply.

Indeed, as discussed in the preceding subsection, dealers' share of purchases at auction steadily decreases after the crisis, especially for coupon securities. Notably, as revealed in Figure 7, the steep decline in dealers' share of coupon auction purchases is almost exactly offset by the increasing share purchased by investment funds, while all other investor classes collectively purchase a relatively stable share of new issuance over time. More importantly, if these investment funds used to be liquidity demanders and buy Treasury securities from dealers after the auction, their increasing participation in the primary market would depress intermediary compensation through both an increase in the competition for liquidity provision and a decrease in the post-auction demand underpinning the post-auction price appreciation. We hypothesize that it is this transformation of liquidity demanders to liquidity providers that contributes to the dissipation of compensation for intermediating new issuance.

To test this hypothesis, we use the more granular auction-level data so that we can directly link the post-auction price appreciation to the level of participation by investment funds at auction. For this test, our measure of post-auction price appreciation (Δp) is the negative of the five-day change in yield $\Delta y(5)$ as used in our analysis of auction-cycle pricing effects in Section 6.2; i.e., $\Delta p \propto -\Delta y(5)$. We thus run the following panel regression:

$$\Delta p_{i,t} = \beta_1 InvFunds_{i,t} + \beta_2 OtherPtcp_{i,t} + \beta_3 BidCover_{i,t} + \beta_4 IssueSize_{i,t} + FEs + \epsilon_{i,t}. \quad (8)$$

In this regression, $InvFunds_{i,t}$ and $OtherPtcp_{i,t}$ are the shares of auction purchases by investment funds and other non-dealer participant types, respectively. $BidCover$ is the bid-to-cover ratio, capturing how oversubscribed an auction is. It thus serves as a proxy for the overall market demand for the auctioned security. $IssueSize$ is the issuance amount, which proxies for the size of the supply shock intermediaries have to absorb. The larger the issuance, the greater the capital commitment, and thus the greater the compensation expected for intermediaries. We estimate this regression using the auction data available for all nominal coupons (2-, 3-, 5-, 7-, 10-, and 30-year), starting from when data on investor class allotment became available in 2001. We include security-by-period fixed effects to control for differences in auction-cycle effects across securities and time. Thus, we are able to identify the effect of the variation in investment funds' participation in the same security in the same subsample period on the post-auction price appreciation. Standard errors are clustered at the security level.

Based on our hypothesis, we expect to observe a negative β_1, indicating that an increase in investment funds' participation dampens the post-auction price appreciation. This is what we find, as shown in Table 11 in which β_1 is significantly negative across various model specifications. This result is consistent with prior evidence that investment funds have increasingly provided liquidity in fixed income markets in recent years. The increased competition for liquidity provision thus contributes to eroding the compensation for such activity. On the other hand, participation by other investor types (such as depository institutions, pension funds, and individual investors)—who are not known to engage in significant liquidity provision in the post-crisis period—exhibits no significant effect on post-auction price patterns.

Overall, our analysis in this section provides several important policy implications. On the one hand, the increased role of non-dealer liquidity providers in the primary market helps ease the concern that the aggregate balance sheet capacity of the dealer sector, already constrained by regulatory changes, is not keeping pace with the growth of Treasury issuance, which could consequently harm market liquidity. It seems that investment funds are adequately filling the void left by increasingly constrained dealers, at least up to now. Moreover, the diminished compensation for intermediation means issuance cost savings for the U.S. Treasury; Lou et al. (2013) estimate that auction-cycle price effects cost taxpayers over half a billion dollars in 2007—a cost that would be in the billions if projected on today's issuance.

On the other hand, there is no guarantee that alternative liquidity providers will always be present to provide liquidity, unlike primary dealers which are obligated to bid competitively in all auctions. A financial stability concern is that non-obligatory liquidity providers stop providing liquidity in crisis times, precisely when it is needed most. This may have happened in the secondary market for Treasury securities: the emergence of HFTs increases liquidity provision in normal times but may adversely affect liquidity stability in volatile times (see Joint Staff Report, 2015). In the primary market, the sudden withdrawal of liquidity providers could adversely affect the U.S. government's ability to borrow at low costs.

That said, the "one-to-all" market structure and the regular and predictable nature of Treasury issuance may make the primary market more amenable to intermediation by non-dealers and more immune to sudden liquidity withdrawal than the secondary market. Even during the height of the Covid-19 pandemic, when the secondary market experienced massive disruptions due to extraordinary selling pressure from customers (see Duffie, 2020), auction data indicate that the primary market functioned largely as usual. Thus, the evidence gives us reason to believe that the greater diversity and competition of liquidity providers in the primary market is beneficial on balance.

8 Conclusion

The regular issuance and redemption of Treasury securities create a different inventory management problem for government bond dealers versus equity or foreign exchange dealers. In this paper, we examine how U.S. Treasury dealers manage their positions and in fact find that underwriting plays a key role. Specifically, we find that Treasury dealers absorb a large share of new Treasury supply and retain significant exposure for at least a week, offsetting only small shares of their auction purchases in adjacent weeks. Further results show that dealer positions decline at redemption of Treasury securities, suggesting that dealers buy and hold many securities from issuance through maturity and/or that redemptions result in increased demand for other Treasury securities from customers who need to reinvest the funds.

Examining the use of derivatives to hedge inventory risk, we find that dealers engage in selective hedging. They are more likely to hedge exposure associated with coupon securities than with bills, likely due to coupon securities' higher interest rate risk, and also more likely to hedge position changes perceived to be prone to greater adverse selection risk. Dealers offset a much smaller share of spot position changes in the futures market when such changes are explained by issuance and redemptions, presumably because such position changes are not information-based. Such behavior is consistent with that of U.K. government bond dealers who also adjust their hedging depending on the perceived level of asymmetric information as documented in Naik and Yadav (2003b).

As dealers intermediate new Treasury supply intertemporally through the use of inventory, and inventory is costly to hold, a natural question is how dealers get compensated for their services. We find that this compensation is by means of price appreciation subsequent to auction inventory acquisition—a result consistent with the auction-cycle effects found in Lou et al. (2013). Our results therefore add to the evidence from equity markets (Hendershott and Seasholes, 2007) that market-maker inventories have significant asset pricing effects at a multi-day horizon, and show that such effects can exist even when the inventory changes are publicly known. Furthermore, our results explain a microstructure component of Treasury yield predictability related to dealer intermediation of frequent Treasury supply shocks, a result subsequently corroborated by other papers such as Lou et al. (2013).

Lastly, we contribute additional evidence on changes related to dealers' inventory management and inventory risk compensation amid many important market developments since the 2007–09 financial crisis, coupled with the changing structure of the Treasury market. We find that dealers significantly reduce their position taking at auctions, especially for coupons, and turn around inventory faster. This finding is consistent with increased inventory holding costs that result from post-crisis regulatory changes and more stringent capital requirements. We also find that investment funds have stepped in to offset the declining share of dealer purchases at auction in recent years.

Their increased role in the primary market correlates with diminished price effects surrounding auctions. Our evidence suggests that the transition of many investment funds from being liquidity demanders to liquidity providers increases the competition for liquidity provision in the primary market while weakening the post-auction demand for Treasury securities in the secondary market, thereby driving down the compensation for taking inventory risk at auctions.

Overall, we conclude that Treasury dealers play an important role in underwriting and intermediating Treasury securities, but that they operate somewhat differently in the post-crisis period. Regulatory changes and the rise of new participants in the primary market point to a new environment in which dealers cut back on their position taking and tighten their inventory turnover to cope with increased balance sheet costs while obtaining less compensation for bearing inventory risk. Nonetheless, primary dealers are still critical to the functioning of the market. With their committed underwriting and market making roles, the importance of primary dealers becomes clearer at times of stress when non-obligatory liquidity suppliers may step back from the market. Having a robust dealer sector despite the trend toward disintermediation remains crucial to financial stability.

