How Do Treasury Dealers Manage Their Positions?*

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Abstract

Using 31 years of data on U.S. Treasury dealer positions from 1990 to 2020, we find evidence of a significant role for dealers in the intertemporal intermediation of new Treasury security supply. Dealers regularly take into inventory a large share of Treasury issuance so that dealer positions significantly increase during auction weeks. These inventory increases are only partially offset in adjacent weeks and are not significantly hedged with futures. Dealers seem to be compensated for the risk associated with these inventory changes by means of price appreciation in the subsequent week. In the period since the 2007–09 crisis, dealers lay off inventory faster and receive decreased compensation for inventory risk exposure taken on at auctions. These changes occur amid increased inventory holding costs attributable to post-crisis regulatory changes and increased participation of non dealers (investment funds) in the primary market.

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1 Introduction

The U.S. Treasury securities market is the "single most important financial market in the world" (see Group of Thirty, 2021), with an outstanding size of $20.9 trillion 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, especially in crisis times, is critical. A well-functioning Treasury market in turn depends critically on the dealer sector. Recent episodes of market disruptions due to dealers' inability to intermediate the full extent of customer trading flows bring the topic of dealer inventory management to the fore (see Duffie, 2020).

It is well established that intermediaries are important for the proper functioning of financial markets and that how they manage their inventory has important implications for market liquidity and asset prices. 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." An extensive literature examines how dealers manage the inventory risk of the securities in which they make a market and how inventory control motives affect prices and liquidity. Early and influential papers such as Garman (1976), Stoll (1978), and Amihud and Mendelson (1980) provide models where 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. Recent work by Chung and Huh (2016) indicates that the noninformation component of trading costs (arising mainly from inventory holding risk and order processing costs) is more strongly correlated with stock returns than the adverse-selection component, highlighting again the importance of inventory effects on asset prices.

Numerous empirical papers assess the actual inventory management behavior of dealers in equity markets, futures markets, and the foreign exchange market.[1] At the time of writing 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., 2017 for a review).[2]

A distinctive feature of fixed income markets is that dealer positions are subject to inventory changes less pertinent to other markets, specifically, issuance and redemptions. That is, fixed income securities are often underwritten by dealers, and by the same dealers who make secondary markets in the securities. Moreover, fixed income securities are redeemed, often within weeks of issuance for short term securities, providing a regular manner of disposition distinct from the secondary market.

In the Treasury securities market in particular, issuance is frequent and sizable. Because dealers' capital is limited, a question of interest and policy relevance is how dealers manage to absorb such supply shocks in addition to their regular market making activities. This question becomes even more important as the size of the Treasury market continues to grow dramatically (from $2.1 trillion in 1990 to $5.8 trillion in 2008 to $21 trillion in 2020) while the balance sheet of the intermediary sector stagnates following the 2007–09 crisis (see Adrian et al., 2017; Duffie, 2020). These two trends imply that dealers' capital constraints become even more binding over time, potentially resulting in greater price pressures associated with issuance-related intermediation activities unless there are alternative liquidity providers taking dealers' place. As Lou et al. (2013) point out, these issuance-related price pressures are costs borne by Treasury, and ultimately, taxpayers.

[1] 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.

[2] 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.

Our paper is the first to analyze how dealers in the Treasury market manage their positions. In particular, we assess how dealer positions respond to issuance and redemptions of Treasury securities — factors affecting dealer inventories not yet well studied in the prior literature. Extant studies also largely ignore how dealers use derivatives to manage their overall risk exposure, and no study examines the behavior of U.S. Treasury security dealers in this regard.[3] We thus examine how dealers use futures to manage their risk exposure and whether futures use is driven by the same factors that cause spot positions to change. Lastly, we test whether dealers are compensated for bearing risk and, in particular, inventory risk associated with Treasury issuance.

Our analysis is based on the weekly net positions of the primary government securities dealers over the July 1990 to December 2020 period. Dealers report their long and short spot (and historically, futures) positions in various fixed income securities to the Federal Reserve Bank of New York, which then publishes the data netted and aggregated across dealers. The data offer valuable insights into how dealers manage their positions, given that data on individual dealers inventories are usually not available. The 31-year sample allows us to examine whether and how the role of dealers in the intermediation of Treasury securities 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 Treasury securities from customers who need to reinvest the funds. Our analysis shows that Treasury issuance and redemptions by themselves explain a large share of the variation in Treasury dealer positions. Although the evidence indicates that dealers smooth auction-induced inventory shocks by taking offsetting positions in adjacent weeks, these are much smaller in magnitude

[3]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 greater. When Naik and Yadav (2003b) examine the profitability of dealer trading strategies, they find no evidence that dealer positions appreciate in value.

compared to inventory activities during auction weeks. These results highlight a key difference in the inventory management problem facing government bond dealers versus dealers in other markets.

With a shorter sample of data on dealers' derivatives positions, we find several key results on how dealers hedge the inventory exposure they take on at auction. First, dealers are more likely to hedge exposure associated with coupon securities 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 trade. By separating inventory changes into a component driven by auctions and another driven by dealers' other activities (e.g., speculative trading, secondary market making etc...), we uncover the evidence that dealers are less concerned with hedging auction-related inventory changes than with hedging inventory changes driven by other factors. There is little asymmetric information from purchases at auction (as the Treasury Department is precommitted to regular and predictable auctions), but there is potential for significant asymmetric information in trades with customers. That dealers use futures to hedge a much smaller share of spot position changes attributable to Treasury issuance than they do of other position changes is consistent with dealers wanting to mitigate adverse selection risk (see also 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 associated with auctions. We find mild evidence of a negative correlation between dealer position changes due to issuance and contemporaneous Treasury returns and strong evidence of a positive correlation between dealer position changes due to issuance and future Treasury returns. These results suggest that dealers buy Treasuries during auction weeks when prices are depressed and then sell these securities sometime later after prices have recovered. We therefore identify and explain a microstructure component of Treasury yield predictability not previously explored. Moreover, our findings add to the evidence from equity markets (Hendershott and Seasholes, 2007) that 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 asset pricing effects of Treasury auction cycles. Lou et al. (2013) find that U.S. Treasury security prices decrease in the few days leading up to Treasury auctions 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 many important market developments in the years since the 2007–09 financial crisis, coupled with the changing structure of the Treasury market. Specifically, we observe that dealers' share of purchases at auction of Treasury coupon securities has declined steadily in the post-crisis period, which is roughly offset by the rise in the role of investment funds (while the collective share of other investor classes remains quite stable). In addition, dealers turn around inventory faster, resulting in a lower share of auction purchases still on hand by the end of the auction week. Post-crisis regulatory changes and more stringent capital requirements imply that holding inventory is now more costly, which is consistent these findings.

Alongside the increased role of investment funds in the primary market in the post-crisis period, we find that dealers' compensation for taking on inventory risk at auctions has lessened. In particular, the post-auction price appreciation becomes weaker after the crisis. It is likely that the transition of many investment funds from being liquidity demanders to liquidity providers weakens the post-auction demand for Treasury securities in the secondary market, which in turn cuts into the post-auction price appreciation that compensates dealers. Furthermore, the greater competition from the new liquidity providers could drive down compensation for bearing inventory risk. Lower compensation for inventory risk in the post-crisis period also manifests in the weakened

auction-cycle effects in the post-crisis period compared to those found in Lou et al. (2013) for the pre-crisis period from 1980 to 2008.

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 tighten their inventory turnover to optimize on increased balance sheet costs while they obtain less compensation for taking on inventory exposure.

The paper is organized as follows. In Section 2, we discuss the role of Treasury dealers and institutional features of the market. Section 3 provides description of the data used in our empirical analysis. In Section 4, we present our analysis of the determinants of dealers' position changes, focusing on the effects of issuance and redemptions. Section 5 examines the asset pricing effects of dealer inventory management and evaluates the general auction-cycle price effects. Section 6 concludes.

2 The Role of Treasury Dealers

U.S. Treasury securities trade in a multiple-dealer over-the-counter market. Trading takes place 22 to 23 hours per day during the week, although 95% of the volume occurs during New York trading hours, roughly 7:30 a.m. to 5:00 p.m. (Fleming, 1997). The predominant market makers are the primary government securities dealers. Primary dealers are banks and securities broker-dealers that trade with the Federal Reserve Bank of New York 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. We discuss these roles in more detail below.

2.1 Participating in auctions

Certain features of the Treasury market make it a good laboratory for examining how dealers manage their inventory. In the Treasury market, the primary dealers have a special obligation to "participate meaningfully" in auctions of U.S. Treasury securities.[4] This underwriting function is

[4]Primary dealers are also expected to "make reasonably good markets in their trading relationships with the Fed's trading desk" and to "provide the trading desk with market information and analysis that may be useful to the Federal

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. However, Treasury dealers are also expected to place competitive bids for their own account, and they are encouraged to submit bids at a range of prices to ensure that the entire issue is sold at a reasonable price.[5]

Because of this underwriting role, primary dealer inventories are subject to large, predictable changes associated with the Treasury auction cycle. Using data available since May 2003, Fleming (2007) finds that primary dealers acquire an average 71% share of Treasury issues sold at auction for their own accounts. 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. To promote selling, dealers can reduce their offer prices for the newly auctioned security to increase the likelihood that customers will buy it, i.e., quote shading as discussed in Ho and Stoll (1981).

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. Until 1992, the primary dealers were required to maintain a 1% share of total customer activity reported by all primary dealers. Since then, making markets to customers has not been a criterion for being a primary dealer, but the dealers are nonetheless still the predominant market makers. In the last quarter of

Reserve in the formulation and implementation of monetary policy." Dealer responsibilities are listed in the Federal Reserve Bank of New York's January 22, 1992 memorandum, "Administration of Relationships with Primary Dealers," posted at `http://www.newyorkfed.org/markets/pridealers_policies.html`.

[5]See "U.S. Primary Dealers Say Fed Urges More Active Tsy Bids at Mtg," Market News International, June 15, 2004.

2020, for example, primary dealers reported average daily Treasury trading volume of $372 billion with customers and $157 billion with other dealers.[6] Dealers can hedge positions acquired through market making using the same methods described in the previous section.

Dealers generally make markets in several types of debt instruments resulting in a more complicated inventory risk management problem. Perhaps due to the decentralized decision-making of individual traders within a dealing firm, dealers could manage inventory risk over asset classes separately, e.g., Naik and Yadav (2003a). However, portfolio theory suggests that risk management should occur at the firm level as discussed in Ho and Stoll (1983).

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 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.

Several studies show that order flow of U.S. Treasury dealers is informative for prices, both in general (Fleming, 2003; Brandt and Kavajecz, 2004) and around macroeconomic announcements (Green, 2004; Pasquariello and Vega, 2007). Vitale (1998) finds that U.K. gilt dealer trades are informative for prices, but that customer trades are not. Massa and Simonov (2003) identify the

[6]From Federal Reserve Bank of New York's Primary Dealer Statistics data, available at `https://www.newyorkfed.org/markets/counterparties/primary-dealers-statistics`. The customer figure is based on reported trading that did not occur through an interdealer broker, and the dealer figure is based on trading that did occur through an interdealer broker. The latter figure includes significant double-counting, because trades between primary dealers are reported by both parties.

dealers in the Italian government bond market whose trades move prices the most. In terms of profitability, Naik and Yadav (2003b) conclude that dealers do not profit from their positions, whereas Massa and Simonov (2003) identify types of dealers whose trades are profitable.

3 Data

3.1 Treasury dealers' positions

Our data on dealer positions come from the Federal Reserve Bank of New York's FR 2004A 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 lately municipal debt securities. While the 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. Summary data are then released by the Fed with a one-week lag.[7] The data are netted and aggregated across all dealers and 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).

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.[8] Spot and futures positions are reported in terms of market value.[9] Options positions are reported in terms of the delta-weighted value of the security

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

[8]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.

[9]Spot position changes are almost entirely determined by changes in portfolio composition as opposed to valuation effects. For bills and coupon-bearing 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

underlying the option. In our analyses, we generally combine the options and futures positions and refer to the combined positions as futures positions for brevity.

Figure 2 plots net dealer positions in Treasuries over our sample period. We observe that spot bill positions are mostly positive over the entire sample (fluctuating in the $0–50 billion range for the most part), whereas net positions in coupon-bearing securities ("coupon securities," or "coupons") exhibit a structural break around the 2008 financial crisis. Specifically, dealer Treasury coupon positions are mostly negative and declining in the earlier period of the sample, up until the onset of the 2008 financial crisis, but revert sharply thereafter and stay mainly positive after 2013.[10] The changed direction of Treasury coupon positions coincides with dealers' shrinking long inventory positions in other fixed income securities, most notably corporate bonds, as seen in Figure 3. Treasury inventory is strongly and negatively correlated with dealer corporate bond inventory (a correlation of -0.79) and agency debt inventory (a correlation of -0.56), indicating the extensive use of Treasury coupon securities to hedge interest rate risk in these other fixed income securities. After the financial 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), lessening the need to hold short positions in Treasury coupon securities.

Given these changes, we conduct our empirical tests using the full 31-year sample as well as two subsample periods divided by the crisis. We use the same crisis start date of August 9, 2007 as in Nguyen et al. (2020), which partitions the sample into a pre-crisis period (July 4, 1990 to August 8, 2007) and a period since the start of the crisis (August 9, 2007 to December 30, 2020). For ease of reference, we refer to the latter period as the "post-crisis" period.

In Table 1, we report summary statistics for the positions data. The full-sample statistics in Panel A show that coupon position levels always fluctuate more than bill position levels, with a standard

coupon-bearing 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.

