The scarcity value of Treasury collateral: Repo market effects of security-specific supply and demand factors*

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Abstract

In the specific collateral repo market, forward agreements are security-specific, which may magnify demand and supply effects. We quantify the scarcity value of Treasury collateral by estimating the impact of security-specific demand and supply factors on the repo rates of all outstanding U.S. Treasury securities. We find an economically and statistically significant scarcity premium. This scarcity effect is quite persistent and seems to pass through to Treasury market prices, providing additional evidence for the scarcity channel of QE. Through the same mechanism, the Fed's reverse repo operations could alleviate potential shortages of high-quality collateral.

JEL Codes: G1, G12, G19, C23, E43.

Keywords: Treasury bonds; Repo contracts; Special repo rate; Supply-demand factors; Liquidity; Large Scale Asset Purchase programs; Treasury auctions.

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A growing literature finds significant price responses to expected and unexpected changes in the net supply of various securities, including stocks (e.g., Shleifer, 1986; Kaul et al., 2000; Wurgler and Zhuravskaya, 2002; Greenwood, 2005) and bonds (e.g., Brandt and Kavajecz, 2004; Lou et al., 2013; D'Amico and King, 2013), suggesting the presence of a "scarcity premium." In very liquid cash markets, price impacts of anticipated and repeated supply shocks are typically shown to be temporary, as this premium is quickly arbitraged away.[1] In these cases, however, the securities in question generally have a large pool of close substitutes. Consequently, arbitrage is relatively riskless, allowing quantity fluctuations in a particular security to be readily absorbed in a broader market. This both makes it harder to isolate supply effects empirically and, arguably, reduces their importance from an asset-pricing standpoint.

This paper examines supply effects in the context of a vast and liquid market where substitution across assets is limited by the contract specification, creating an extreme form of imperfect substitutability. In the specific collateral repurchase agreement (SC repo) market, collateralized transactions are security-specific (i.e., the contract precludes the possibility of delivering substitutes); therefore, the scarcity of the underlying collateral should be the main determinant of the transaction's cost, that is, the repo rate. This market constitutes the bulk of the U.S. bilateral repo market, whose size is estimated to be approximately $2 trillion based on recent studies, and it is the core of the bank/nonbank nexus in the U.S. allowing hedging, shorting, and derivatives margining.[2]

Since Treasury securities are estimated to make up about 80 percent of the collateral

[1] See Lou et al. (2013) for price responses around Treasury auctions, and D'Amico and King (2013) for price reactions to the Federal Reserve's Treasury purchase operations. Both studies indicate that these supply effects reverse after a few days.

[2] Copeland et al. (2014) estimate the size of the bilateral repo market to be approximately $1.9-2.1 trillion based on data from April 2013 to October 2014 and the majority of bilateral transactions to be for specific rather than general collateral. Similar values are reported in Pozsar (2014).

posted in bilateral repos (Copeland et al., 2014), their availability is essential to the functioning of the SC repo market. Over the past few years, reduced issuance by the Treasury, the sharp increase in Treasury holdings by the Federal Reserve and new financial regulation have reportedly shrank the availability of Treasury collateral. Beyond the functioning of the SC repo market, broader concerns are that the scarcity of Treasury collateral in repos could (i) pressure money market rates lower potentially complicating efforts by the Federal Reserve to lift interest rates when the appropriate time comes, and (ii) affect the liquidity in bond cash markets causing extreme volatility episodes.[3]

Using a novel dataset, we provide evidence that, in the Treasury SC repo market, supply effects are significant and persistent: the repo rate on a specific security falls in response to a reduction in the amount of that security and remains lower for at least three months. These effects are also found to be important for off-the-run securities, which, to the best of our knowledge, has never been documented before in the repo market and is somewhat puzzling in light of existing theories of specialness (e.g., Vayanos and Weill, 2008). This widespread response measures a scarcity premium that has potentially important implications for both the conduct of monetary policy through operations that change the available supply of Treasury collateral, and the Treasury's management of the auction cycle of its securities. Further, this scarcity premium, if transmitted to the cash market, could amplify price swings in government bonds.

In particular, we quantify the scarcity value of Treasury collateral by estimating the impact of *security-specific* supply factors on the SC repo rates of *all available* U.S. Treasury securities.[4] Thus, we do not limit our attention to just a few on-the-run securities. Exploit-

[3]For example, see Burne (2015), WSJ article.