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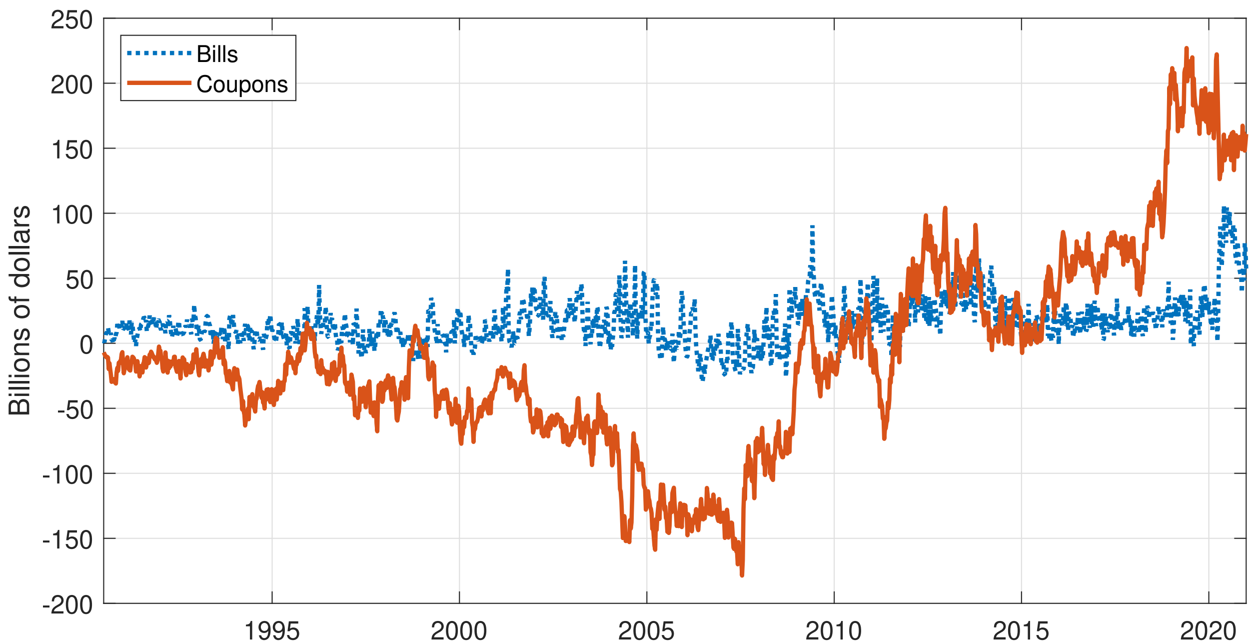
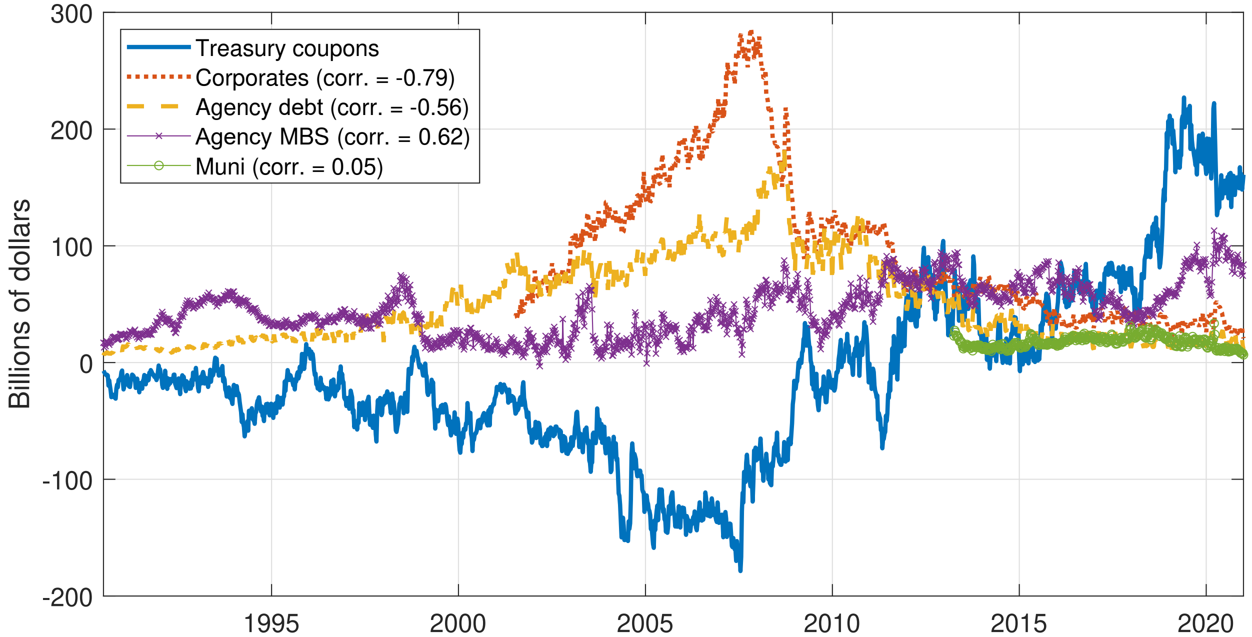
Figure 1: Dealer Treasury Positions 1990–2020



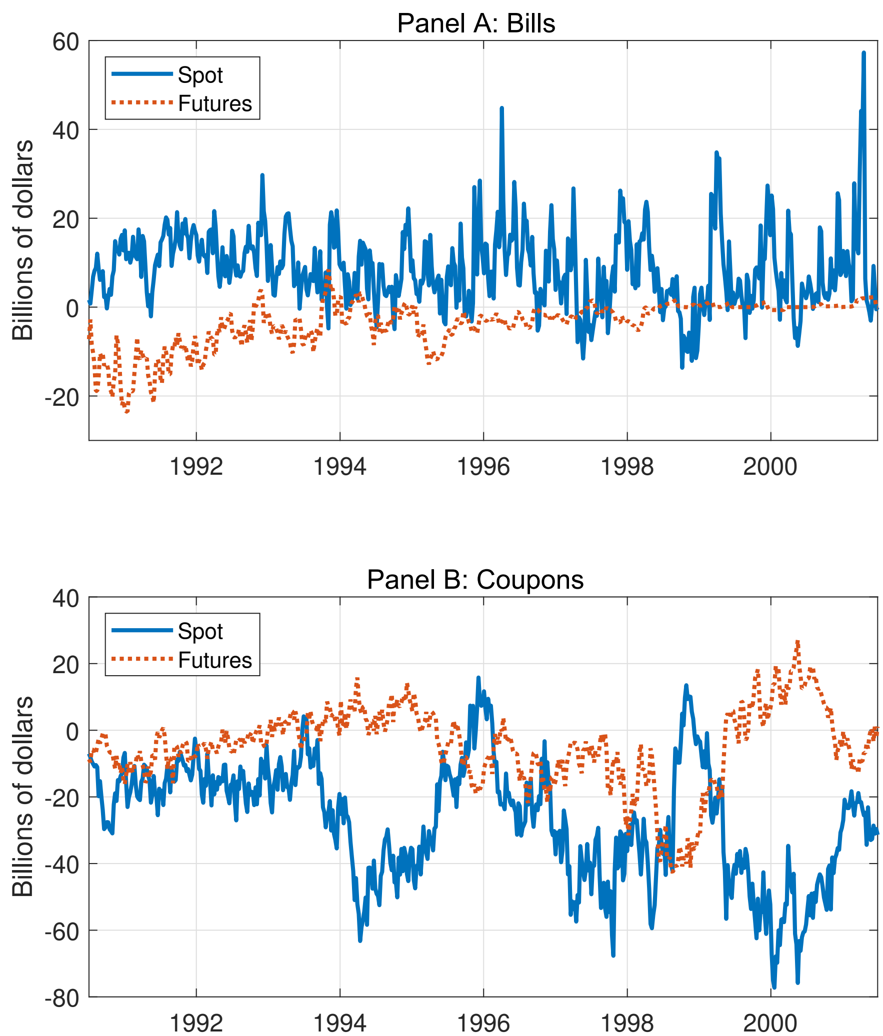
This figure plots primary dealer net spot positions in U.S. Treasury bills and coupon-bearing securities by week from July 4, 1990 to December 30, 2020.

Figure 2: Dealer Net Positions in Fixed Income Securities 1990-2020



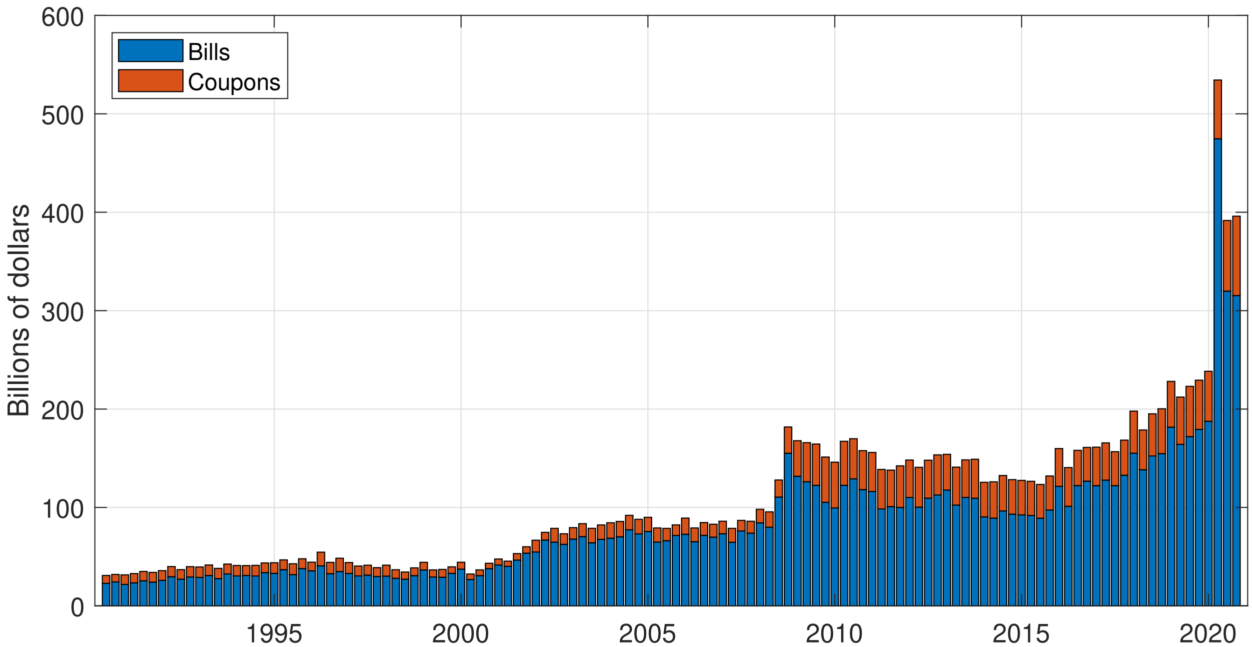
This figure compares net positions of primary dealers in U.S. Treasury coupon-bearing securities with those in other fixed income securities (agency MBS, agency debt, corporate debt, and municipal debt) by week from July 4, 1990 to December 30, 2020. The legend shows the correlation of net positions in each of the other fixed income categories with Treasury coupon net positions.