[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 current buckets are: due in 3 years or less, due in more than 3 but less than or equal to 6 years, due in more than 6 but less than or equal to 11 years, and due in more than 11 years. Treasury inflation-protected securities (TIPS) are reported in their own bucket 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).

deviation in levels of $76.6 billion for coupons versus $17.5 billion for bills. On average, primary dealers are $15.85 billion net long in bills but $9.96 billion net short in coupons. However, these full-sample averages mask the drastically different inventory levels over time, especially for coupons (as seen in Figure 2). The subsample statistics reported in Panels B and C reveal that the average level of coupons inventory is $52.73 billion net short in the pre-crisis period but flips to $44.68 billion net long in the period since the crisis. Bill positions, on the other hand, remain consistently positive and increase over time, from $9.84 billion before the crisis to $23.54 billion thereafter. In terms of weekly changes, the magnitude for coupons exceeds that for bills, but both pale in comparison to the corresponding inventory level. Weekly inventory changes for bills and coupons exhibit rather similar volatility, but differ in their autocorrelation. The one-week autocorrelation is always negative and appears stronger in the post-crisis period compared to the pre-crisis period.

Previous studies (e.g., Naik and Yadav, 2003b) have interpreted a mean reversion coefficient on positions of less than one as evidence that dealers have a fixed inventory target. We find that bill positions are more strongly mean-reverting than coupon positions, with one-week spot autocorrelations of 0.85 and 0.99 respectively over the full sample (with similar observation for the sub-samples). To appreciate the difference in inventory management practice for bills and coupons, we compute the corresponding inventory half-life and find that bills' inventory half-life is an order of magnitude shorter than coupons' inventory half-life.[11]

We also examine dealers' use of Treasury futures in relation to spot Treasury positions. Figure 4 compares dealers' Treasury spot positions with futures positions over the short period for which futures positions data are available (1990–2001). In both panels of Figure 4, there appears to be a negative correlation between spot and futures positions, with a stronger correlation for coupons (the correlation is -0.13 for bills and -0.50 for coupons). This is consistent with dealers using futures to hedge spot exposures, although the magnitude of futures positions is visibly smaller than that of

[11]Following Naik and Yadav (2003b), we regress inventory change over week t on the level of inventory at the beginning of the week to obtain the mean-reversion coefficient, denoted by α. The inventory half-life (the time it takes for an inventory shock to fade in half) is equal to $log(2)/log(|1-\alpha|)$. The inventory half-life for bills is 4 and 4.5 weeks respectively for the pre-crisis and post-crisis periods, whereas that for coupons is 53.7 and 52.4 weeks.

corresponding spot positions (see also Panel D of Table 1) and the use of bill futures largely fades away after 1995.

3.2 Variables used to explain dealer positions

3.2.1 Treasury issuance

Our issuance data is from the U.S. Treasury Department.[12] 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 1 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 often than coupons. The average weekly issuance amounts to $82.8 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 after September 11, the 2008 financial crisis, and the COVID-19 pandemic.

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.[13] Most securities are redeemed at their maturity, except some that were called or bought back in debt buyback operations over our sample period.[14] We collect data on calls and buybacks and adjust the weekly redemption amount accordingly.[15] Over our sample, 24 bonds with a total par value of $93 billion were called. All of these bonds were

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

[13]Auction data start from 1980 and thus contain information on only securities that are issued since 1980. For securities issued prior to 1980 but matured during the sample period (there were 26 such securities), 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`).

[14]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 Clifford W. Smith, 1987 for an analysis of flower bonds). Maturing 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).

[15]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`.

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.[16] Figure 5 plots the average weekly redemptions by quarter and shows that called and bought back amounts are dwarfed by the maturing amounts. Overall, bill redemptions in our sample average $79.8 billion 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.[17] 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 crisis, Fed holdings of coupon securities have gone up significantly (as a result of large-scale asset purchases) from a pre-crisis average of $281.8 billion to a post-crisis average of $1,758.4 billion, while Fed holdings of bills decrease from $196.4 billion to $42.7 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 $2,626.6 billion compared to $612.3 billion before the crisis). We use the weekly changes of the Fed's and foreign central banks' holdings as control variables 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 dealer activity in other debt securities, we collect data on dealer MBS, agency debt, corporate debt, and municipal debt positions. These positions are also reported in the FR 2004A release, although data on corporate and municipal

[16] 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.

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

debt positions are not available for the full sample period.[18] Over the full sample period, 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 amount by week (ending on Wednesdays) to correspond with our other data. Over our sample, corporate issuance averages $10.5 billion and muni issuance $7.0 billion per 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.[19] 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 the amount of paid interest during week t. Weekly excess returns are then calculated as actual returns minus returns on the 3-month Treasury bill.

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

[18] Data on corporate debt positions are available from July 4, 2001 and municipal debt positions from April 3, 2013.

[19] On-the-run securities are the most recently auctioned securities of a given maturity. When the weekly return for the 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, or due to plain data errors. 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.

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 year 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 dealers' inventory management

4.1 Baseline model

We model Treasury dealers' inventory management by expanding the basic inventory adjustment model (in which inventory changes are regressed on beginning-of-period inventory levels, as in e.g., Naik and Yadav, 2003b or Schultz, 2017) to include activities that are unique to government bond dealers, namely the issuance and redemption of Treasury securities. Because Treasury issuance is exogenous to dealers' existing positions and risk preferences, use of this data allows for a fairly clean test of supply effects on dealer positions. We also control for the possibility that dealers' Treasury inventory adjustment is affected by their trading in other fixed income securities (due to hedging or arbitrage trading motives), as well as their roles as counterparties to the Federal Reserve. Therefore, we include in the regression model changes in Federal Reserve holdings, foreign central bank holdings, dealer agency debt positions, dealer MBS positions, and the weekly amount of corporate and municipal bond issuance.

Thus, the inventory model we estimate is:

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

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 $t-1$. In this model, β_1 is the mean-reversion coefficient, which indicates the extent to which dealers manage their inventory around some target level. β_2 and β_3 capture the effects of Treasury issuance and redemption on dealers' inventory. Z_t include control variables

discussed above. We estimate the regression separately for bills and coupons, and report the results in Panels A and B of Table 2 respectively.[20]

The basic inventory adjustment model (in column (1) for bills and column (4) for coupons) shows that dealers have a stronger tendency to manage their inventory around a target level for bills than for coupons. The beginning inventory level explains about 7% of variation in weekly bill inventory changes, whereas it barely explains any variation in weekly coupon inventory changes (R^2 of 0.2%). The inventory mean-reversion coefficient is -0.146 for bills, but only -0.006 for coupons. These coefficients imply that following an increase in the inventory level at the beginning of the week, dealers eliminate 14.6% of the increase during the week for bills, but only 0.6% for coupons. Because there are bill auctions every week and the weekly issuance amount is several times greater than that of coupons, the stronger mean-reversion behavior of bill inventory is consistent with the need to maintain inventory at a target level to enable dealers to absorb a large quantity of new bill supply every week.

Evidence from other securities markets shows that there is substantial variability in dealer willingness to hold new inventory. 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). Here, even among the same class of securities (Treasury securities), dealers' inventory strategy differs markedly between bills and coupons.

The effects of Treasury supply cycles (issuance and redemption) reported in Table 2 indicate that dealers play a significant role in underwriting new issuance. The issuance coefficients (β_2) can be interpreted as the change in dealer positions over the week relative to the total amount of auctions during the week. Thus, dealer bill positions increase by an average of $126 million per $1

[20]The issuance, redemption, and changes in the Federal Reserve holdings variables are defined separately for each security type (i.e., bills and coupons separately). However, other variables, i.e., changes in foreign central bank holdings, changes in agency debt positions, changes in MBS positions, corporate bond issuance, and municipal bond issuance are only defined in aggregate and thus do not vary between bill and coupon regressions.

billion of bill issuance in a week (column 3) and dealer coupon positions increase by an average of $153 million per $1 billion of coupon issuance in a week (column 6).

To gauge how fast dealers shed the exposure taken on at auctions, we perform the following back-of-envelope calculation. Investor class allotment data (available from August 8, 2001) indicate that broker-dealers purchase on average a roughly 63% share of bill issuance and 46% share of coupon issuance at auction.[21] Broker-dealers include both primary and non-primary dealers, but primary dealers account for the bulk of broker-dealers' purchases: 87.3% for bills and 89.8% for coupons.[22] Thus, primary dealers retain about 23% of the bill position exposure and about 37% of the coupon position exposure taken on through their auction purchases ($0.126/(0.873 \times 0.63) = 0.23$ for bills; $0.153/(0.898 \times 0.46) = 0.37$ for coupons). That is, dealers sell, or hedge with other spot sales, roughly 77% of Treasury bills and 63% of Treasury coupons they buy at auction in the same week.

We also see evidence that redemptions have a meaningful impact on dealer spot inventories. The redemption coefficients in Table 2 can be interpreted as the change in dealer positions relative to redemption amount. Based on the full specification reported in columns (3) and (6), dealer bill positions decline by an average of $87 million per $1 billion of bill redemptions and dealer coupon positions decline by an average of $90 million per $1 billion of coupon redemptions in a week. As Treasury securities mature, it is natural to see a reduction in dealers' inventory, either because the dealers themselves hold some securities through maturity (most likely the case with short-term bills) or because investors buy other securities from dealers' inventory to replace the redeemed ones.

Looking at our control variables (columns 3 and 6), several observations are worth noting. First, changes in central bank holdings (both the Federal Reserve and foreign central banks) are significantly and negatively correlated with dealers' coupon inventory changes, but show no relationship with bill inventory changes. This is consistent with the Fed and foreign central banks buying Treasury coupons from dealer inventory, driven by post-crisis large-scale asset purchases

[21] These figures are lower than the 74% and 60% respective shares reported in Fleming (2007) because dealers' share of purchases at auctions have declined in recent years.

[22] These statistics are based on detailed data on primary dealers' purchases at auctions, available from April 23, 2008 onward.

which focus on longer-term Treasury securities. In relation to other fixed income instruments, we find evidence that dealer Treasury positions (both bills and coupons) are negatively correlated with MBS positions: dealer bill (coupon) positions tend to decrease by $111 million ($83 million) per $1 billion increase in MBS positions on average. This could be a result of dealers hedging positions across markets or putting on speculative spread positions. We observe a similar relationship between Treasury position changes and municipal bond issuance. However, with respect to corporate debt issuance, we observe the significant negative relationship only for bills (and not for coupons). This is surprising because one would expect a stronger relationship between coupon inventory changes and corporate bond issuance due to the closer maturity match in hedging interest rate risk.

That said, the most striking finding from our inventory model is that the two supply cycle factors (issuance and redemption) are the main drivers of the variation in dealer position changes. They collectively explain 18.7% and 27.6% of the variation in weekly inventory changes for bills and coupons respectively, which are far greater than the explanatory power of the mean-reversion component of inventory as discussed above. Furthermore, adding other control variables to the regression results in only a minuscule further increase in R^2 (see columns 3 and 6). Overall, our results point to underwriting as a key determinant of dealer positions and highlight a key difference in the institutional setting and therefore the inventory management problem of government bond dealers versus dealers in the equity or foreign exchange markets.

4.2 How does inventory management change over time?

As Figures 2 and 3 show, the 2008 financial crisis appears to mark a structural break in dealers' positions, especially with respect to coupon Treasuries and other fixed income securities. As a result, the full sample analysis presented above might mask important changes between the pre-crisis and post-crisis periods. In this section, we analyze the sub-sample periods separately to illuminate whether and how dealers' inventory management has changed. Many significant market developments have occurred since the 2007–09 crisis, including large-scale asset purchases, regulatory changes that impose stricter capital requirements (hence making inventory more expensive to hold), and the rise of non-dealer liquidity providers (such as hedge funds, as studied in Kruttli

et al., 2021 and Barth and Kahn, 2021, among others). Amid these developments, how Treasury dealers adapt and continue to fulfill their intermediary roles is an important question to explore.

We estimate the regression in Equation (1) separately for the pre- and post-crisis periods and tabulate the results in Table 3. We test for the difference in the coefficient estimates between the sub periods using the Welch-Satterthwaite t-test. Focusing first on the results for bills in Panel A, dealers seem to have significantly tightened bill inventory management since the crisis, as evidenced by the following observations. First, inventory is significantly more mean-reverting (mean reversion coefficient changes from -0.134 to -0.248). Second, new exposure taken on through auction purchases has a significantly smaller effect on position changes by the end of the week. Third, the effect of redemptions on dealer position changes also decreases. The smaller effect of bill issuance on weekly bill position changes could be due to dealers selling off the newly acquired bill exposure faster, and/or dealers acquiring a smaller share of purchases at auctions. To distinguish between these possible explanations, we plot the share of broker-dealers' purchases at bill auctions from 2001 to 2020 (see Figure 6) and observe that broker-dealers have been buying a consistent, or even increasing, fraction of bill issuance over time. Thus, the smaller effect of issuance on dealers' bill inventory changes can be reliably attributed to their selling off the newly acquired inventory faster. This is also consistent with the smaller effect of redemptions, because there are now less bills remaining in inventory through maturity.

Dealers' management of coupons positions (reported in Panel B) has also changed in key aspects. Most notably, the effect of issuance is much lower in the post-crisis period compared to the pre-crisis period. Specifically, for every $1 billion in new issuance during the week, the end-of-week inventory increases by $139 million as opposed to $219 million pre-crisis. However, unlike bills, the share of broker-dealers' purchases at coupon auctions actually declines over time, as shown in Figure 6, with a 56% average share before the crisis compared to a 43% average share in the post-crisis period. Still, the decrease in the share of purchase at auctions is milder than the decrease in the issuance coefficient estimate, which suggests that dealers also sell off newly acquired coupon inventory faster. Had dealers shed their coupon exposure taken on at auction at the same rate as they did before

the crisis, they would have had $167 million in inventory, on average, at the end of each auction week in the post-crisis period ($(0.219/0.56) \times 0.43 = 0.167$). The lower estimated $139 million that remains on hand at the end of each auction week reflects faster inventory layoff, although the increased speed of coupon inventory turnover still lags behind that of bill inventory turnover.