[4]Except for Jordan and Jordan (1997), which uses Treasury auction results on 39 distinct notes from September 1991 to December 1992, most other studies focus on the specialness spreads of a few on-the-run Treasury securities and use mainly aggregate demand variables (e.g., interest-rate-risk hedging demand, buy-

ing the daily cross-sectional variation of these security-level data over a period of almost four years, we estimate panel regressions to carefully pin down quantity effects. Quantity variations in our sample mostly come from purchases and sales of Treasury securities under various Federal Reserve (Fed) programs.[5] Since these programs targeted longer-term yields in the Treasury cash market rather than overnight repo market rates, it is safe to assume that they were not directly responding to changes in SC repo rates. By tracking cumulative price responses in the months following these quantity shocks, we can estimate impulse-responses and gain some understanding of whether the inability to substitute across securities exacerbates the supply effects' persistence. Finally, in our panel specification, time dummies sweep out any market-wide effects, including Fed and Treasury actions that affect the overall repo market. Therefore, our security-specific estimates can be considered to be lower bounds on the total supply effect.

Our results indicate that security-specific demand and supply factors are statistically significant and carry the expected signs. In particular, the coefficient on the amount purchased at the Fed's operations is negative and significant for both on- and off-the-run securities. This suggests that as the supply of a specific security available to private investors shrinks, the repo rate decreases (and the specialness spread increases) and borrowers of that security face an increased *holding cost* as they must lend money at relatively lower interest rates. In addition, these impacts are larger in shorter-term securities, with average effects of -1.8 and -0.5 basis points per billion dollars for on- and off-the-run securities, respectively. Overall, these additional holding costs constitute about 7 to 18 percent of the average overnight repo

and-hold investors' demand, and mortgage-convexity hedging demand); see Moulton (2004) and Graveline and McBrady (2011).

[5]From March 2009 to December 2012, the Fed conducted two Large-Scale Asset Purchase programs by removing $900 billion of Treasury securities from the market, and two Maturity Extension Programs by purchasing a total of $667 billion of Treasury securities with maturity between 6 and 30 years and selling an equal amount of securities with remaining maturity of 3 years or less.

specialness spread, depending on the security characteristics. Since this spread often spikes well above 100 basis points, these scarcity premia can get quite large. Further, they are found to dissipate quite slowly, with the estimated effects staying significant for about three months.

Lastly, since bonds that trade special in the repo market should trade at a premium in the cash market (e.g., Duffie, 1996; Jordan and Jordan, 1997; Buraschi and Menini, 2002), we also analyze the relation between security-specific Treasury cash market premia and repo specialness spreads, finding that this relation is significantly stronger on the days of the Fed operations and only for securities eligible for the Fed's purchases. This suggests that, on these days, the SC repo scarcity premium passes through to Treasury cash market prices, providing additional evidence in favor of the scarcity channel of quantitative easing (QE) (e.g., Krishnamurthy and Vissing-Jorgensen, 2011; D'Amico et al., 2012), and helps explain how repeated and fairly predictable changes in supply can still affect Treasury prices when they occur. That result, known as the flow- or pace-effect of QE, was one of the puzzling findings of D'Amico and King (2013).

Overall, in this study, we provide new evidence that changes in provision of public, safe, and liquid collateral by the Federal Reserve have affected SC repo rates for both on-the-run and off-the-run Treasury securities, *which are key ingredients for there to be potentially important implications for monetary policy.* In general, this is because the average Treasury SC repo rate constitutes a lower bound for key money market rates, such as the Treasury GC repo rate and the effective federal funds rate, which, as we will show later, tend to move in lockstep with this bound. Threfore, by affecting the average Treasury SC repo rate, the Fed can move the floor for money market rates. In particular, this can be relevant for the future implementation of monetary policy during the normalization process. For example, if the Fed decides to gradually redeem maturing Treasury securities, it will effectively increase the availability of Treasury collateral, which in turn will put upward pressure on SC repo rates and related money market rates. Further, and more directly, since the Fed intends to use overnight reverse repos as a supplementary policy tool, it could in theory become the largest (and most creditworthy) borrower in the repo market, with the power to set a floor on repo rates (Martin et al., 2013).[6] Our estimates indeed suggest that, by changing the net supply of Treasury collateral, the Fed's reverse repos could potentially both help control money market rates and alleviate shortages of high-quality collateral.[7]

Our findings also have potentially important implications for the Treasury's management of the auction cycles of its securities. For example, they suggest that available options such as increasing the issuance at auction or reopening a security could reduce the scarcity premium by increasing the tradable supply.

Finally, our results can help quantify the potential impact on the repo market of new financial regulation that might affect the net supply of high-quality collateral such as Treasuries. For example, the new bank holding companies' supplementary leverage and liquidity coverage ratios might lead to a reduced willingness and ability to engage in repo transactions; and the mandatory central clearing of standardized over-the-counter derivatives (OTCD) will increase demand for high-quality assets by requiring initial margin on most OTCD transactions and limiting the re-hypothecation of pledged assets.[8]

The paper is organized as follows. Section 1 describes the data and the variables used in the empirical analysis, whose results are discussed in detail in Section 2, including some

[6] As announced at the September 2014 FOMC meeting in "Policy Normalization Principles and Plans." Available at `http://www.federalreserve.gov/newsevents/press/monetary/20140917c.htm`.