Figure 3: Dealer Treasury Spot and Futures Positions 1990-2001



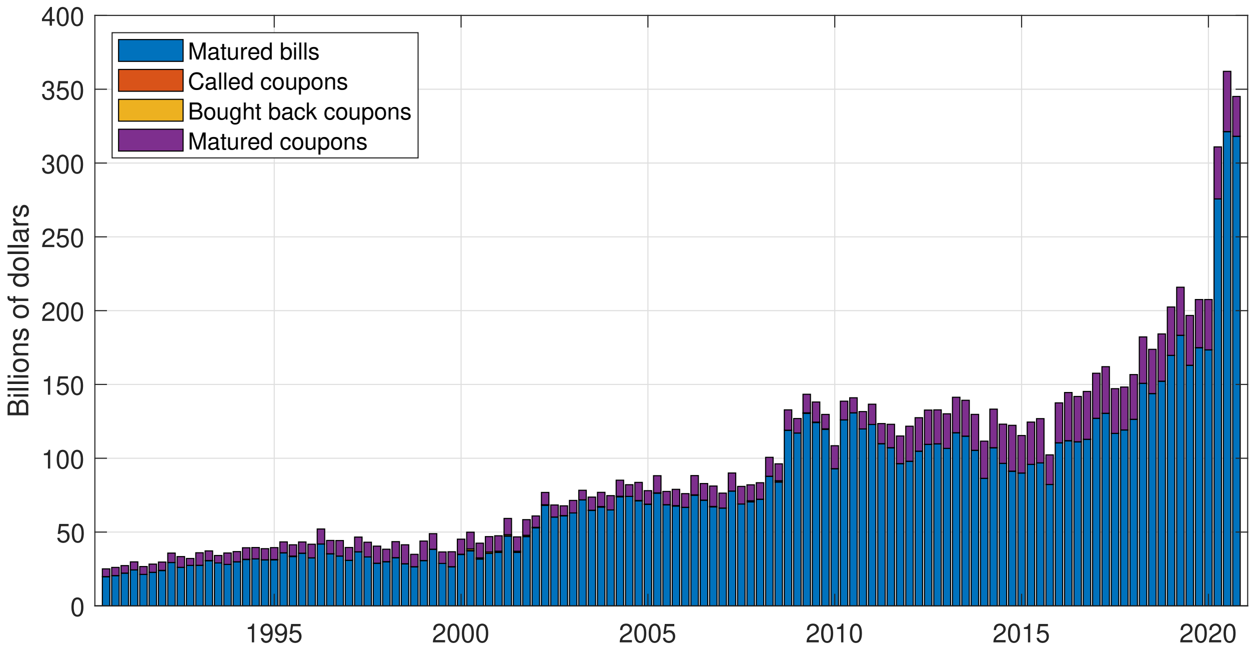
This figure compares spot and futures net positions of primary dealers in U.S. Treasury bills (Panel A) and coupon-bearing securities (Panel B) by week from July 4, 1990 to June 27, 2001.

Figure 4: Treasury Issuance 1990–2020



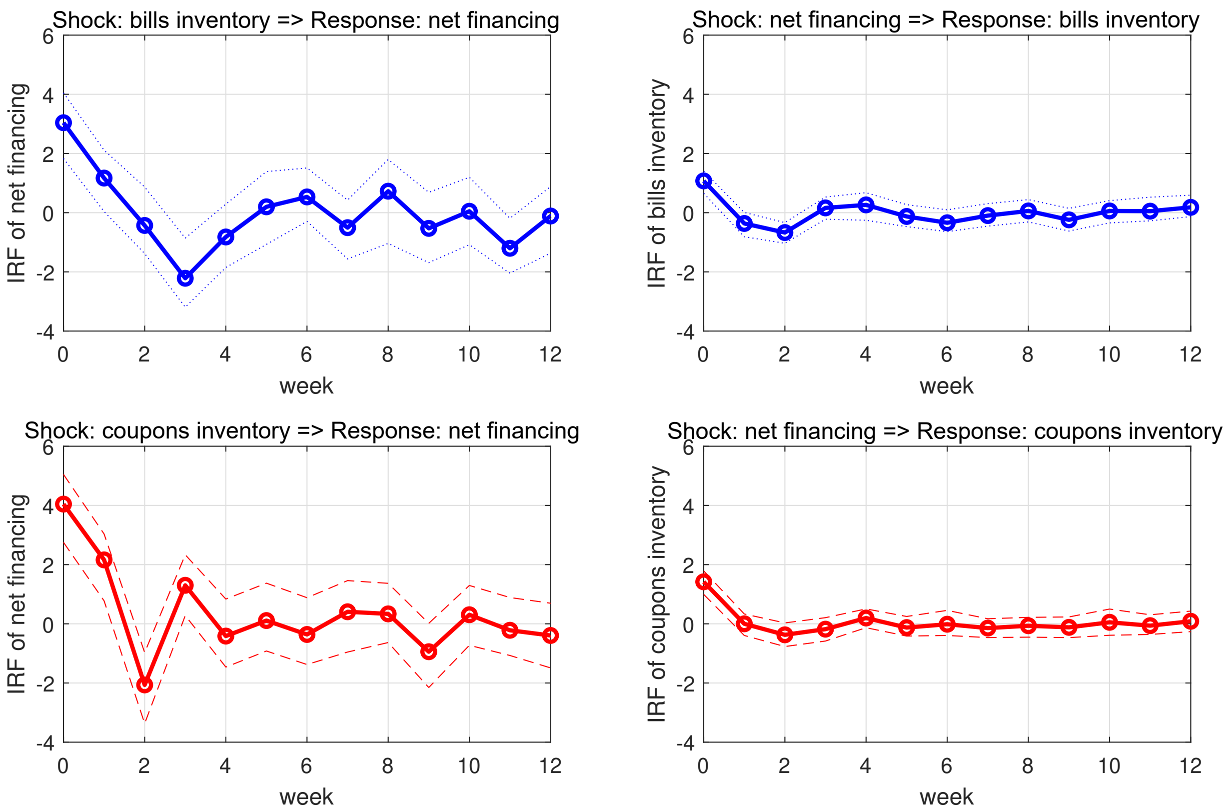
This figure plots average weekly auction amounts of U.S. Treasury bills and coupon-bearing securities by quarter for the weeks ending July 4, 1990 to December 30, 2020.

Figure 5: Treasury Redemptions 1990–2020



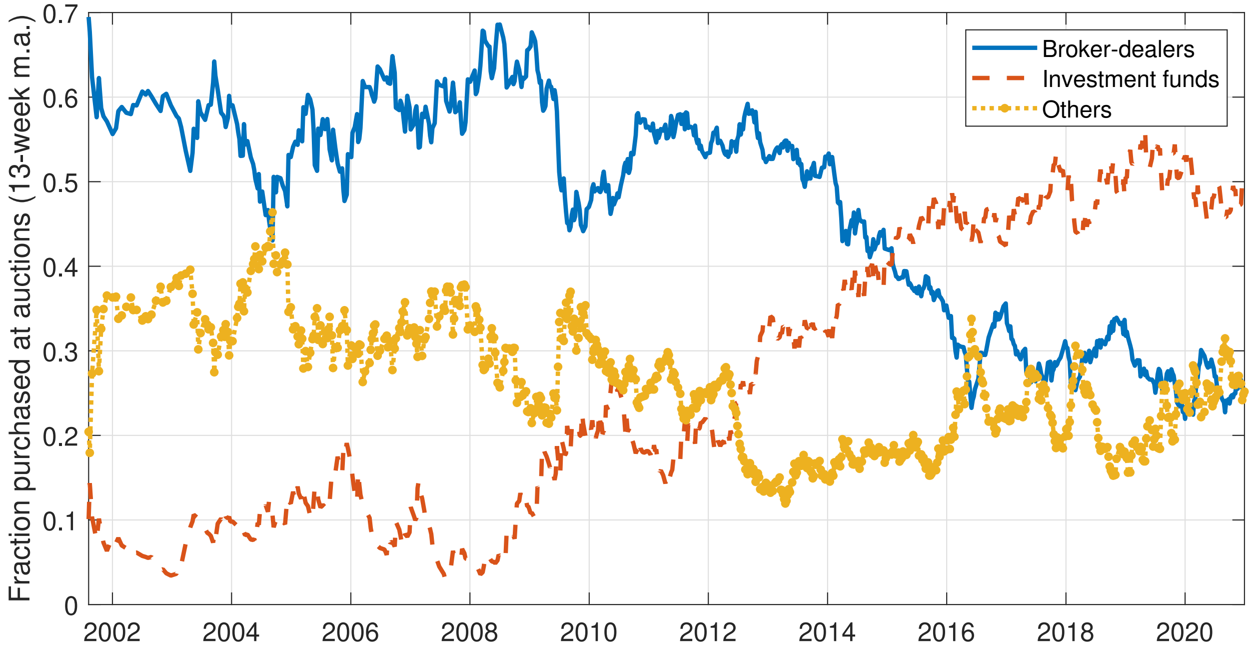
This figure plots average weekly redemptions of U.S. Treasury bills and coupon-bearing securities by quarter for the weeks ending July 4, 1990 to December 30, 2020.