The subsample analysis also highlights the important role of dealers in facilitating central bank purchases (specifically of Treasury coupon securities) after the crisis. The coefficients on changes in the Fed's holdings and foreign central banks' holdings are significantly negative only in the later subsample period, and only for coupons. Lastly, while there is clear evidence of Treasury positions being responsive to positions in other fixed income instruments before the crisis (suggesting the use of Treasuries for hedging interest rate risk in other fixed income assets or spread trades), this relationship is largely gone in the post-crisis period. Regulatory changes after the crisis are often linked to reduced proprietary trading and increased inventory holding costs. The diminished inventory across fixed income securities might alleviate the need for cross holding Treasuries, which offers a possible explanation for our finding.

4.3 Issuance and redemption effects by maturity

We next analyze whether dealer inventory management varies across the maturity dimension using finer classifications than before. We expand the regression model in Equation (1) by replacing the bill and coupon issuance and redemption variables with maturity-specific issuance and redemption variables, i.e.:

$$\Delta Inv_t = \alpha + \beta_1 \, Inv_{t-1} + \sum_s \beta_{2,s} \, Issuance_{t,s} + \sum_s \beta_{3,s} \, Redemption_{t,s} + \gamma' \, Z_t + \epsilon_t, \qquad (2)$$

where s indicates a specific maturity. As before, we estimate this regression separately for bill position changes and coupon position changes. For the bills regression, s takes on the following terms: cash management bills (CMB), 4-week, 13-week, 26-week, and 52-week. For the coupons regression, s takes on the following terms: 2-year, 3-year, 5-year, 7-year, 10-year, and 30-year.[23] We

[23]We omit securities that are not issued but redeemed over our sample period (i.e., 15- , 20-, 25-, and 40-year bonds) and securities that are only issued a small number of times over our sample (i.e., 4-year notes and the recently reintroduced 20-year bonds in 2020).

report $\beta_{2,s}$'s and $\beta_{3,s}$'s for the full sample as well as the two subsample periods in Table 4. We also show the t-test statistic for the difference in each coefficient estimate between the two subsample periods. Coefficients for the control variables are qualitatively the same as previously reported and are omitted for brevity.

The results indicate that almost all securities contribute to the issuance effect observed in Table 2, except the 13-week bills among Treasury bills and the 30-year bonds among Treasury coupons. Between the subsample periods, the issuance effects in general have lessened in the later period, consistent with dealers laying off inventory faster. Notably, in the post-crisis period, while dealers still retain a sizable amount of auction purchases in inventory by the end of the auction week for shorter coupon securities (2-, 3-, 5-, and 7-year notes), they finish the week almost flat with respect to auction purchases of the longer maturities (10- and 30-year). The effects of redemption on dealers' inventory adjustment concentrate among short-term bills (CMB and 4-week bills) and short-term coupons (2- and 3-year notes). In the post-crisis period, the redemption effects attenuate somewhat, consistent with the overall finding that dealers have been selling off their auction-driven inventory faster with fewer securities remaining on hand at maturity.

In general, shorter-term securities might have a greater effect on dealer inventories for various reasons. First, for the irregularly scheduled CMB, dealers may not be able to effectively reduce inventory by selling to customers. Customers may avoid these securities because of their irregular issuance and maturity dates as well as their short maturities. Second, dealers may be more willing to hold large positions in short-term securities, because of their short maturity and hence low interest rate risk. This is consistent with an inventory management strategy focused on duration risk documented by Naik and Yadav (2003b) for U.K. gilt dealers.

4.4 Intertemporal inventory management: Issuance effects around auctions

The baseline results discussed in Section 4.1 suggest that dealers take into inventory a large share of Treasury issuance and still hold a sizable amount by the end of the auction week. We now study dealers' intertemporal inventory management practice and ask whether dealers smooth the inventory impact of their auction purchases by selling Treasuries in the week before or the week

after an auction.[24] By actively managing inventories in adjacent weeks, dealers could substantially offset the effects of auctions. To examine this possibility, we refine the regression model in Equation (1) by adding previous-week and next-week issuance amounts as follows:

$$\begin{aligned} \Delta Inv_t &= \alpha + \beta_2\, Issuance_t + \beta_{2b}\, Issuance_{t-1} + \beta_{2a}\, Issuance_{t+1} + \beta_3\, Redemption_t \\ &\quad + \gamma'\, Z_t + \epsilon_t, \end{aligned} \tag{3}$$

where β_{2b} reflects the extent to which dealers continue to sell off the inventory exposure taken on at auctions in the previous week and β_{2a} reflects the extent to which dealers prepare for auctions in the upcoming week (pre-hedging).[25] Deviating from the baseline regression model in Equation (1) in which the starting inventory level is among the explanatory variables, we exclude it from the model in Equation (3) because its effects will subsume the effects of previous-week's issuance—an explanatory variable of interest in this analysis. We report β_2, β_{2b}, and β_{2a} in Table 5.

As shown by the coefficients reported in Table 5, spot positions do tend to decrease in the weeks before and after an auction. Specifically, dealers' bill positions decline by about $67 million in the week before and about $52 million in the week after, but increase by $207 million in the current week. Likewise, each additional billion dollars of coupon issuance causes dealers' coupon positions to decrease by $22 million the week before auction, increase by $136 million the week of auction, and then decrease by $40 million the week after auction. Across the subsample periods, this pattern consistently prevails. However, the effects of issuance in adjacent weeks are far smaller in magnitude compared to the effects of issuance in the same week. Nonetheless, even the effects of same-week issuance diminish somewhat in the post-crisis period, most likely due to dealers shedding off auction-induced inventory shocks quicker as previously discussed.

[24] 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.

[25] Because auction schedules and offering amounts are announced well in advanced, the amount of next-week's issuance $Issuance_{t+1}$ is known at week t and therefore can be included in the regression to explain dealers' position changes in week t.

4.5 Use of derivatives for inventory management

In this section, we explore dealer use of derivatives for inventory management. Given the sizable exposure taken on at auctions, it might be natural for dealers to take offsetting positions in derivatives (mostly Treasury futures) to hedge newly acquired inventory. If so, there should be a negative relationship between changes in dealers' spot and futures positions. We have the opportunity to shed light on this question using the short sample of FR2004 data on dealers' futures and options positions (1990–2001), with the obvious caveat that dealers' use of derivatives for managing auction-induced inventory risk 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 (4) of Table 6. We find that Treasury futures and spot positions indeed tend to move in opposite directions. The coefficient on bill spot positions 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 their spot positions by adjusting the amount they hedge depending on the nature of the trade. For this reason, 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 precommitment to a regular and predictable auction schedule), they expose dealers to relatively little adverse selection risk and are thus not as important to hedge. In contrast, position changes due to market-making activities might emanate from customer trades that are based on private information. These are exactly the types of inventory changes that a dealer would prefer

to offset. Indeed, 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 the use of derivatives to hedge auction-related inventory changes to be less than that to hedge inventory changes driven by other factors.

To do this decomposition, we first estimate the regression model specified in Equation (1) (again separately for bills and coupons) using data over the short sample period used in this section. We then compute the issuance-induced spot position changes as $\Delta Inv_{issuance} = \beta_2 \times Issuance$, and the redemption-induced spot position changes as $\Delta Inv_{redemption} = \beta_3 \times Redemption$. Position changes due to other factors is 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 and report the results in columns (2) and (5) of Table 6.

The results reveal that futures are used to hedge position changes due to issuance and redemption to a much smaller degree than other position changes, consistent with our hypothesis of selective hedging to mitigate adverse selection risk. For bills, the coefficients on position changes due to issuance and redemptions are insignificant, and only the coefficient on position changes due to other factors is negative (-0.042) and statistically significant. For coupons, the coefficient on position changes due to issuance is significantly negative (-0.133), but much smaller in magnitude than the coefficient on position changes due to other factors (-0.282). The coefficient on position changes due to redemptions for coupons is not significantly different from zero. The rationale for the insignificant redemption coefficients is fairly straightforward. Securities that are about to mature have very low price risk and high redemption liquidity (they are about to be turned into cash) and are thus similar to cash, obviating the need for hedging. While redemptions are important in an accounting sense when evaluating dealers' nominal position changes, they are not very important to dealers in managing inventory risk. The same logic can be applied to explain the minimal hedging of bill issuance.

Our analysis above assumes that dealers hedge spot positions with futures—and this is the interpretation offered by Naik and Yadav (2003b)—but it is also possible that dealers hedge futures

positions with spot positions. To rule out the latter interpretation, we examine whether dealers' futures position changes are correlated with overall hedging activities in the futures market. If dealers are not using futures to hedge spot positions (and instead are using spot positions to hedge their futures positions), there should not be any correlation between dealers' futures positions changes and commercial traders' position changes. Commercial traders are generally classified by the Commodity Futures Trading Commission (CFTC) as those who use futures or options markets for hedging. The CFTC reports the positions of these hedgers in the weekly Commitments of Traders (COT) reports.[26] Thus, we regress dealers' position changes in bills futures on commercial traders' position changes in the 13-week bill futures (see column 3 of Table 6), and regress dealers' position changes in coupon futures on commercial traders' position changes in the 2-, 5-, 10-year note and 30-year bond futures (see column 6 of Table 6).

The results show that primary dealer futures position changes are highly correlated with the futures position changes of hedgers as reflected in statistically significant and positive coefficients, as well as sizable R^2's (explaining around 22% of variation in dealers' futures position changes). Thus, the evidence is consistent with primary dealers engaging in the futures market for hedging purposes and thus supports our interpretation that dealers use futures to hedge their spot positions. Overall, we conclude that 1) dealers use futures to selectively hedge spot position changes due to other factors to mitigate adverse selection risk, 2) dealers leave issuance- and redemption-driven position changes largely unhedged (for bills) or hedged with a much lower hedging ratio (for coupons), and 3) dealers' use of futures for inventory management is more important for coupons than for bills.

5 Asset Pricing Effects of Dealer Inventory Management

We now use our data on Treasury dealer positions, Treasury issuance, and Treasury returns to examine asset pricing effects related to dealer inventory management. In their underwriting and market-making roles, dealers accumulate undesired inventory. This inventory is costly to dealers,

[26]The COT data are available from the CFTC website. We match the weekly COT positions data (reported as of the close each Tuesday) as close as possible to the weekly FR 2004A positions data (reported as of the close each Wednesday).

because it generates both inventory risk and asymmetric information risk. We investigate whether dealers are indirectly compensated for the resulting risk by price appreciation of these positions.[27]

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 only examine secondary market prices, so our analysis does not incorporate dealer compensation for buying securities at a presumably underpriced auction price and immediately reselling at a higher price in the secondary market. Instead, our primary interest is in dealer compensation for the risk associated with inventory changes in the form of future appreciation of positions taken on 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 study 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

[27]Compensation for risk need not only be received by dealers. Other market participants who provide liquidity services (e.g., hedge funds or proprietary trading desks) would also receive such compensation.

changes is common knowledge does not preclude a price effect to the extent that such an effect is fair compensation for bearing inventory risk. In fact, anecdotal evidence supports the idea that Treasury issues cheapen around auction dates to attract sufficient demand for the new supply.[28]

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.[29] However, it is also important to recognize that dealers' order flow might contain information that moves prices, especially with 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. Thus, an increase in dealer positions—implying dealers are buying—might be accompanied by a contemporaneous price increase, which is opposite 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 often challenging to distinguish the inventory risk compensation effects from the price impact of dealer order flow. Our earlier findings discussed in section 4 that Treasury issuance and redemption are the main driver of dealers' position changes provide a helpful starting point for us to separate the two channels above. That is, we can decompose dealers' position changes into a component driven by Treasury auctions (representing frequent, predictable, and sizeable inventory shocks) and another component due to other factors (e.g., customer flows, dealer hedging, or dealer speculative activity). Because Treasury auctions are on a regular schedule and details are announced in advance, there is naturally minimal adverse selection associated with issuance-driven inventory changes. Thus, any price effects observed for issuance-driven inventory changes can be cleanly attributed to compensation for bearing inventory risk. With regard to the non-issuance component

[28]For example, see, "Treasurys End Modestly Lower On Refunding Pressures," Ramez Mikdashi, Dow Jones Newswires, November 8, 2004 and "U.S. Treasuries Firm to Day's Highs as Stocks Sag," Ros Krasny, Reuters News, January 11, 2005.

[29]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."

of inventory changes, a contemporaneous and positive relationship with price (without reversal) would provide evidence of information content of dealers order flow separately from the inventory risk compensation channel.

To test this hypothesis, we regress weekly excess returns on contemporaneous and lagged values of weekly spot position changes decomposed into issuance-driven and other factors. To control for the Treasury return predictability documented by Cochrane and Piazzesi (2005), we include five forward rates as used in their model. Thus, the regression model is:

$$\begin{aligned} r_t &= \alpha + \beta_1 \Delta Inv_{issuance,t} + \beta_2 \Delta Inv_{others,t} + \beta_3 \Delta Inv_{issuance,t-1} + \beta_4 \Delta Inv_{others,t-1} \\ &\quad + \gamma_1 f_{t-1}^{(1)} + ... + \gamma_5 f_{t-1}^{(5)} + \epsilon_t, \end{aligned} \tag{4}$$

where r_t is the weekly excess returns on a given Treasury security (in bps), $\Delta Inv_{issuance}$ 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 in year 1 through 5. We estimate this regression using excess returns for the 13-week and 26-week bills, and the 2-, 5-, and 10-year notes. These securities are the most liquid representatives of bills and coupons, which allow us to capture the price effects not contaminated by liquidity concerns. Bill returns are regressed on changes in bill positions and coupon returns on changes in coupon positions.

5.1 Full sample analysis of inventory risk compensation

We first estimate the regression model specified in Equation (4) using the full data sample covering nearly 31 years from 1990 to 2020. 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 (1) as reported in columns (3) and (6) in Table 2. For bills, $\Delta Inv_{issuance,t} = 0.126 \times Issuance_t$. For coupons, $\Delta Inv_{issuance,t} = 0.153 \times Issuance_t$. The non-issuance component is then computed as $\Delta Inv_{others,t} = \Delta Inv_t - \Delta Inv_{issuance,t}$ respectively for bills and coupons. We tabulate the results in Table 7. To assess the incremental predictive power of dealers' position changes, we also report the increase in R^2 relative to a Cochrane-Piazzesi styled regression with just the five forward rates.

The contemporaneous price effects appear to differ between bills and coupons. For bills, inventory changes driven by bill issuance are negative and statistically significant, consistent with our prediction that dealers are taking on these inventory exposures while price declines. On the other hand, there is no significant contemporaneous price effect observed for coupon inventory changes driven by same-week auction. An institutional feature might contribute to explaining this difference. The 13-week and 26-week bills are auctioned on a set day each week (currently Monday, except for holidays and special circumstances), which is near the end of the Wednesday week ending. Thus, the auction-week return reflects closely the price pattern at the time dealers acquire auction-related inventory. In contrast, coupon auctions (the three notes examined) are on a monthly calendar and fall on different days of week. For auctions that occur late in the week (Thursday and Friday), the auction-week return does not line up closely in timing with the auction inventory acquisition and could dilute the pricing effects of auctions that occur early in the week.

The most notable observation with regard to contemporaneous price effects is that dealers' coupon inventory changes due to other factors are significantly positive. For example, a $1 billion increase in dealers' non-issuance-related order flow is accompanied by a contemporaneous 1.74 bps increase in excess return on the 10-year note. The result implies that dealers' trading activity in coupon securities contain information for Treasury returns, which is consistent with the idea that coupons are more likely to be used for speculation and proprietary trading than bills.

The lagged pricing effects reveal strong evidence of subsequent price appreciations following dealers' acquisition of inventory at auctions. Specifically, the coefficients on previous-week position changes due to issuance are positive and statistically significant for all five securities. In contrast, previous-week position changes due to other factors have no significant effect, further supporting the view that non-issuance order flow has an immediate price impact due to adverse selection and that such price impact does not subsequently revert. Overall, our results on previous-week position changes are consistent with dealers being compensated for inventory risk through subsequent appreciation in position values.[30] Because data on dealer positions are only released to the public

[30]Subsequent to the first draft of this paper, other authors have provided further evidence on the asset pricing effects of Treasury auction cycles. Lou et al. (2013) find that U.S. Treasury security prices decrease in the few days leading up

with a lag, any value positions data have at explaining future price changes would not necessarily be arbitraged away. In terms of magnitude, the results show that each additional billion dollars of position changes driven by coupon issuance is associated with a 10-year note return 3.51 bps higher 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 bp (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 come from the dealers' intertemporal intermediation of supply across weeks.

Lastly, we find that dealers position changes add considerable explanatory power to explaining Treasury excess returns. Without dealers position changes, the Cochrane-Piazzesi-styled regression models explain between 0.1% to 3.4% variation in excess returns.[31] Adding dealer position changes increase the regression R^2 by 2.1%–3.2%. The incremental R^2 appear larger for coupons than for bills, indicating that dealers' coupon inventory changes are slightly more informative for future Treasury excess returns than bills.

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 mitigate price disruptions by buying securities at auction and selling 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 auctions.

to Treasury auctions 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.

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

5.2 Subsample analysis of inventory risk compensation

As the results in Section 4 show, Treasury dealer positions management has changed since the crisis. In this section, we explore if the asset pricing effects of dealer inventory management also change between the pre-crisis and post-crisis periods. Thus, we estimate the regression model in Equation (4) separately for the two subsample periods. The decomposition of dealers' position changes into issuance and non-issuance components is based on subsample-specific estimates of issuance effects reported in Table 3.

Panel A of Table 8 presents the results for the pre-crisis period. The key findings obtained from the full sample (shown in Table 7) are observed in this subsample period as well. In particular, the significant price appreciation in the week after dealers have acquired auction-induced inventory is present for most securities and is stronger for the longer maturity securities. There is also some mild evidence of negative return accompanying the issuance-driven order flow in the auction week (negative sign for all five securities but statistically significant only for the 2- and 5-year notes), adding to dealer compensation for inventory risk associated with auctions. Moreover, dealers' order flow driven by non-issuance factors has significant and positive immediate price impact, but no significant price impact in the subsequent week, indicating the presence of information in dealers' non-issuance order flow.

The results for the post-crisis period are reported in Panel B of Table 8. While the price appreciation in the subsequent week following auction-induced inventory shocks continue to be significant for all but one security, several key changes compared to the pre-crisis period are apparent. First, the information content of dealers' non-issuance order flow in coupon securities prevalent in the pre-crisis period now seems to disappear. Formal tests for the statistical significance of the difference between the two periods reported in Panel C of Table 8 confirm that this disappearance of adverse selection effects is the major change between the two periods. Second, the now significant negative returns of bills (especially for the 26-week bills) that accompany dealers' auction-driven order flow in the same week suggest that a good portion of dealers' compensation for inventory risk in bills accrues from "buying low" in the auction week, in addition to that from "selling high"

in the subsequent week. Third, the magnitude of the price appreciation in the subsequent week appears to be smaller compared to the pre-crisis period, indicating that dealers now obtain lower compensation for inventory risk than before. This is most clearly seen in the 10-year note, where the subsequent-week price appreciation is 4.61 bps in the pre-crisis period but reduced to just 1.89 bps in the post-crisis period.

Comparing the regression R^2 between the two periods also reveals that dealers' coupon position changes were more informative than bill position changes in explaining variation in Treasury excess returns in the pre-crisis period. However, coupon positions' informativeness diminished after the crisis with the incremental R^2 dropping to below 1%. Meanwhile, dealer bill position changes become more predictive of excess bill returns, explaining an extra 3.7-5.3% of variation in the latter. It is worth noting that excess bill returns are more predictable in the post-crisis period, as reflected in the R^2 of 10-14$\%$. This could be due to the zero-lower bound interest rate environment in the post-crisis period, which is more binding for securities at the very short end of the yield curve.

The changes described above are consistent with several market trends in the period after the crisis. First, post-crisis regulatory changes and more stringent capital requirements contribute to reduced proprietary trading, thereby reducing the information content of dealers' order flow from secondary market activities (especially for Treasury coupons). Second, the increased participation of investment funds (including hedge funds) in the primary market in recent years might have contributed to lessening the compensation for taking on exposure at auctions. Data on investor class allotment of Treasury auctions plotted in Figure 7 clearly show that in the years after the crisis, broker-dealers' share of purchase at auctions steadily decreases—a trend that is almost exactly offset by the increasing share purchased by investment funds, while all other investor classes collectively purchase a relatively stable share of auctions over time.

Why does the increased participation of investment funds in the primary market result in less compensation for inventory risk? According to Duffie (2010), compensation for inventory risk arises due to slow moving capital and inattentive investors. It is possible that many of these investment funds used to be dealers' clients, who bought Treasury securities after auctions through the dealers.

Their demand collectively contributed to robust price appreciation after auctions, which served as dealer compensation for intermediating new Treasury supply. As investment funds transitioned to buying Treasuries directly at auctions in the period after the crisis, the post-auction demand for the securities in the secondary market weakened, resulting in milder post-auction price appreciation. Furthermore, some of the investment funds can be liquidity providers as well. Their increased presence in the primary market along with additional capital brought into intermediation naturally intensifies the competition among intermediaries and lowers the compensation as a result. We will examine this point further below.

5.3 Auction-cycle pricing effects

Our results so far focus only on the pricing effects of dealers' position changes driven by Treasury issuance and other factors. We now explore more closely the general price patterns around Treasury auctions first documented in Lou et al. (2013) based on data from 1990 to 2008. They find that Treasury yields increase in the few days before but decrease in the few days after the auction of the next on-the-run security and attribute these patterns to dealers' limited risk-bearing capacity and end-investors' imperfect capital mobility. If investors can now access the new supply directly and total risk-bearing capacity of the intermediary sector increases with the emergence of new liquidity providers, we expect the auction-cycle price patterns to weaken in the period since the crisis.

To pursue this line of inquiry, we follow a similar approach to Lou et al. (2013) and track the changes in the secondary market yield 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 the 10 days after. That is, we capture the evolution of yield of the same security as it transitions from being an on-the-run security to being the first off-the-run on 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). One important consideration in designing our analysis of auction-cycle effects is that these Treasury securities are currently auctioned once per month at around the same time of month. As shown in Figure 8, the 2- and 5-year notes are auctioned toward the end of the month whereas the 10-year note is auctioned early in the month. Thus, the evolution of yield 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 need to adjust yields for the 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. 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). We do this exercise separately for the two subsample periods used in the paper, and plot the corresponding auction-cycle effects (zoomed in to 5 days before and 5 days after auctions) in Figure 9. The full auction cycle effects are presented in Table 9.

Focusing on the pre-crisis period in the left column of Figure 9, we find significant auction-cycle effects (especially in the 2- and 5-year notes), which are qualitatively similar to the results in Lou et al. (2013) even though we have adjusted for the day-of-month effects in yields.[32] That is, Treasury securities tend to cheapen in the run up to auctions, but then appreciate in price thereafter, providing compensation to intermediaries who absorb a large supply shock and redistribute it to investors over time. However, this pattern is visually weaker in the second subsample period since the crisis, as shown by the plots in the right column of Figure 9. Formal results in Table 9 confirm this observation: many of the significant auction-cycle effects in the pre-crisis period are no longer significant in the post-crisis period. We also test for whether the magnitude of the effects has significantly changed between the two subsample periods (reported in "Diff. t-stat"

[32]The pattern around the 10-year note's auctions is weak even in Lou et al. (2013) using raw yields. Once we control for the day-of-month effects, the 10-year note does not exhibit any significant auction-cycle effects. Moreover, the low number of auctions does not help with statistical power.

columns in Table 9) and obtain some mild evidence that it does. Overall, our evidence of weakened auction-cycle effects in the period following the 2007–09 crisis is consistent with our interpretation that increased disintermediation of dealers (as large institutional investors mobilize their capital to purchase Treasury securities directly at auction) and the emergence of new liquidity providers (e.g., hedge funds) contribute to lower compensation for intermediation.

6 Conclusion

The regular issuance and redemption of Treasury securities creates a different inventory management problem for government bond dealers versus equity or foreign exchange dealers. In this study, 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 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 due to higher interest rate risk and also more likely to hedge position changes perceived to be prone to 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 dealers tend to buy Treasuries during auction weeks when prices are depressed by the new supply and are then compensated by price appreciation the subsequent week—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 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 not previously explored related to dealer intermediation of frequent Treasury supply shocks.

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 turn around inventory faster, 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 purchase at auctions in recent years. Their increased role in the primary market correlates with weakened price effects surrounding auctions, implying that compensation for inventory risk acquired at auctions has lessened. It is likely that the transition of many investment funds from being liquidity demanders to liquidity providers weakens the post-auction demand for Treasury securities in the secondary market, which in turn cuts into the post-auction price appreciation meant to compensate dealers. Furthermore, the greater competition from the new liquidity providers could drive down compensation for bearing inventory risk.

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 tighten their inventory turnover to optimize on increased balance sheet costs while obtaining less compensation for taking on inventory exposure. 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 obvious at times of stress (e.g., March 2020) when non-obligatory liquidity suppliers step back from the market. Having a robust dealer sector despite the trend toward disintermediation remains crucial to financial stability.