Figure 6: Impulse Response Functions of Treasury Inventory and Net Financing



This figure plots the generalized impulse response functions (GIRF) of Treasury inventory and net financing based on the vector autoregression (VAR) model of Treasury inventory and net financing changes with exogenous control variables (Treasury issuance, redemptions, changes in Federal Reserve holdings, and changes in foreign central banks' holdings). The optimal lag length is chosen by the Bayesian Information Criterion (13 lags for the VAR model of bill inventory and net financing, and 14 lags for that of coupon inventory and net financing). The full sample period is from July 4, 1990 to December 30, 2020. The GIRF is computed using a one-standard-deviation shock in the shocked variable.

Figure 7: Coupon Auction Purchases by Investor Class 2001–2020



This figure plots the 13-week moving average of the fraction of weekly coupon auction amounts purchased by broker-dealers, investment funds, and other investor classes as reported in the Investor Class Allotment data. The data are available from the Department of the Treasury from the week ending August 8, 2001.

Table 1: Descriptive Statistics

This table reports descriptive statistics of key variables used in the paper. All variables are in billions of dollars. The sample period is from July 1990 to December 2020, but some variables are not available for the whole sample period. Positions and financing data are from the Federal Reserve Bank of New York. Treasury auctions and redemptions data are from the U.S. Department of Treasury. Central bank holdings are from the Federal Reserve. Corporate and municipal issuance data are from Mergent.

	N	Mean	Median	StDev	Min	Max
Bill positions	1592	15.86	13.87	17.51	−29.77	105.82
Bill position changes	1591	0.04	−0.34	9.49	−50.90	51.10
Coupon positions	1592	−9.96	−18.91	76.62	−178.61	227.06
Coupon position changes	1591	0.11	−0.35	9.36	−36.92	40.99
Bill issuance	1592	82.92	68.40	66.25	12.55	604.79
Bill redemptions	1592	79.94	67.38	57.52	15.83	366.89
Coupon issuance	1592	23.18	14.84	28.18	0.00	202.78
Coupon redemptions	1592	15.38	0.00	25.05	0.00	116.12
Broker-dealer bill auction purchases	1014	70.31	66.23	37.16	18.15	300.05
Broker-dealer coupon auction purchases	1014	13.44	9.88	13.45	0.00	70.74
Bill futures positions	574	−3.67	−2.14	5.25	−23.55	8.42
Bill futures position changes	573	0.01	0.00	1.63	−6.17	8.71
Coupon futures positions	574	−4.94	−4.00	12.03	−42.53	27.06
Coupon futures position changes	573	0.02	0.05	3.25	−12.24	10.74
Changes in Fed's bill holdings	1591	0.14	0.00	2.99	−38.27	22.50
Changes in Fed's coupon holdings	1591	2.44	0.00	15.30	−30.05	335.74
Changes in foreign central banks' holdings	1591	1.77	1.20	9.63	−104.53	62.93
Agency position changes	1591	0.00	0.02	5.30	−25.08	28.31
MBS position changes	1591	0.04	0.01	5.34	−31.07	30.85
Corporate bond issuance	1592	10.53	7.91	9.97	0.00	91.22
Municipal bond issuance	1592	7.15	6.53	4.37	0.23	36.67
Net financing	1592	166.37	154.60	129.37	−36.95	642.52
Net financing changes	1591	0.20	−0.35	24.98	−106.65	127.23

Table 2: Treasury Dealer Inventory Management

This table reports the results from the following regression model:

$$\Delta Inv_t = \alpha + \beta_1\, Inv_{t-1} + \beta_2\, Issuance_t + \beta_3\, Redemption_t + \gamma'\, Z_t + \epsilon_t,$$

where ΔInv_t is the change in dealer inventory over week t, Inv_{t-1} is the beginning-of-week inventory level, and $Issuance$ and $Redemption$ are the amount of Treasury issuance and redemptions, respectively. Z_t is a vector of control variables, including central banks' purchases, inventory changes in other fixed income securities, changes in dealers' financing activity, changes in the fed funds rate, changes in the Treasury/repo spead (using 3-month Treasury bill and 5-year Treasury yields, respectively, in the bill and coupon inventory regression models), changes in interest rate volatility, and dealers' trading volume (logged). The regression model is estimated separately for bills (Panel A) and coupons (Panel B). The full sample period is from July 4, 1990 to December 30, 2020, with shorter sample periods in some specifications due to data availability. The following variables are defined separately for bills and coupons: beginning inventory, issuance, redemption, change in the Fed's holdings, change in Treasury/repo spread, and trading volume. All other variables are common between Panels A and B. Coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors in parentheses. *$p < .1$; **$p < .05$; ***$p < .01$.

Independent Variable	Panel A: Bill Position Changes			Panel B: Coupon Position Changes		
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.031	0.030	0.046	0.105	0.101	0.444**
	(0.222)	(0.205)	(0.214)	(0.186)	(0.194)	(0.184)
Beginning inventory ($B)	−0.146***	−0.200***	−0.201***	−0.006*	−0.018***	−0.020***
	(0.017)	(0.021)	(0.021)	(0.003)	(0.004)	(0.004)
Issuance ($B)		0.121***	0.126***		0.145***	0.165***
		(0.018)	(0.019)		(0.009)	(0.010)
Redemptions ($B)		−0.096***	−0.084***		−0.094***	−0.079***
		(0.018)	(0.016)		(0.010)	(0.011)
Δ Fed holdings ($B)			−0.026			−0.091***
			(0.068)			(0.012)
Δ Foreign CB holdings ($B)			0.003			−0.059**
			(0.027)			(0.025)
Δ Agency positions ($B)			0.134***			0.021
			(0.041)			(0.044)
Δ MBS positions ($B)			−0.114***			−0.087*
			(0.040)			(0.045)
Corporate issuance ($B)			−0.086**			0.037
			(0.037)			(0.028)
Municipal issuance ($B)			−0.183**			−0.088
			(0.074)			(0.064)
Δ net financing ($B)			0.038***			0.049***
			(0.012)			(0.010)
Δ fed funds rate (%)			−0.183			−0.261
			(0.719)			(0.908)
Δ Treasury/repo spread (%)			0.013			−0.262
			(0.934)			(0.992)
Δ interest rate volatility			4.433			4.293
			(2.964)			(2.934)
Log trading volume			−0.182			−1.209**
			(0.936)			(0.610)
Adjusted R^2 (%)	7.1	25.8	29.1	0.2	27.8	32.3
# Observations	1591	1591	1545	1591	1591	1545

Table 3: Granger Causality Tests

This table reports the F-test results of whether the row variable Granger-causes the column variable. This is based on the vector autoregression (VAR) model of Treasury inventory and net financing changes with exogenous control variables (Treasury issuance, redemption, changes in the Fed's holdings, and changes in foreign central banks' holdings). The optimal lag length is chosen by the Bayesian Information Criterion (13 lags for the VAR model of bill inventory and net financing, and 14 lags for that of coupon inventory and net financing). The full sample period is from July 4, 1990 to December 30, 2020. $*p < .1$; $**p < .05$; $***p < .01$.

Panel A: Bill Positions and Net Financing

	Δ Bill Positions	Δ Net Financing
Δ Bill positions		4.600^{***}
Δ Net financing	1.335	

Panel B: Coupon Positions and Net Financing

	Δ Coupon Positions	Δ Net Financing
Δ Coupon positions		5.139^{***}
Δ Net financing	0.5893	

Table 4: Interest Rate Risk Management

This table reports the results from the following regression model:

$$\Delta InvRisk_t = \alpha + \beta_1\, InvRisk_{t-1} + \beta_2\, IssuanceRisk_t \; + \gamma'\, Z_t + \epsilon_t,$$

where $InvRisk$ is dealers' inventory and $IssuanceRisk$ is the weekly issuance amount, both measured in risk terms (separately for level and slope risks). Yield curve level risk exposure is the dollar value change in response to a one basis point change in yield. Yield curve slope risk exposure is the dollar value change in response to a one basis point change in the slope of the yield curve (defined as the difference between the 2- and 10-year yields). Z_t is a vector of control variables, including central banks' purchases (bills and coupons combined), inventory changes in other fixed income securities, changes in dealers' financing activity, changes in the fed funds rate, changes in the Treasury/repo speads (using 3-month Treasury bill and 5-year Treasury yields), changes in interest rate volatility, and dealers' trading volume (logged). The sample period is from January 21, 1998 to December 30, 2020. Coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors in parentheses. *$p < .1$; **$p < .05$; ***$p < .01$.

Independent Variable	Level Risk	Slope Risk
Constant	0.724***	−1.020***
	(0.165)	(0.388)
Beginning inventory	−0.027***	−0.051**
	(0.008)	(0.025)
Issuance	0.190***	0.306***
	(0.018)	(0.068)
Δ Fed holdings ($B)	−0.046***	0.064**
	(0.011)	(0.028)
Δ Foreign CB holdings ($B)	−0.044**	0.080
	(0.019)	(0.061)
Δ Agency positions ($B)	−0.019	0.063
	(0.025)	(0.051)
Δ MBS positions ($B)	0.011	−0.083
	(0.030)	(0.079)
Corporate issuance ($B)	−0.011	0.029
	(0.024)	(0.067)
Municipal issuance ($B)	−0.002	−0.054
	(0.044)	(0.088)
Δ net financing ($B)	0.024***	−0.003
	(0.007)	(0.021)
Δ fed funds rate (%)	0.889	0.386
	(1.306)	(2.619)
Δ 3-month Treasury/repo spread (%)	4.564**	−7.504
	(1.928)	(4.753)
Δ 5-year Treasury/repo spread (%)	2.818**	−6.945**
	(1.356)	(2.733)
Δ interest rate volatility	5.129***	−10.197***
	(1.902)	(3.836)
Log bill trading volume	−0.898	−0.871
	(0.715)	(2.124)
Log coupon trading volume	−1.192	2.225
	(0.860)	(2.270)
Adjusted R^2 (%)	19.7	25.7
# Observations	1194	1194

Table 5: Intertemporal Inventory Adjustment

This table reports the results from the following regression model:

$$\Delta Inv_t = \alpha + \beta_1 Inv^*_{t-1} + \beta_2\, Issuance_t + \beta_{2a}\, Issuance_{t-1} + \beta_{2b}\, Issuance_{t+1} + \beta_3\, Redemption_t + \gamma'\, Z_t + \epsilon_t,$$

where ΔInv_t is the change in dealer net positions over week t, Inv^*_{t-1} is the net positions at the end of the previous week excluding the effects of the previous week's issuance. $Issuance$ and $Redemption$ are the amount of issuance and redemptions of Treasury securities, respectively. Z_t is a vector of control variables, including central banks' purchases, inventory changes in other fixed income securities, changes in dealers' financing activity, changes in the fed funds rate, changes in the Treasury/repo spead (using 3-month Treasury bill and 5-year Treasury yields, respectively, in the bill and coupon inventory regression models), changes in interest rate volatility, and dealers' trading volume (logged). The regression model is estimated separately for bills and coupons. Panel A shows the regression in which the $Issuance$ variable is the total issuance amount, with data available from May 22, 1991 (when data on some control variables became available) to December 30, 2020. Panel B shows the regression in which the $Issuance$ variable is the issuance amount purchased by broker-dealers (BDs), with data available from August 8, 2001 to December 30, 2020. Coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors in parentheses. *$p < .1$; **$p < .05$; ***$p < .01$.

	Panel A: Total Issuance		Panel B: Issuance Purchased by BDs	
	Bills	Coupons	Bills	Coupons
Next-week's issuance	-0.078^{***}	-0.004	-0.087^{***}	-0.047^{*}
	(0.013)	(0.010)	(0.023)	(0.024)
Same-week's issuance	0.195^{***}	0.163^{***}	0.341^{***}	0.310^{***}
	(0.018)	(0.010)	(0.027)	(0.023)
Previous-week's issuance	-0.042^{***}	-0.029^{**}	-0.072^{***}	-0.084^{***}
	(0.015)	(0.013)	(0.021)	(0.028)
Adjusted R^2 (%)	33.0	32.6	37.4	32.4
# Observations	1544	1544	1012	1012

Table 6: Use of Derivatives for Inventory Management

This table reports results from regressions of weekly changes in primary dealers' net futures positions in U.S. Treasury securities on changes in their net spot positions in Treasury securities in whole and in parts. Changes in net spot positions are decomposed into three parts: 1) due to issuance, 2) due to redemption, and 3) due to other factors, based on the full inventory model specified in Equation (2). The sample period is July 4, 1990 to June 27, 2001. The regressions are estimated separately for bills and coupons and the independent variables are defined accordingly. Coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors in parentheses. $^*p < .1$; $^{**}p < .05$; $^{***}p < .01$.

	Dependent Variable: Futures Position Changes			
Independent Variable	Bills		Coupons	
	(1)	(2)	(3)	(4)
Constant	-0.129	0.708^{*}	0.536^{**}	0.764^{**}
	(0.184)	(0.393)	(0.254)	(0.336)
Spot position changes – total	-0.015^{*}		-0.232^{***}	
	(0.008)		(0.023)	
Spot position changes – due to issuance		0.017		-0.140^{***}
		(0.013)		(0.044)
Spot position changes – due to redemption		-0.008		0.156
		(0.036)		(0.225)
Spot position changes – due to other factors		-0.042^{***}		-0.282^{***}
		(0.014)		(0.030)
Adjusted R^2 (%)	-0.0	0.8	19.1	21.0
# Observations	573	573	573	573

Table 7: Dealer Compensation for Inventory Risk and Other Factors

This table reports results from the following regression:

$$r_t = \alpha + \beta_1 \Delta Inv_{issuance,t} + \beta_2 \Delta Inv_{others,t} + \beta_3 \Delta Inv_{issuance,t-1} + \beta_4 \Delta Inv_{others,t-1} + \gamma_1 f^{(1)}_{t-1} + ... + \gamma_5 f^{(5)}_{t-1} + \epsilon_t,$$

where r_t is the weekly excess returns on a given Treasury security, $\Delta Inv_{issuance}$ is dealers' weekly position changes due to Treasury auctions, ΔInv_{others} is dealers' weekly position changes due to other factors, and $f^{(i)}$ are forward rates for years 1 through 5. The decomposition of position changes into issuance-driven and non-issuance-driven components is based on coefficient estimates from the full inventory model reported in Table 2 (column 3 for bills and column 6 for coupons). Bill returns are regressed on changes in bill positions and coupon returns are regressed on changes in coupon positions. Incremental R^2 refers to the increase in explanatory power when position change variables are added to the predictive regression of excess returns on the five forward rates. The sample period is from July 4, 1990 to December 30, 2020. Coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors in parentheses. Returns are in basis points and position changes are in billions of dollars. *$p < .1$; **$p < .05$; ***$p < .01$.

	3-Month Bill	6-Month Bill	2-Year Note	5-Year Note	10-Year Note
Same-week position change:					
Due to issuance (β_1)	-0.066	-0.145^{**}	0.007	0.121	0.165
	(0.040)	(0.067)	(0.120)	(0.352)	(0.634)
Due to other factors (β_2)	-0.029^{**}	-0.021	0.329^{***}	1.037^{***}	1.743^{***}
	(0.014)	(0.020)	(0.065)	(0.192)	(0.352)
Previous-week position change:					
Due to issuance (β_3)	0.066^{*}	0.179^{***}	0.645^{***}	2.078^{***}	3.225^{***}
	(0.037)	(0.068)	(0.122)	(0.366)	(0.652)
Due to other factors (β_4)	0.006	0.005	0.002	-0.044	-0.247
	(0.007)	(0.012)	(0.057)	(0.172)	(0.341)
# Observations	1587	1587	1587	1587	1587
Adjusted R^2 (%)	5.8	5.0	2.8	3.4	2.9
Incremental R^2 (%)	2.4	2.1	2.3	3.2	2.8

Table 8: Auction Cycle Pricing Effects

This table reports the time-series average of the change in yields (in basis points) between day t and auction day (day 0), with t ranging from -10 to 10, for the 2-, 5-, and 10-year Treasury notes. Each given note is on-the-run before the auction (of the next security) and off-the-run after the auction, except for reopenings (mostly for the 10-year note) after which the security continues to be on-the-run. The sample period is from July 4, 1990 to December 30, 2020. Daily yields are pre-adjusted for day-of-month effects. The standard errors for reported estimates are calculated using Newey-West standard errors (with 12 lags). $*p < .1$; $**p < .05$; $***p < .01$.

t	2-Year Note	5-Year Note	10-Year Note
-10	-1.40^{*}	-1.14	1.30
-9	-2.72^{***}	-2.41^{**}	0.12
-8	-2.46^{***}	-3.26^{***}	0.26
-7	-1.28	-1.30	0.87
-6	-0.98	-1.43^{*}	0.17
-5	-1.77^{***}	-2.33^{***}	0.30
-4	-2.29^{***}	-1.28^{**}	-0.29
-3	-1.37^{***}	-0.17	-0.01
-2	-0.54	0.62	-0.11
-1	-0.35	-0.01	-0.11
0	0.00	0.00	0.00
1	-0.21	-0.48	1.14^{***}
2	-0.72^{*}	-1.61^{***}	3.25^{***}
3	-0.97^{*}	-1.55^{***}	3.43^{***}
4	-1.73^{***}	-1.83^{***}	1.51
5	-2.00^{***}	-2.57^{***}	-0.01
6	-1.89^{***}	-1.96^{**}	-2.17^{*}
7	-0.61	-0.25	-3.92^{***}
8	-0.53	-0.20	-1.96^{**}
9	-2.29^{**}	-1.12	-2.78^{***}
10	-4.82^{***}	-2.75^{***}	-2.26^{**}
# Auctions	366	322	245

Table 9: How Do Dealers Manage Auction Inventory Shocks over Time?