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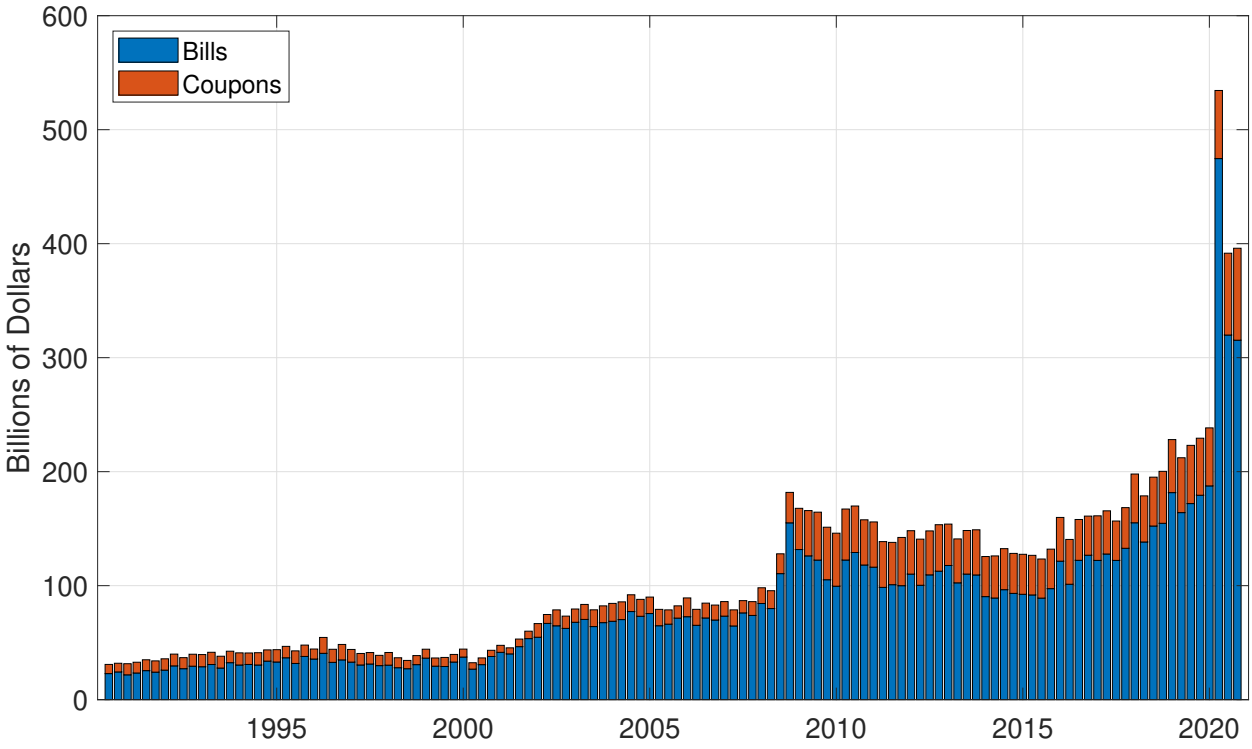
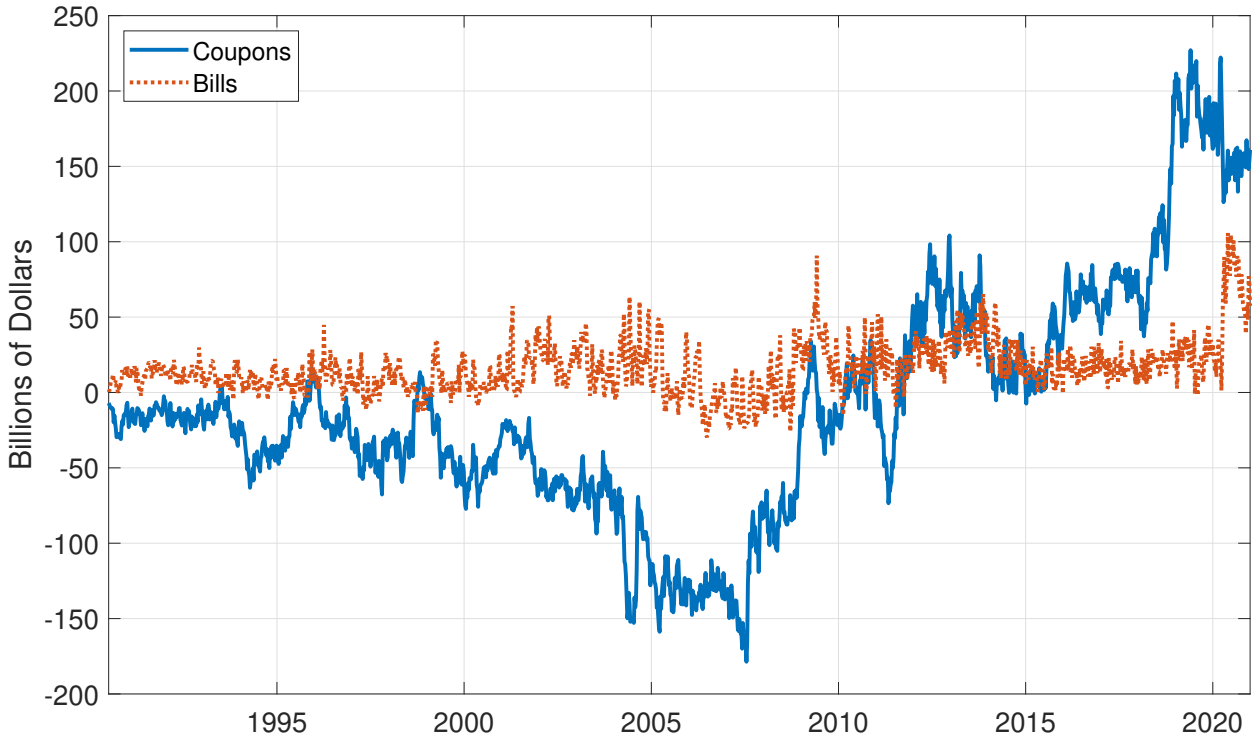
Figure 1: Treasury Issuance 1990–2020



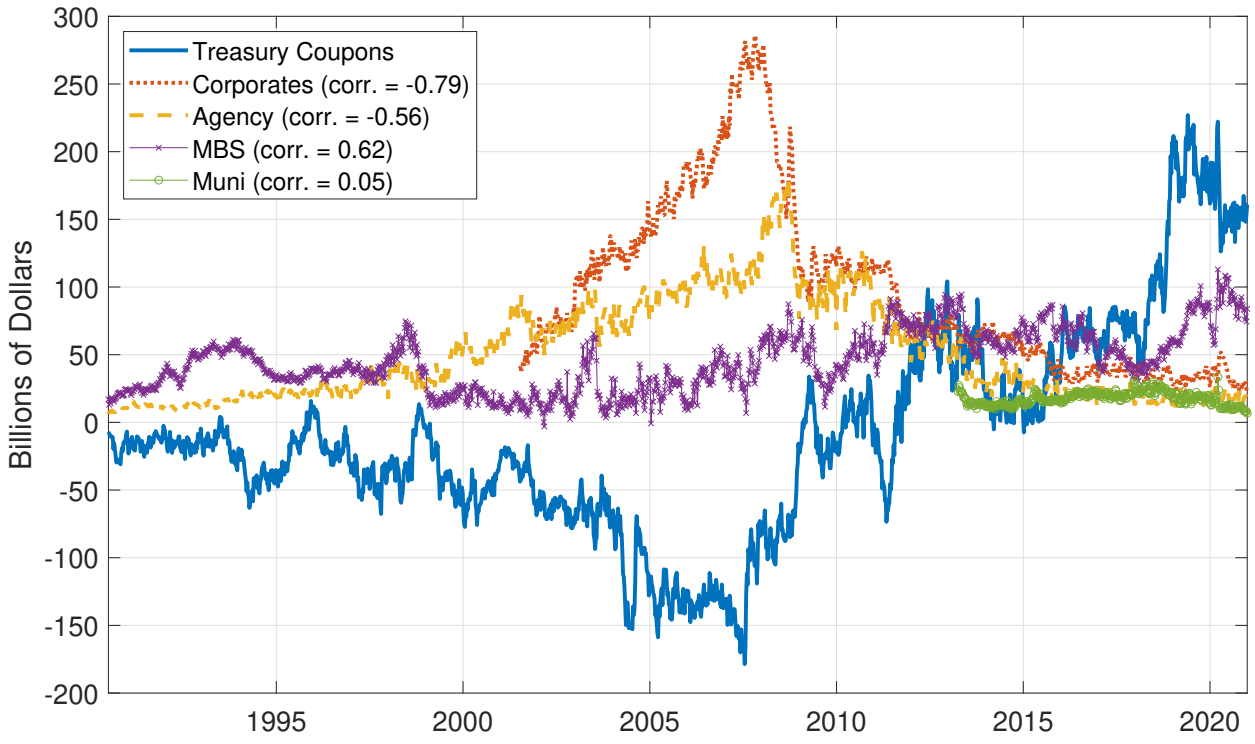
This figure plots average weekly auction amounts of U.S. Treasury bills and coupon-bearing securities by quarter for the weeks ending July 4, 1990 to December 30, 2020.

Figure 2: Dealer Treasury Spot Positions 1990–2020



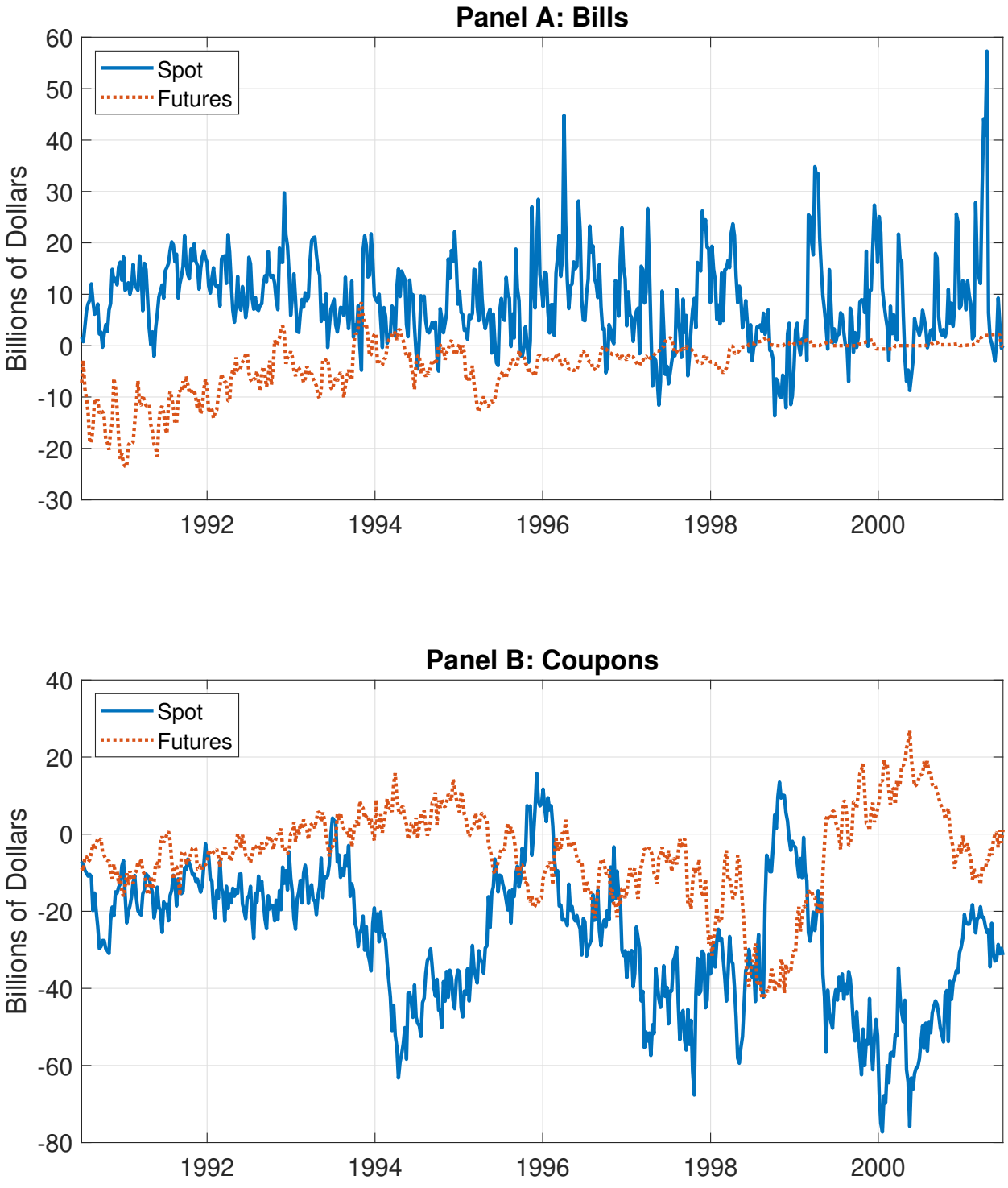
This figure plots primary dealer net spot positions in U.S. Treasury bills and coupon-bearing securities by week from July 4, 1990 to December 30, 2020.

Figure 3: Dealer Net Positions in Fixed Income Securities 1990-2020



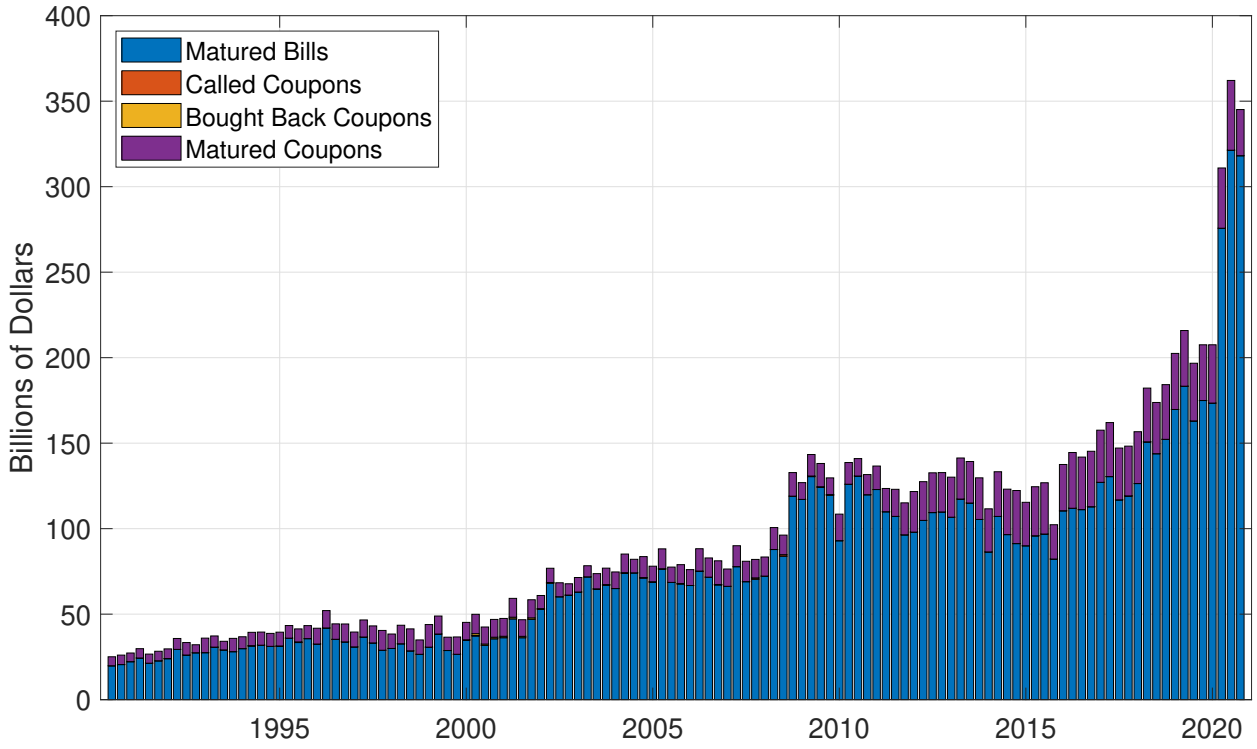
This figure compares net positions of primary dealers in U.S. Treasury coupons with those in other fixed income securities (MBS, agency, corporate debt, and municipal debt) by week from July 4, 1990 to December 30, 2020. The legend shows the correlation of net positions in each of the other fixed income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