This table compares dealers' position-taking at auctions and auction inventory intermediation rate across four subsample periods: 1) pre-crisis period (start of sample period to December 31, 2006), 2) crisis period (from January 1, 2007 to December 31, 2009), 3) rule development period (from January 1, 2010 to December 31, 2014), and 4) rule implementation period (from January 1, 2015 to the end of the sample). The sample period is from August 1, 2001 (when data on broker-dealers' auction purchases became available) to December 30, 2020. The estimates are reported with standard errors in parentheses. The data for weekly auction amount and the amount purchased by broker-dealers are from TreasuryDirect. The fraction of unsold inventory is the coefficient of broker-dealer auction purchase amount on dealers' weekly position changes, controlling for other explanatory variables as specified in Equation (2). The lower panel of the table shows the Welsh-Satterthwaite t-statistics for tests of significant difference between subsample periods. *$p < .1$; **$p < .05$; ***$p < .01$.

	Bills			Coupons		
	Amount Purchased at Auction	Fraction Purchased at Auction	Fraction of Unsold Inventory	Amount Purchased at Auction	Fraction Purchased at Auction	Fraction of Unsold Inventory
Pre-crisis	40.273***	0.593***	0.551***	6.973***	0.563***	0.423***
	(0.688)	(0.004)	(0.057)	(0.484)	(0.011)	(0.054)
Crisis	61.151***	0.598***	0.348***	13.243***	0.580***	0.272***
	(2.379)	(0.006)	(0.058)	(1.073)	(0.012)	(0.056)
Rule development	74.373***	0.700***	0.428***	20.748***	0.519***	0.386***
	(0.957)	(0.004)	(0.041)	(1.023)	(0.005)	(0.039)
Rule implementation	98.676***	0.619***	0.220***	13.308***	0.298***	0.391***
	(2.550)	(0.004)	(0.032)	(0.637)	(0.005)	(0.055)
Tests of Significant Change between Subsample Periods						
$H_{crisis=pre-crisis}$	8.431***	0.613	−2.491**	5.327***	1.052	−1.931*
$H_{development=pre-crisis}$	28.916***	18.825***	−1.746*	12.175***	−3.522***	−0.550
$H_{implementation=pre-crisis}$	22.108***	4.707***	−5.060***	7.922***	−21.558***	−0.415
$H_{development=crisis}$	5.156***	13.704***	1.118	5.062***	−4.740***	1.670*
$H_{implementation=crisis}$	10.759***	2.891***	−1.954*	0.052	−22.193***	1.520
$H_{implementation=development}$	8.921***	−14.806***	−3.996***	−6.174***	−31.508***	0.072

Table 10: Compensation for Intermediating Auction Inventory Shocks across Subsample Periods

This table compares measures of compensation for positions taken at auction across four subsample periods: 1) pre-crisis period (start of sample period to December 31, 2006), 2) crisis period (from January 1, 2007 to December 31, 2009), 3) rule development period (from January 1, 2010 to December 31, 2014), and 4) rule implementation period (from January 1, 2015 to the end of the sample). The sample period is from August 1, 2001 (when data on broker-dealers' auction purchases became available) to December 30, 2020. Panel A reports the change in excess return due to auction positions taken during the same week. Panel B reports the change in excess return due to auction positions taken in the previous week. All estimates are from the regression specified in Equation (7) except that the total issuance amount is replaced by the amount purchased by broker-dealers. The estimates are reported with Newey-West standard errors in parentheses. The data for weekly auction amount and the amount purchased by broker-dealers are from TreasuryDirect. $^{*}p < .1$; $^{**}p < .05$; $^{***}p < .01$.

	3-Month Bill	6-Month Bill	2-Year Note	5-Year Note	10-Year Note
Panel A: Do Dealers Acquire Auction Inventory while Price Declines?					
Pre-crisis	-0.003	0.016	0.054	0.819	1.213
	(0.009)	(0.020)	(0.435)	(1.164)	(1.871)
Crisis	-0.138	-0.198	-0.979	-3.406^{*}	-4.605
	(0.087)	(0.142)	(0.640)	(1.754)	(3.001)
Rule development	-0.006	-0.012	-0.178^{**}	-0.626	-1.481
	(0.004)	(0.007)	(0.085)	(0.474)	(1.080)
Rule implementation	-0.070^{**}	-0.123^{**}	0.145	0.238	-0.126
	(0.029)	(0.060)	(0.222)	(0.674)	(1.355)
Panel B: Does Price Appreciate Subsequent to Auction Inventory Acquisition?					
Pre-crisis	0.018	0.004	0.973^{**}	2.788^{**}	4.640^{**}
	(0.012)	(0.031)	(0.402)	(1.140)	(2.004)
Crisis	0.068	0.196^{*}	1.119^{*}	4.764^{**}	7.217^{**}
	(0.059)	(0.107)	(0.671)	(1.834)	(3.172)
Rule development	0.004	-0.003	0.178	0.440	0.461
	(0.004)	(0.008)	(0.110)	(0.586)	(1.193)
Rule implementation	0.004	0.010	0.461	0.939	0.922
	(0.014)	(0.030)	(0.295)	(0.772)	(1.460)

Table 11: The Rise of Alternative Liquidity Providers and Attenuation of Auction Price Effects

This table reports the result of the following panel regression:

$$\Delta p_{i,t} = \beta_1 InvFunds_{i,t} + \beta_2 OtherPtcp_{i,t} + \beta_3 BidCover_{i,t} + \beta_4 IssueSize_{i,t} + FEs + \epsilon_{i,t}$$

where $\Delta p_{i,t}$ is the five-day post-auction price appreciation measure (equal to the negative of the change in yield between day 5 and auction day) following the auction of security i at time t. $InvFunds$ is the share of issuance purchased by investment funds at the auction. $OtherPtcp$ is the share of issuance purchased by other participants (i.e., excluding broker-dealers and investment funds). $BidCover$ is the bid-to-cover-ratio of the auction. $IssueSize$ is the total amount issued at the auction. All explanatory variables are standardized to have a zero mean and unit standard deviation at the security level. The model includes security-by-subsample fixed effects (FEs) and is estimated using data on six Treasury nominal coupon securities (2-, 3-, 5-, 7-, 10-, and 30-year). The sample period is from August 1, 2001 (when data on auction purchases by investor class become available) to December 30, 2020. It consists of four subsample periods: 1) pre-crisis period (start of sample period to December 31, 2006), 2) crisis period (from January 1, 2007 to December 31, 2009), 3) rule development period (from January 1, 2010 to December 31, 2014), and 4) rule implementation period (from January 1, 2015 to the end of the sample). Robust standard errors are clustered at the security level and reported in parentheses. *$p < .1$; **$p < .05$; ***$p < .01$.

Explanatory Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Investment fund share	-2.018***				-1.878**	-1.630*	-1.624*
	(0.465)				(0.480)	(0.647)	(0.658)
Other participant share		0.636			0.434	0.787	0.735
		(0.370)			(0.381)	(0.456)	(0.491)
Bid-to-cover ratio			-1.236			-1.421	-1.301
			(0.933)			(0.937)	(1.055)
Issue size				0.793*			0.423
				(0.351)			(0.534)
Security $\times$ Subsample FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,134	1,134	1,134	1,134	1,134	1,134	1,134
R-squared (%)	4.9	4.6	4.8	4.6	5.0	5.5	5.5

Internet Appendix to

“How Do Treasury Dealers Manage Their Positions?”

March 25, 2024

Table A1: Effects of Auction Purchases by Broker-Dealers

This table reports results from regressions of weekly changes in primary dealers' net positions in U.S. Treasury securities on beginning-of-week inventory level, amount of Treasury issuance purchased by broker-dealers, redemptions (including buybacks, calls, and regular maturity) of Treasury securities, and control variables as in Table 2. The sample period is from August 8, 2001 to December 30, 2020. Coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors in parentheses. $*p < .1$; $**p < .05$; $***p < .01$.

	Dependent Variable	
Independent Variable	Bill Position Changes	Coupon Position Changes
Beginning inventory ($B)	-0.221^{***}	-0.005
	(0.022)	(0.004)
Broker-dealer auction purchases ($B)	0.286^{***}	0.331^{***}
	(0.025)	(0.023)
Redemptions ($B)	-0.059^{***}	-0.086^{***}
	(0.012)	(0.012)
Constant	Yes	Yes
Control variables	Yes	Yes
Adjusted R^2 (%)	35.4	31.4
# Observations	1014	1014

Table A2: Effects of Monetary Policy Actions during 2009–2019

This table reports results from regressions of weekly changes in dealers' coupon inventory as in Table 2 except that the sample period is limited to 2009–2019 and, in column (2), separate coefficients are estimated for increases and decreases in Federal Reserve holdings. Coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors in parentheses. $*p < .1$; $**p < .05$; $***p < .01$.