Figure 4: Dealer Treasury Spot and Futures Positions 1990-2001



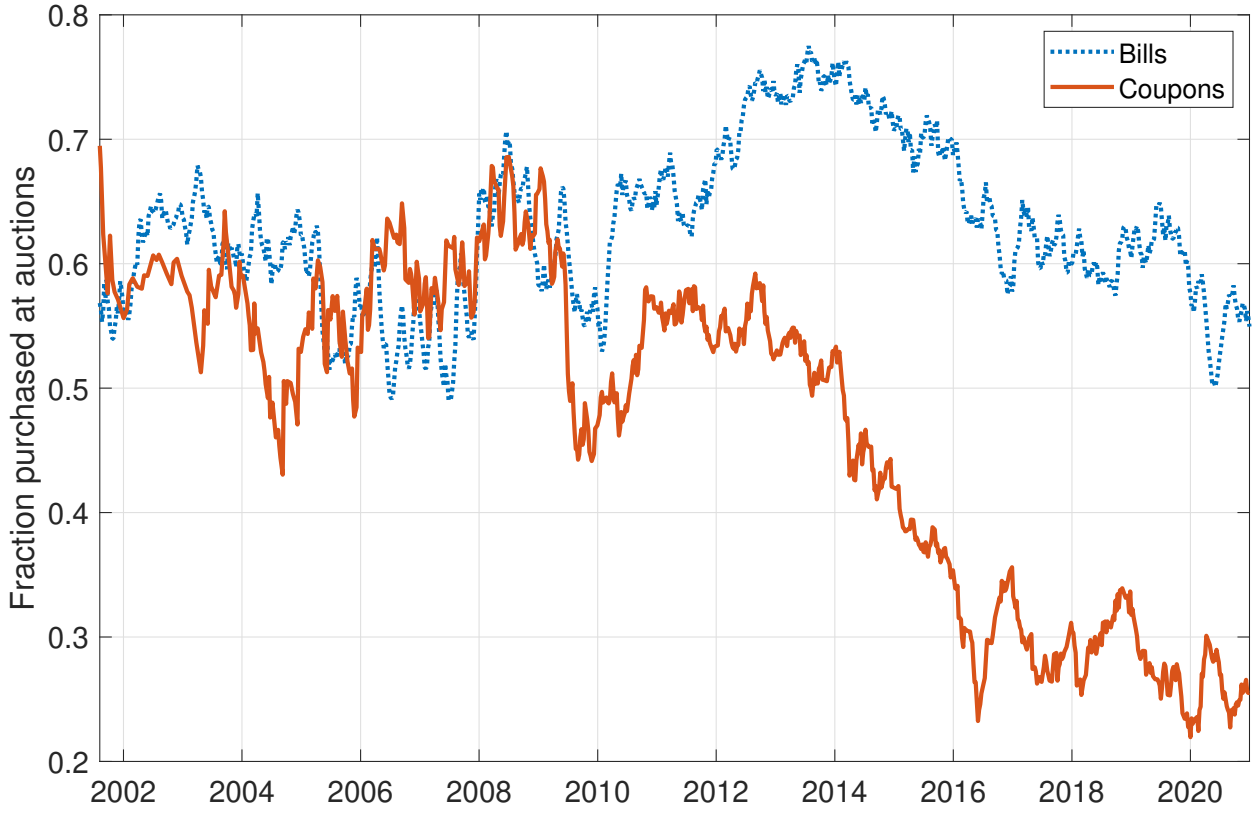
This figure compares spot and futures net positions of primary dealers in U.S. Treasury bills (Panel A) and coupon-bearing securities (Panel B) by week from July 4, 1990 to June 27, 2001.

Figure 5: Treasury Redemptions 1990–2020



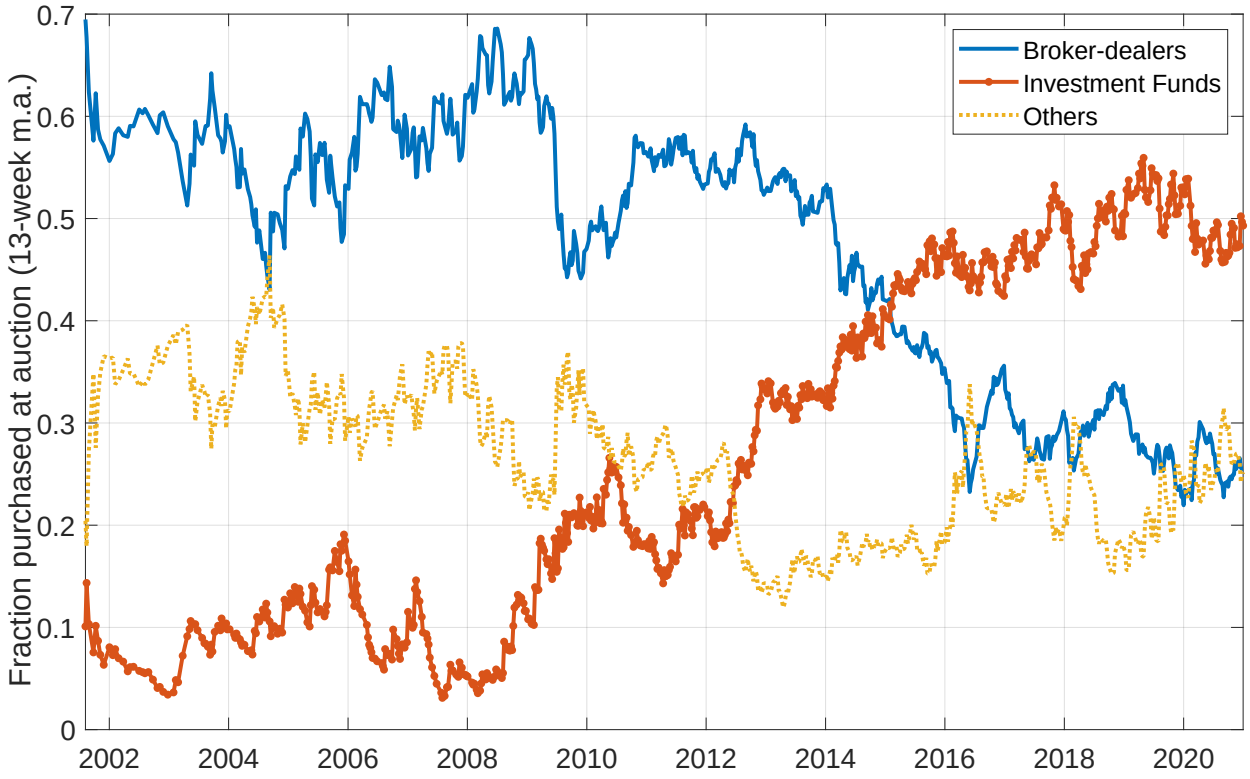
This figure plots average weekly redemptions of U.S. Treasury bills and coupon-bearing securities by quarter for the weeks ending July 4, 1990 to December 30, 2020.

Figure 6: Share of Broker-Dealers' Purchases at Auction 2001–2020



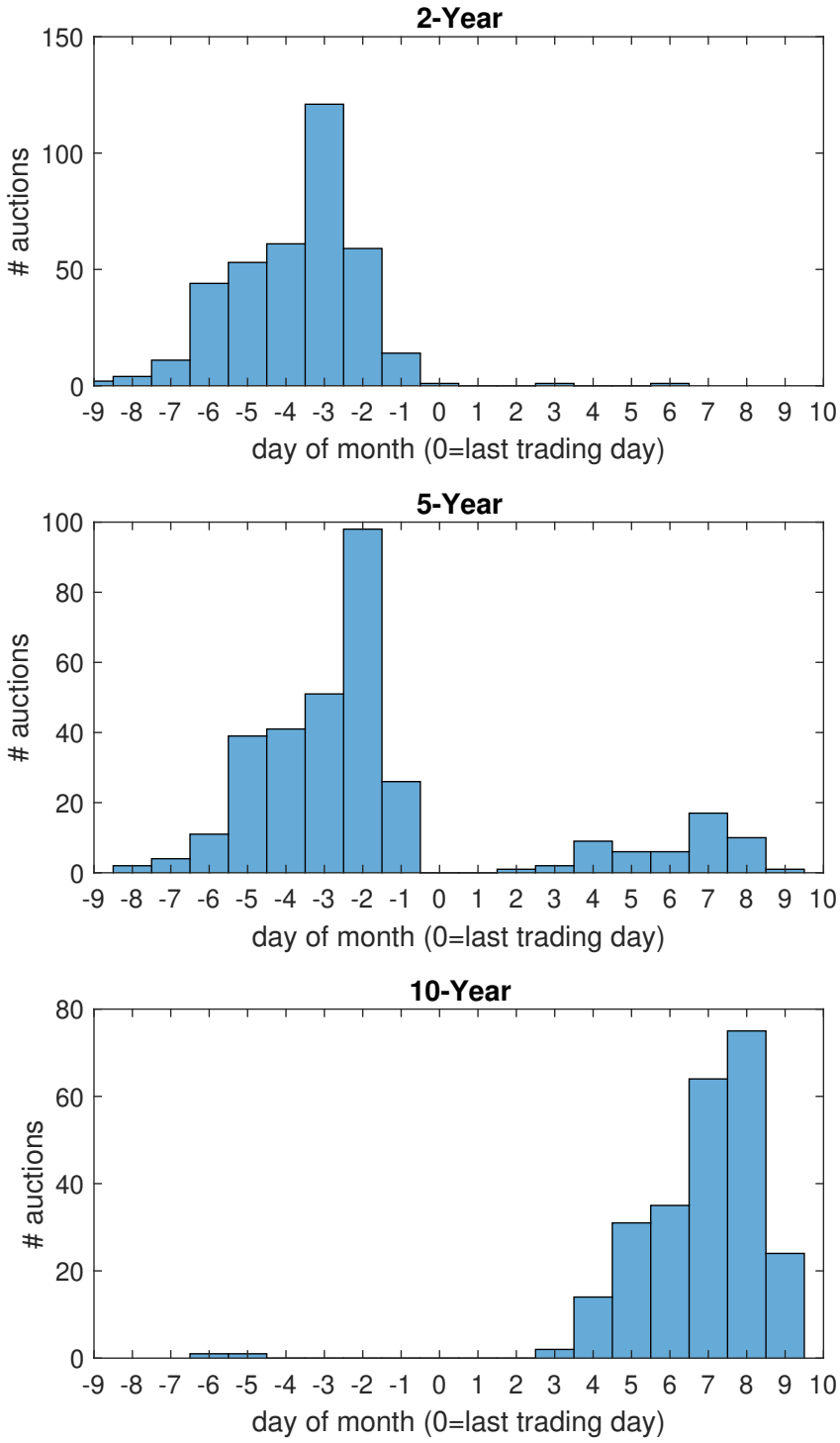
This figure plots the 13-week moving average of the fraction of weekly auction amounts purchased by broker-dealers as reported in the Investor Class Allotment data. The data are available from the Department of the Treasury from the week ending August 8, 2001.