	(1)	(2)
Beginning inventory ($B)	-0.019^{***}	-0.019^{***}
	(0.007)	(0.007)
Issuance ($B)	0.166^{***}	0.167^{***}
	(0.014)	(0.013)
Redemptions ($B)	-0.095^{***}	-0.086^{***}
	(0.015)	(0.015)
Δ Fed holdings ($B)	-0.166^{***}	
	(0.057)	
Positive Δ Fed holdings ($B)		-0.241^{***}
		(0.059)
Negative Δ Fed holdings ($B)		0.053
		(0.123)
Δ Foreign CB holdings ($B)	-0.051^{*}	-0.053^{*}
	(0.029)	(0.029)
Constant	Yes	Yes
Control variables	Yes	Yes
Adjusted R^2 (%)	39.1	39.5
# Observations	573	573

Table A3: Estimates of VAR Model of Treasury Bill Inventory and Net Financing Changes

This table reports the parameter estimates of the VAR model of dealers' Treasury bill inventory and net financing changes. Optimal lag length is chosen based on BIC. $*p < .1$; $**p < .05$; $***p < .01$.

Lag	Regressor	Δ Bill Positions	Δ Net Financing
	Constant	0.2326	1.120
L1	Δ Bill positions	-0.2966^{***}	0.2288^{***}
	Δ Net financing	-0.0021	-0.1964^{***}
L2	Δ Bill positions	-0.2456^{***}	0.1377^{**}
	Δ Net financing	-0.0240^{***}	-0.2433^{***}
L3	Δ Bill positions	-0.2634^{***}	-0.1429^{**}
	Δ Net financing	0.0022	-0.0993^{***}
L4	Δ Bill positions	-0.1261^{***}	-0.1662^{**}
	Δ Net financing	0.0039	0.0465^{*}
L5	Δ Bill positions	-0.1518^{***}	-0.1263^{*}
	Δ Net financing	-0.0025	-0.0356
L6	Δ Bill positions	-0.1663^{***}	0.0048
	Δ Net financing	-0.0077	-0.1505^{***}
L7	Δ Bill positions	-0.1187^{***}	0.0048
	Δ Net financing	-0.0113	-0.1148^{***}
L8	Δ Bill positions	-0.1274^{***}	0.1387^{**}
	Δ Net financing	-0.0104	-0.0955^{***}
L9	Δ Bill positions	-0.0485^{*}	-0.0502
	Δ Net financing	-0.0215^{**}	-0.0241
L10	Δ Bill positions	-0.1360^{***}	-0.0550
	Δ Net financing	-0.0036	-0.0172
L11	Δ Bill positions	-0.1420^{***}	-0.1452^{**}
	Δ Net financing	-0.0009	-0.1334^{***}
L12	Δ Bill positions	-0.0865^{***}	-0.0706
	Δ Net financing	-0.0006	-0.0347
L13	Δ Bill positions	0.0575^{**}	-0.2287^{***}
	Δ Net financing	0.0079	0.1458^{***}
L0	Issuance	0.1224^{***}	0.0259
	Redemptions	-0.1280^{***}	-0.0333^{*}
	Δ Fed holdings	-0.0607	0.0802
	Δ Foreign CB holdings	-0.0131	-0.0935
	R^2	0.3421	0.2395

Table A4: Estimates of VAR Model of Treasury Coupon Inventory and Net Financing Changes

This table reports the parameter estimates of the VAR model of dealers' Treasury coupon inventory and net financing changes. Optimal lag length is chosen based on BIC. *$p < .1$; **$p < .05$; ***$p < .01$.

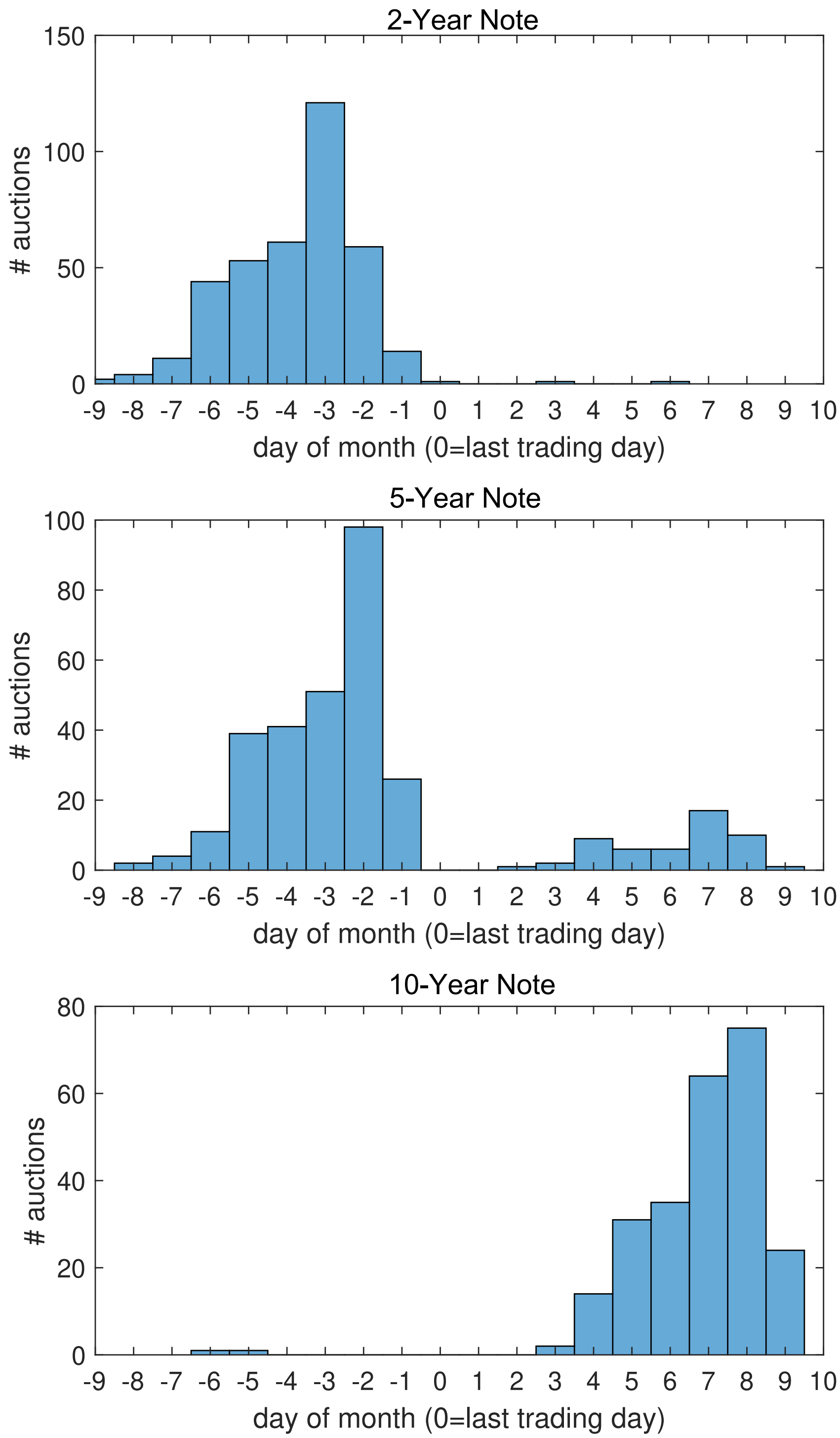
Lag	Regressor	Δ Coupon Positions	Δ Net Financing
	Constant	-0.8156^{***}	2.313^{***}
L1	Δ Coupon positions	-0.1120^{***}	0.3874^{***}
	Δ Net financing	0.0073	-0.1973^{***}
L2	Δ Coupon positions	-0.0190	-0.0355
	Δ Net financing	-0.0146	-0.2591^{***}
L3	Δ Coupon positions	-0.0361	0.2647^{***}
	Δ Net financing	-0.0087	-0.1386^{***}
L4	Δ Coupon positions	0.0355	-0.0198
	Δ Net financing	0.0009	0.0250
L5	Δ Coupon positions	-0.0279	0.0123
	Δ Net financing	-0.0070	-0.0527^{**}
L6	Δ Coupon positions	-0.0108	0.0876
	Δ Net financing	0.0004	-0.1342^{***}
L7	Δ Coupon positions	-0.0443^{*}	0.1178^{*}
	Δ Net financing	-0.0038	-0.1157^{***}
L8	Δ Coupon positions	-0.0416^{*}	0.1403^{**}
	Δ Net financing	-0.0050	-0.0877^{***}
L9	Δ Coupon positions	0.0065	-0.0421
	Δ Net financing	-0.0099	-0.0401
L10	Δ Coupon positions	-0.0392	0.0586
	Δ Net financing	-0.0006	-0.0308
L11	Δ Coupon positions	-0.0603^{**}	0.0696
	Δ Net financing	-0.0010	-0.1480^{***}
L12	Δ Coupon positions	-0.0793^{***}	-0.0027
	Δ Net financing	0.0083	-0.0165
L13	Δ Coupon positions	0.0222	-0.0559
	Δ Net financing	-0.0075	0.1504^{***}
L14	Δ Coupon positions	-0.0893^{***}	-0.1642^{**}
	Δ Net financing	-0.0091	0.0280
L0	Issuance	0.1099^{***}	-0.0229
	Redemptions	-0.0786^{***}	-0.0850^{***}
	Δ Fed holdings	-0.1032^{***}	0.0279
	Δ Foreign CB holdings	-0.0525^{**}	-0.0984^{*}
	R^2	0.3391	0.2465

Table A5: Do HFTs Affect Dealer Inventory Dynamics?