Figure 7: Purchases at Auction by Investor Type 2001–2020



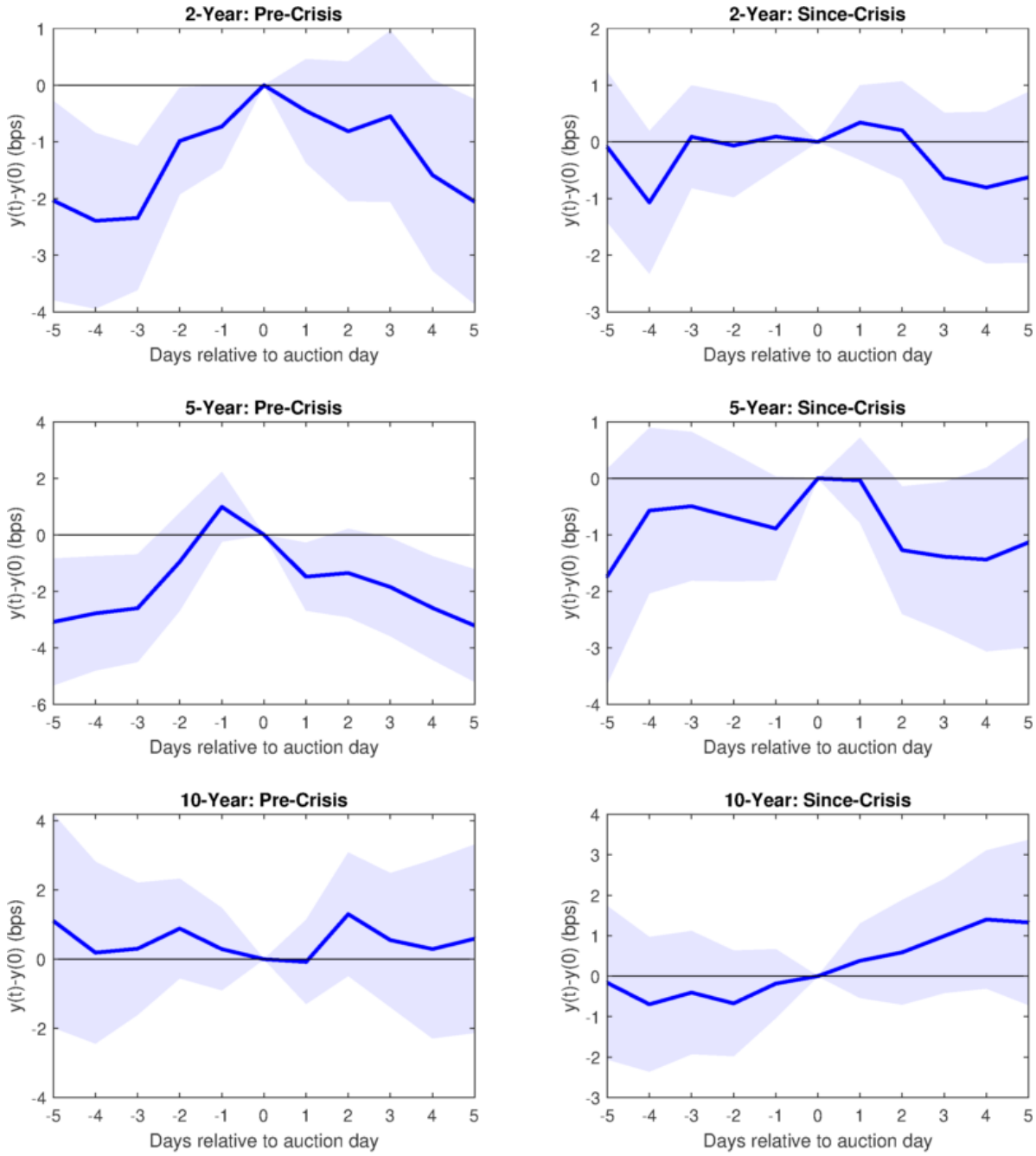
This figure plots the 13-week moving average of the fraction of weekly auction amounts purchased by broker-dealers, investment funds, and other investor classes as reported in the Investor Class Allotment data. The data are available from the Department of the Treasury from the week ending August 8,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

Figure 8: Distribution of Auctions by Day of Month



This figure shows the distribution of auctions by day of month. The x-axis shows the days 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 available from the Department of the Treasury.

Figure 9: Pricing Effects of Auction Cycle



This figure plots the average change in yields (bps) between day t and auction day (day 0), with t ranging from -5 to 5. Yields are pre-adjusted for day-of-month effects. Each given note is on-the-run before the auction (of the next security) and off-the-run after the auction (except for reopenings, which occur mainly for the 10-year note, after which the security continues to be on-the-run). Figures in the left column are for the pre-crisis period (July 4, 1990 – August 8, 2007). Figures in the right column are for the post-crisis period (August 9, 2007 – December 30, 2020). The shaded band represents the 95% confidence interval based on Newey-West standard errors (calculated with 12 lags).

Table 1: Descriptive Statistics of Dealer Treasury Positions

This table reports descriptive statistics of primary dealer net positions in U.S. Treasury securities in billions of dollars. Panel A reports spot positions statistics for the full sample period from July 1990 to December 2020. Panels B and C report spot positions statistics for the pre-crisis (July 4, 1990 to before August 9, 2007) and post-crisis (August 9, 2007 to December 30, 2020) subsample periods. Panel D reports futures positions statistics for the period over which futures positions data are available (July 4, 1990 to June 27, 2001). Data are from the Federal Reserve Bank of New York.

	Levels		Weekly Changes	
Statistic	Bill Positions	Coupon Positions	Bill Positions	Coupon Positions
	(1)	(2)	(3)	(4)
Panel A: Spot Positions – Full Sample (7/1990–12/2020)				
Mean	15.86	-9.96	0.04	0.11
Standard Deviation	17.50	76.60	9.48	9.36
Autocorr. (1-week)	0.851	0.991	-0.164	-0.303
# Observations	1592	1592	1591	1591
Panel B: Spot Positions – Pre-Crisis Subsample (7/1990–7/2007)				
Mean	9.84	-52.73	-0.02	-0.12
Standard Deviation	13.01	43.67	7.98	7.14
Autocorr. (1-week)	0.810	0.985	-0.066	-0.137
# Observations	893	893	892	892
Panel C: Spot Positions – Post-Crisis Subsample (8/2007–12/2020)				
Mean	23.54	44.68	0.11	0.39
Standard Deviation	19.40	74.86	11.11	11.58
Autocorr. (1-week)	0.831	0.983	-0.229	-0.383
# Observations	699	699	699	699
Panel D: Futures Positions – Futures Subsample (7/1990–6/2001)				
Mean	-3.67	-4.94	0.01	0.02
Standard Deviation	5.24	12.02	1.62	3.24
Autocorr. (1-week)	0.951	0.963	0.117	-0.043
# Observations	574	574	573	573

Table 2: Treasury Dealer Inventory Management

This table reports results from regressions of weekly changes in primary dealer net spot positions in U.S. Treasury securities on beginning-of-week inventory level, amount of issuance and redemption (including buybacks, calls, and regular maturity) of Treasury securities, changes in Federal Reserve holdings of Treasury securities, changes in foreign central bank holdings of Treasury securities, changes in dealer agency debt positions, changes in dealer MBS positions, U.S. corporate bond issuance, and U.S. municipal bond issuance. The sample period is from July 4, 1990 to December 30, 2020. Panels A and B report the results for bills and coupons respectively. Except for the issuance, redemption, and Federal Reserve holdings variables which are defined specifically for each security type, all other variables are only available on an aggregate basis and do not vary between Panels A and B. Coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors in parentheses. All variables are in billions of dollars. $^{*}p < .1$; $^{**}p < .05$; $^{***}p < .01$.

Independent variable	Panel A: Bill Inventory			Panel B: Coupon Inventory		
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	2.340^{***}	0.794^{**}	1.774^{***}	0.046	-1.999^{***}	-1.190^{***}
	(0.294)	(0.358)	(0.400)	(0.192)	(0.324)	(0.370)
Begining Inventory	-0.146^{***}	-0.200^{***}	-0.201^{***}	-0.006^{*}	-0.018^{***}	-0.017^{***}
	(0.017)	(0.020)	(0.020)	(0.003)	(0.004)	(0.004)
Issuance		0.121^{***}	0.126^{***}		0.145^{***}	0.153^{***}
		(0.016)	(0.015)		(0.009)	(0.009)
Redemption		-0.096^{***}	-0.087^{***}		-0.094^{***}	-0.090^{***}
		(0.015)	(0.015)		(0.010)	(0.010)
Federal Reserve holdings			-0.023			-0.094^{***}
			(0.064)			(0.012)
Foreign central bank holdings			0.000			-0.065^{***}
			(0.028)			(0.025)
Agency debt positions			0.181^{***}			0.074^{*}
			(0.041)			(0.041)
MBS positions			-0.111^{***}			-0.083^{*}
			(0.041)			(0.044)
Corporate issuance			-0.090^{**}			0.022
			(0.037)			(0.026)
Municipal issuance			-0.160^{**}			-0.129^{**}
			(0.067)			(0.053)
Adjusted R^2 (%)	7.1	25.8	28.3	0.2	27.8	30.6
# Observations	1591	1591	1591	1591	1591	1591

Table 3: Subsample Analysis of Treasury Dealer Inventory Management

This table reports results from regressions of weekly changes in primary dealer net spot positions in U.S. Treasury securities on beginning-of-week inventory level, amount of issuance and redemption (including buybacks, calls, and regular maturity) of Treasury securities, changes in Federal Reserve holdings of Treasury securities, changes in foreign central bank holdings of Treasury securities, changes in dealer agency debt positions, changes in dealer MBS positions, U.S. corporate bond issuance, and U.S. municipal bond issuance. The regression is estimated separately for the pre-crisis (July 4, 1990 to before August 9, 2007) and post-crisis (August 9, 2007 to December 30, 2020) subsample periods. The Welch-Satterthwaite t-test for the difference in a given coefficient estimate between the two subsample periods is reported in the corresponding "Diff. t-stat" column. Panels A and B report the results for bills and coupons respectively. Except for the issuance, redemption, and Federal Reserve holdings variables which are defined specifically for each security type, all other variables are only available on an aggregate basis and do not vary between Panels A and B. Coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors in parentheses. All variables are in billions of dollars. $*p < .1$; $**p < .05$; $***p < .01$.

	Panel A: Bill Inventory			Panel B: Coupon Inventory		
Independent variable	Pre-Crisis	Post-Crisis	Diff. t-stat	Pre-Crisis	Post-Crisis	Diff. t-stat
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	-0.165	1.200	0.981	-1.455^{***}	-1.749^{*}	-0.261
	(0.436)	(1.321)		(0.438)	(1.039)	
Begining Inventory	-0.134^{***}	-0.248^{***}	-3.520^{***}	-0.019^{***}	-0.016^{***}	0.415
	(0.016)	(0.028)		(0.007)	(0.005)	
Issuance	0.318^{***}	0.088^{***}	-11.297^{***}	0.219^{***}	0.139^{***}	-3.936^{***}
	(0.017)	(0.011)		(0.017)	(0.011)	
Redemption	-0.215^{***}	-0.038^{***}	8.710^{***}	-0.049^{***}	-0.102^{***}	-2.448^{**}
	(0.015)	(0.014)		(0.018)	(0.012)	
Federal Reserve holdings	0.052	-0.051	-0.875	0.332	-0.095^{***}	-1.944^{*}
	(0.074)	(0.091)		(0.219)	(0.012)	
Foreign central bank holdings	-0.028	-0.016	0.237	-0.020	-0.076^{***}	-1.003
	(0.039)	(0.030)		(0.047)	(0.029)	
Agency debt positions	0.056	0.272^{***}	2.799^{***}	-0.002	0.151^{**}	1.926^{*}
	(0.043)	(0.064)		(0.052)	(0.060)	
MBS positions	-0.128^{***}	-0.082	0.564	-0.146^{***}	-0.002	1.652^{*}
	(0.042)	(0.069)		(0.052)	(0.070)	
Corporate issuance	-0.056	-0.053	0.045	-0.017	0.039	0.781
	(0.049)	(0.039)		(0.065)	(0.029)	
Municipal issuance	-0.527^{***}	-0.123	3.130^{***}	-0.293^{***}	-0.018	2.091^{**}
	(0.092)	(0.091)		(0.106)	(0.078)	
Adjusted R^2 (%)	54.7	24.6		22.7	36.1	
# Observations	892	699		892	699	

Table 4: Inventory Effects of Issuance and Redemption by Security

This table reports results from regressions of weekly changes in primary dealer net spot positions in U.S. Treasury securities on weekly auction amounts of Treasury securities, redemptions of Treasury securities (including buybacks, calls, and regular maturities), and other variables (as specified in Table 2). The sample period is from July 4, 1990 to December 30, 2020. The pre-crisis subsample period is from July 4, 1990 to August 8, 2007. The post-crisis subsample period is from August 9, 2007 to December 30, 2020. Coefficients are estimated separately for Treasury bills and coupon-bearing securities, and separately for subsample periods. The Welch-Satterthwaite t-test for the difference in a given coefficient estimate between the two subsample periods is reported in the corresponding "Diff. t-stat" column. Issuance and redemption coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors in parentheses. $^{*}p < .1$; $^{**}p < .05$; $^{***}p < .01$.

	Dependent Variable: Weekly Spot Position Change							
	Issuance Coefficients				Redemption Coefficients			
Security	Full Sample	Pre-Crisis	Post-Crisis	Diff. t-stat	Full Sample	Pre-Crisis	Post-Crisis	Diff. t-stat
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A. Treasury bills:								
Cash management bill	0.152^{***}	0.447^{***}	0.108^{***}	-10.239^{***}	-0.104^{***}	-0.188^{***}	-0.013	5.361^{***}
	(0.024)	(0.029)	(0.017)		(0.021)	(0.026)	(0.020)	
4-week bill	0.178^{***}	0.405^{***}	0.169^{***}	-3.363^{***}	-0.076^{***}	-0.225^{***}	-0.045	2.933^{***}
	(0.034)	(0.057)	(0.041)		(0.029)	(0.052)	(0.033)	
13-week bill	-0.221	-0.086	-0.075	0.049	0.134^{**}	-0.133	0.187^{**}	2.414^{**}
	(0.137)	(0.157)	(0.154)		(0.067)	(0.108)	(0.077)	
26-week bill	0.297^{*}	0.582^{***}	0.024	-2.132^{**}	-0.204^{***}	-0.349^{***}	-0.180^{**}	1.243
	(0.154)	(0.187)	(0.183)		(0.068)	(0.110)	(0.081)	
52-week bill	0.222^{***}	0.251^{***}	0.216^{***}	-0.769	0.024	-0.030	0.073^{*}	2.070^{**}
	(0.029)	(0.025)	(0.037)		(0.031)	(0.027)	(0.042)	
B. Treasury coupons:								
2-year note	0.168^{***}	0.199^{***}	0.172^{***}	-0.452	-0.096^{***}	-0.087^{**}	-0.121^{***}	-0.591
	(0.024)	(0.026)	(0.054)		(0.027)	(0.034)	(0.046)	
3-year note	0.172^{***}	0.155^{**}	0.263^{***}	0.947	-0.081^{**}	-0.155^{**}	-0.081^{*}	0.986
	(0.055)	(0.075)	(0.086)		(0.034)	(0.061)	(0.043)	
5-year note	0.126^{***}	0.210^{***}	0.087^{*}	-1.812^{*}	-0.020	0.038	-0.034	-0.856
	(0.027)	(0.048)	(0.049)		(0.040)	(0.065)	(0.054)	
7-year note	0.061^{**}	0.139	0.074^{**}	-0.535	-0.144^{**}	-0.177^{*}	-0.133^{**}	0.378
	(0.030)	(0.117)	(0.033)		(0.056)	(0.096)	(0.065)	
10-year note	0.267^{***}	0.381^{***}	0.110	-1.869^{*}	0.013	0.062	0.001	-0.599
	(0.072)	(0.088)	(0.115)		(0.048)	(0.087)	(0.054)	
30-year bond	-0.008	-0.007	-0.058	-0.443	0.169	-0.266	0.209	1.021
	(0.055)	(0.095)	(0.064)		(0.164)	(0.424)	(0.191)	
Control variables	Yes	Yes	Yes		Yes	Yes	Yes	

Table 5: Inventory Effects of Issuance Surrounding Auctions

This table reports results from regressions of weekly changes in primary dealer net spot positions in U.S. Treasury securities on weekly auction amounts of Treasury securities over adjacent weeks and other variables as specified in Equation (3). The sample period is from July 4, 1990 to December 30, 2020. The pre-crisis subsample period is from July 4, 1990 to August 8, 2007. The post-crisis subsample period is from August 9, 2007 to December 30, 2020. Coefficients are estimated separately for bills and coupon-bearing securities and the issuance variables are defined accordingly. The Welch-Satterthwaite t-test for the difference in a given coefficient estimate between the two subsample periods is reported in the corresponding "Diff. t-stat" column. Issuance coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors in parentheses. $*p < .1$; $**p < .05$; $***p < .01$.

	Bill Positions				Coupon Positions			
Independent variable	Full Sample	Pre-Crisis	Post-Crisis	Diff. t-stat	Full Sample	Pre-Crisis	Post-Crisis	Diff. t-stat
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Next week's issuance	-0.067^{***}	-0.040^{***}	-0.065^{***}	-1.188	-0.022^{**}	-0.020	-0.018	0.095
	(0.012)	(0.014)	(0.016)		(0.009)	(0.018)	(0.011)	
Same-week's issuance	0.207^{***}	0.351^{***}	0.158^{***}	-6.667^{***}	0.136^{***}	0.218^{***}	0.118^{***}	-4.515^{***}
	(0.018)	(0.018)	(0.022)		(0.008)	(0.019)	(0.011)	
Previous-week's issuance	-0.052^{***}	-0.040^{**}	-0.032^{*}	0.303	-0.040^{***}	-0.020	-0.048^{***}	-1.044
	(0.015)	(0.017)	(0.017)		(0.013)	(0.021)	(0.017)	
Adjusted R^2 (%)	24.5	51.2	18.0		30.7	22.0	36.6	
# Observations	1590	892	698		1590	892	698	

Table 6: Use of Derivatives for Inventory Management

This table reports results from regressions of weekly changes in primary dealer net futures positions in U.S. Treasury securities on changes in dealer spot positions in Treasury securities, changes in dealer spot positions decomposed into issuance, redemption, and other factor effects (derived from the Table 2 models for bills and coupons), and commercial trader Treasury futures positions. The sample period when spot positions are used is July 4, 1990 to June 27, 2001. The sample period when commercial trader positions are used is September 30, 1992 to March 8, 2000 (with gaps) for bill positions and September 30, 1992 to June 27, 2001 for coupon positions. Coefficients are estimated separately for bills and coupon-bearing securities 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: Dealers' Weekly Futures Position Change					
Independent variable	Bill Positions			Coupon Positions		
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	-0.129	-0.530	-0.184	0.536^{**}	0.298	0.374
	(0.184)	(0.343)	(0.159)	(0.254)	(0.300)	(0.372)
Dealers' spot position change						
Total	-0.015^{*}			-0.232^{***}		
	(0.008)			(0.023)		
Due to issuance		0.020			-0.133^{***}	
		(0.013)			(0.046)	
Due to redemption		-0.010			0.047	
		(0.035)			(0.169)	
Due to other factors		-0.042^{***}			-0.282^{***}	
		(0.014)			(0.030)	
Commercial traders' futures position change						
13-week bill futures			0.466^{***}			
			(0.075)			
2-year note futures						0.143
						(0.094)
5-year note futures						0.046^{***}
						(0.014)
10-year note futures						0.054^{***}
						(0.014)
30-year bond futures						0.039^{***}
						(0.010)
Adjusted R^2 (%)	-0.0	0.8	21.6	19.1	21.0	21.5
# Observations	573	573	356	573	573	456

Table 7: Dealer Compensation for Inventory Risk and Other Factors

This table reports results from regressions of weekly excess Treasury returns on contemporaneous and lagged weekly changes in primary dealer net spot positions in U.S. Treasury securities decomposed into issuance-driven and other factors. The decomposition is based on coefficient estimates from the regression specified in Equation (1). To control for the Treasury return predictability documented by Cochrane and Piazzesi (2005), we include in the regressions five forward rates as used in their model but do not report the coefficient estimates (nor the constant) in this table for brevity. Bill returns are regressed on changes in bill positions and coupon returns are regressed on changes in coupon positions. Incremental R^2 indicates the increase in R^2 from a regression without dealers' position changes to a regression with such changes. The sample period is from July 4, 1990 to December 30, 2020. The pre-crisis subsample period is from July 4, 1990 to August 8, 2007. The post-crisis subsample period is from August 9, 2007 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. $^*p < .1$; $^{**}p < .05$; $^{***}p < .01$.

Independent variable	13-Week Bill	26-Week Bill	2-Year Note	5-Year Note	10-Year Note
Same-week position change:					
Due to issuance	-0.066^{*}	-0.144^{**}	-0.019	0.047	0.037
	(0.038)	(0.065)	(0.130)	(0.380)	(0.685)
Due to other factors	-0.029^{**}	-0.021	0.329^{***}	1.037^{***}	1.743^{***}
	(0.014)	(0.020)	(0.066)	(0.192)	(0.353)
Previous-week position change:					
Due to issuance	0.065^{*}	0.178^{***}	0.697^{***}	2.251^{***}	3.507^{***}
	(0.034)	(0.067)	(0.132)	(0.395)	(0.706)
Due to other factors	0.006	0.005	0.002	-0.044	-0.247
	(0.007)	(0.012)	(0.057)	(0.172)	(0.337)
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
# Observations	1587	1587	1587	1587	1587

Table 8: Dealer Compensation for Inventory Risk and Other Factors: Sub-sample Analysis

This table reports sub-sample results from regressions of weekly excess Treasury returns on contemporaneous and lagged weekly changes in primary dealer net spot positions in U.S. Treasury securities decomposed into issuance-driven and other factors. The decomposition is based on coefficient estimates from the regression specified in Equation (1). To control for the Treasury return predictability documented by Cochrane and Piazzesi (2005), we include in the regressions five forward rates as used in their model but do not report the coefficient estimates (nor the constant) in this table for brevity. Bill returns are regressed on changes in bill positions and coupon returns are regressed on changes in coupon positions. Incremental R^2 indicates the increase in R^2 from a regression without dealers' position changes to a regression with such changes. 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. Panels A and B report the regression results for the pre- and post-crisis periods respectively. Panel C reports the Welsh-Satterthwaite t-statistics for tests of whether dealer compensation for inventory risk and other factors differs significantly between the pre- and post-crisis periods. $^*p < .1$; $^{**}p < .05$; $^{***}p < .01$.

Panel A: Pre-crisis period (July 4, 1990 – August 8, 2007)

Independent variable	13-Week Bill	26-Week Bill	2-Year Note	5-Year Note	10-Year Note
Same-week position change:					
Due to issuance	-0.017	-0.037	-0.584^{**}	-1.210^{*}	-1.466
	(0.014)	(0.027)	(0.273)	(0.676)	(1.088)
Due to other factors	-0.008	0.001	0.764^{***}	2.348^{***}	3.826^{***}
	(0.010)	(0.017)	(0.115)	(0.298)	(0.506)
Previous-week position change:					
Due to issuance	0.022	0.064^{**}	0.644^{***}	2.533^{***}	4.609^{***}
	(0.015)	(0.031)	(0.248)	(0.630)	(1.038)
Due to other factors	0.010	0.001	0.027	0.016	-0.022
	(0.009)	(0.016)	(0.101)	(0.277)	(0.486)
Adjusted R^2 (%)	4.2	2.7	6.8	9.0	8.7
Incremental R^2 (%)	0.1	0.1	5.4	8.3	8.3
# Observations	888	888	888	888	888

Panel B: Post-crisis period (August 9, 2007 – December 30, 2020)

Independent variable	13-Week Bill	26-Week Bill	2-Year Note	5-Year Note	10-Year Note
Same-week position change:					
Due to issuance	-0.128^{*}	-0.258^{**}	-0.063	-0.087	-0.385
	(0.066)	(0.114)	(0.140)	(0.455)	(0.880)
Due to other factors	-0.047^{**}	-0.041	0.091	0.308	0.528
	(0.021)	(0.030)	(0.078)	(0.236)	(0.480)
Previous-week position change:					
Due to issuance	0.088	0.230^{**}	0.407^{***}	1.385^{***}	1.891^{*}
	(0.057)	(0.100)	(0.152)	(0.493)	(0.971)
Due to other factors	-0.001	0.002	-0.058	-0.228	-0.628
	(0.009)	(0.016)	(0.068)	(0.214)	(0.432)
Adjusted R^2 (%)	10.2	14.0	3.4	2.3	1.4
Incremental R^2 (%)	5.3	3.7	0.8	0.9	0.6
# Observations	697	697	697	697	697

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Panel C: Test of pre- and post-crisis difference					
Independent variable	13-Week Bill	26-Week Bill	2-Year Note	5-Year Note	10-Year Note
Same-week position change:					
Due to issuance	-1.65	-1.90^{*}	1.70^{*}	1.38	0.77
Due to other factors	-1.65^{*}	-1.23	-4.84^{***}	-5.36^{***}	-4.72^{***}
Previous-week position change:					
Due to issuance	1.11	1.60	-0.81	-1.44	-1.91^{*}
Due to other factors	-0.82	0.03	-0.70	-0.70	-0.93

Table 9: Pricing Effects of Auction Cycle

This table reports the time-series average of the change in yields (in bps) 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 after which the security continues to be on-the-run (mostly for the 10-year note). 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). The pre-crisis sample period is from January 1990 to August 8, 2007. The post-crisis period is from August 9, 2007 to December 30, 2020. The Welsh-Satterthwaite t-statistics for tests of the difference between the pre- and post-crisis period are reported in "Diff. t-stat" columns. $^{*}p < .1$; $^{**}p < .05$; $^{***}p < .01$.

	2-Year notes			5-Year notes			10-Year notes		
t	Pre-Crisis	Post-Crisis	Diff. t-stat	Pre-Crisis	Post-crisis	Diff. t-stat	Pre-Crisis	Post-crisis	Diff. t-stat
-10	-2.51^{**}	0.85	2.19^{**}	-4.20^{***}	0.77	2.45^{**}	-0.38	0.25	0.26
-9	-0.64	-0.25	0.26	-4.38^{***}	-0.11	2.12^{**}	0.20	-0.82	-0.46
-8	-0.73	-0.69	0.02	-4.82^{***}	-0.50	2.35^{**}	0.85	-1.29	-0.99
-7	-0.38	-0.27	0.08	-3.00^{**}	-1.06	1.15	2.38	-0.81	-1.58
-6	-1.18	-0.56	0.50	-2.48^{**}	-0.76	1.06	1.47	-0.78	-1.16
-5	-2.04^{**}	-0.09	1.73^{*}	-3.09^{***}	-1.73^{*}	0.90	1.11	-0.16	-0.69
-4	-2.39^{***}	-1.07^{*}	1.30	-2.78^{***}	-0.57	1.74^{*}	0.19	-0.70	-0.56
-3	-2.34^{***}	0.09	3.06^{***}	-2.60^{***}	-0.49	1.79^{*}	0.30	-0.41	-0.57
-2	-0.98^{**}	-0.06	1.38	-0.96	-0.69	0.25	0.89	-0.67	-1.58
-1	-0.73^{*}	0.09	1.73^{*}	0.99	-0.89^{*}	-2.40^{**}	0.29	-0.18	-0.64
1	-0.46	0.34	1.39	-1.48^{**}	-0.03	2.01^{**}	-0.08	0.38	0.59
2	-0.81	0.20	1.33	-1.35^{*}	-1.27^{**}	0.08	1.30	0.59	-0.64
3	-0.55	-0.64	-0.09	-1.85^{**}	-1.39^{**}	0.42	0.55	0.99	0.36
4	-1.59^{*}	-0.81	0.71	-2.59^{***}	-1.44^{*}	0.92	0.29	1.40	0.70
5	-2.06^{**}	-0.63	1.19	-3.22^{***}	-1.13	1.50	0.59	1.33	0.42
6	-2.52^{**}	-0.87	1.21	-2.78^{**}	-1.52	0.77	0.04	0.33	0.16
7	-2.58^{**}	-0.59	1.23	-2.08	-0.45	0.86	-1.06	-0.93	0.08
8	-5.48^{***}	0.01	3.09^{***}	-2.50^{*}	-1.31	0.65	-2.00	-1.18	0.42
9	-6.85^{***}	-0.67	3.44^{***}	-4.23^{***}	-2.21^{*}	1.04	-3.60^{**}	-1.52	1.01
10	-4.52^{***}	-1.50	1.61	-4.32^{***}	-2.70^{**}	0.78	-3.15	-1.88	0.55
# Auctions	205	161		161	161		88	157	