This table reports the results of the main inventory adjustment model specified in Equation (2) estimated using data over two-, four-, and six-year windows around events that increase HFTs' participation in the Treasury secondary market. The regression model is augmented with "Post", an indicator for the post-event period, and its interactions with all explanatory variables in the original model. The two events considered are: 1) the entry of HFTs to the electronic IDB platforms in 2004 as noted in Fleming, Mizrach, and Nguyen (2018) (conservatively dated to January 1, 2004), and 2) a major system upgrade on BrokerTec in March 2012 that significantly increased HFTs' activities as documented in Dobrislav and Schaumburg (2023) (conservatively dated to March 1, 2012). Statistical significance is based on heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors. *$p < .1$; **$p < .05$; ***$p < .01$.

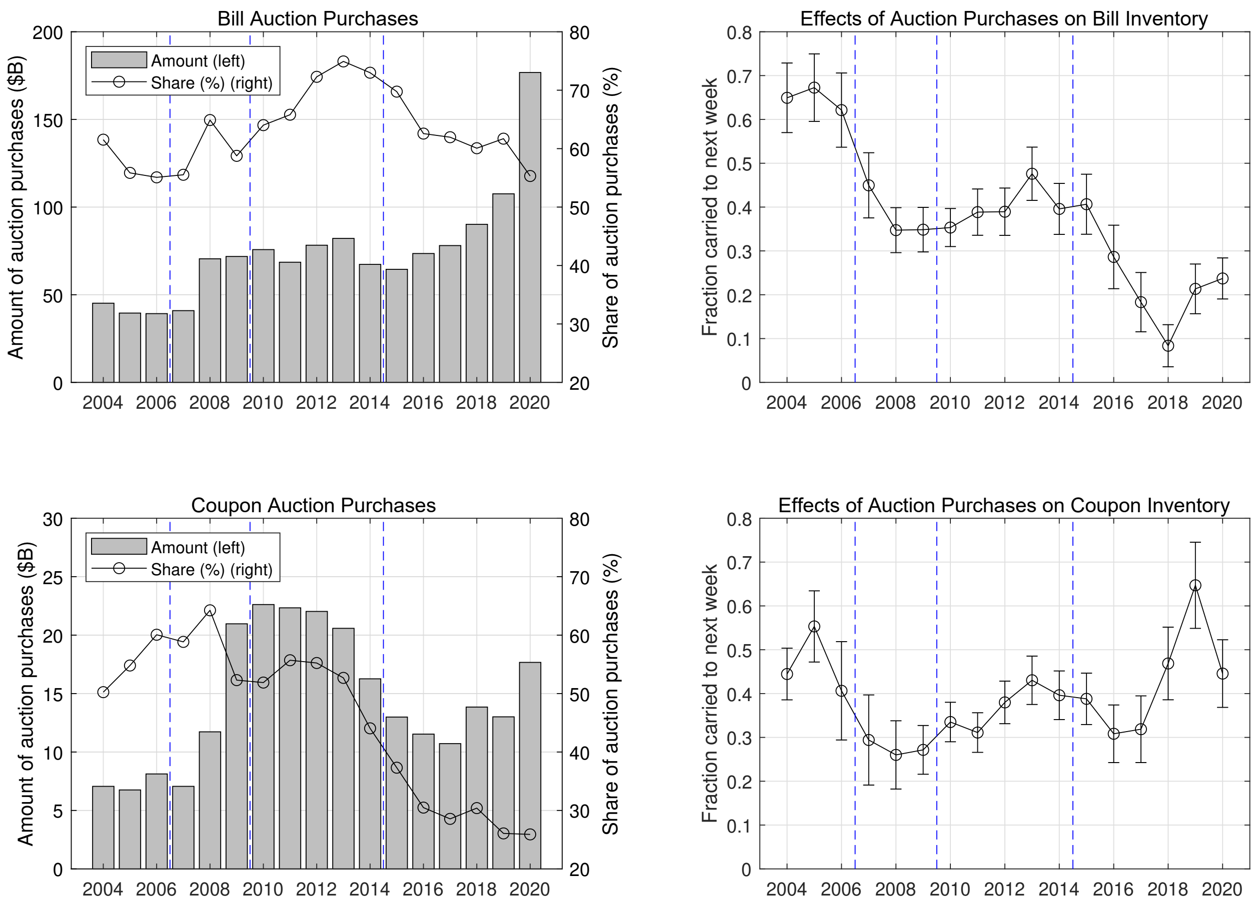
	Event: HFT Entry			Event: BrokerTec System Upgrade		
	Event window = event date +/- h years					
	$h = 1$	$h = 2$	$h = 3$	$h = 1$	$h = 2$	$h = 3$
Constant	-12.66^{*}	-12.66^{***}	-2.04	-0.13	-0.87	-1.17
Beginning inventory ($B)	-0.24^{**}	-0.24^{***}	-0.08^{***}	-0.11	-0.11^{**}	-0.08^{**}
Issuance ($B)	0.18^{**}	0.20^{***}	0.21^{***}	0.19^{***}	0.20^{***}	0.17^{***}
Redemptions ($B)	-0.06	-0.03	-0.05	-0.08	-0.09	-0.06
Δ Fed holdings ($B)	1.79	1.07	0.60	-0.36	-0.28^{**}	-0.22^{**}
Δ Foreign CB holdings ($B)	0.22	0.15	0.10	-0.01	-0.02	-0.06
Δ Agency positions ($B)	-0.27	-0.24^{**}	-0.12	-0.00	-0.03	0.02
Δ MBS positions ($B)	-0.16	-0.09	-0.11^{*}	-0.47	-0.25	-0.19
Corporate issuance ($B)	0.03	-0.08	0.04	-0.18	-0.13	-0.05
Municipal issuance ($B)	-0.49^{**}	-0.38^{**}	-0.47^{***}	-0.17	0.11	-0.02
Log trading volume	1.57	2.27	-2.82	6.16	3.65	2.58
Δ net financing ($B)	0.05^{*}	0.06^{**}	0.06^{***}	0.05	-0.00	0.01
Δ Fed fund rate (%)	-8.06	-7.58	-10.18^{***}	-127.04	18.46	5.22
Δ Treasury/repo spread (%)	13.58^{*}	8.12^{**}	6.40^{**}	-12.26	-3.93	-3.75
Δ interest rate volatility	1.39	0.71	3.22	-34.19	-14.41	-15.25
Post	10.29	5.66	-8.02^{**}	7.20	8.15	3.12
Beginning inventory ($B) × Post	0.19	0.14^{*}	-0.03	0.01	-0.00	0.00
Issuance ($B) × Post	0.05	0.09	-0.01	0.06	0.02	0.03
Redemptions ($B) × Post	-0.02	0.02	0.02	-0.05	-0.05	-0.08
Δ Fed holdings ($B) × Post	-0.04	0.18	0.31	0.02	0.10	0.14
Δ Foreign CB holdings ($B) × Post	0.06	-0.04	0.10	-0.05	-0.02	0.12
Δ Agency positions ($B) × Post	-0.19	-0.03	-0.06	0.83	0.60^{**}	0.37^{*}
Δ MBS positions ($B) × Post	-0.19	0.01	0.04	0.06	0.05	0.04
Corporate issuance ($B) × Post	0.06	0.12	0.06	0.34	0.16	0.07
Municipal issuance ($B) × Post	0.46	-0.16	0.24	-0.05	-0.05	0.18
Log trading volume × Post	-10.21	-7.29	0.87	-14.40	-7.00	-2.54
Δ net financing ($B) × Post	-0.04	-0.01	-0.02	-0.04	0.03	0.04
Δ Fed fund rate (%) × Post	-1.72	-5.51	-1.96	93.89	96.41	37.36
Δ Treasury/repo spread (%) × Post	18.27	20.07^{***}	17.09^{***}	5.29	-3.66	0.32
Δ interest rate volatility × Post	-21.66	1.39	0.92	36.25	24.12	23.64^{*}
Adjusted R^2 (%)	29.7	33.9	27.7	39.4	45.9	42.8
# Observations	104	208	312	104	208	312

Figure A1: Distribution of Auctions by Day of Month



This figure shows the distribution of auctions by day of month. The x-axis shows the day relative to the last trading day of the month (with 0 being the last trading day and 1 being the first trading day). The sample period is from July 1990 to December 2020. Auction history data are from the Department of the Treasury.

Figure A2: Time Series of Auction Purchases and Effects on Dealer Inventory



This figure plots the time series of broker-dealers' auction purchases (dollar amount and share of total issuance) and the fraction of auction inventory that remains in dealer inventory at the end of the auction week. For each year, the auction purchases amount (share) is the average weekly amount (share), whereas the effect on dealer inventory is the coefficient on broker-dealer auction purchases from the inventory model specified in Equation (2) as estimated using data from the noted year and the two preceding years. The sample period is from January 1, 2002 (shortly after data on broker-dealers' auction purchases became available on August 1, 2001) to December 30, 2020. Vertical dashed lines separate four subsample periods: 1) pre-crisis period (start of sample period to December 31, 2006), 2) crisis period (from January 1, 2007 to December 31, 2009), 3) rule development period (from January 1, 2010 to December 31, 2014), and 4) rule implementation period (from January 1, 2015 to the end of the sample).