[7] See Potter (2013) for a more detailed discussion on the overnight reverse repo facility and its objectives.

[8] For more details, see the May 2013 report of the Committee on the Global Financial System for discussions on various factors that could potentially affect availability of collateral assets.

important robustness checks. In Section 3, we estimate the relation between Treasury cash prices and the repo scarcity premium. Section 4 discusses extensively the monetary policy implications of our results. And Section 5 concludes.

1 Market Background and Data Description

1.1 SC Repo Market Background

A repo is a transaction involving the spot sale of a security coupled with a simultaneous forward agreement to buy back the same security, usually on the next day. Thus, it is similar to a collateralized overnight loan where the party providing the funds earns interest at the repo rate. In general collateral (GC) repos the acceptable collateral can be any of a variety of securities, while in specific collateral (SC) repos the underlying collateral is a specific issue or CUSIP.[9] Therefore, the SC repo market is a market for collateral rather than for funding. It is important to stress that the value of a specific security in this market can fluctuate depending on supply and demand dynamics, prompting some securities to become "special". Special securities trade at very low or even negative repo rates as investors are willing to pay to lend their cash so they can have access to these securities.

All SC repos are conducted on a bilateral basis and they constitute the majority of the U.S. bilateral repo trades. These transactions are often open, that is, the agreement has an overnight tenor but continues until one of the counterparties decides to close it (Adrian et al., 2011). In this study, we limit our attention to Treasury securities, which are estimated to make up about 80 percent of the collateral posted in bilateral repos. The high quality of this

[9] For more details on the specific collateral repo market and the bilateral repo market in general, see Fisher (2002) and Singh (2014).

collateral attracts many market participants and, over the past decades, the SC Treasury repo market has grown dramatically in size and popularity.[10] SC repos are used by leveraged accounts, such as hedge funds, private equity firms, real estate investment trusts (REITs), exchange traded funds (ETFs) and broker dealers for a number of purposes, including hedging activity requiring a certain type of collateral, to obtain the cheapest to deliver into futures contracts, to settle other trades, and most commonly to establish short positions (Duffie, 1996), that is, to borrow securities when prices are high in order to return them when prices are low. Broker dealers, mutual and pension funds, money market funds, custodial agents, and other owners of Treasury securities can borrow cash at an advantageous rate by lending specific securities, and eventually re-lend the money at a higher GC repo rate, capturing the spread between the two rates. Since all large broker dealers are banks, the SC repo market, together with the bilateral GC repo market, constitutes the most important link between the bank and the shadow-banking system.

Overall, the SC Treasury repo market, by facilitating market making, hedging, and speculative activities, has been fundamental in ensuring liquidity to the Treasury cash market. And in particular, by mitigating leverage constraints (e.g., Gromb and Vayanos, 2010), it has facilitated arbitrage trading, which is essential to Treasury market efficiency. On the other hand, the smooth functioning of the SC Treasury repo market and prevailing SC repo rates depend on the availability of the underlying Treasury collateral. The latter relation, which has been little investigated at the security level across all outstanding Treasury securities, is the main object of our study.

[10]For example, based on Copeland et al. (2014), from April 2013 to October 2014, the volume of bilateral repo transactions collateralized by Treasury securities averaged to about $1.6 trillion; for comparison, the average daily traded volume in the Treasury cash market was about $500 billion.

1.2 Repo Rate Data

Our proprietary data set is derived from the repo interdealer-broker market. It includes daily averages of SC repo rates quoted between 7:30 and 10 a.m. (Eastern time). This time window is chosen because trading in the repo market begins at about 7 a.m., remains active until about 10 a.m., and then becomes light until the market closes at 3 p.m. Repo transactions with specific collateral are executed on a delivery versus payment (DVP) basis (i.e., same-day settlement). In these transactions, a collateral security is delivered into a cash lender's account in exchange for funds. The exchange occurs via FedWire or a clearing bank. In contrast, GC repo transactions often occur via the tri-party repo market, in which securities and cash are placed on the balance sheet of a custodial agent.

The repo specialness spread is defined as the difference between the overnight GC repo rate and the corresponding SC repo rate. This spread measures how special a security is in the repo market. Figure 1 shows the specialness spread for the 10-year on-the-run Treasury security, which, as can be seen, displays a significant amount of variation over our sample. The largest spikes usually coincide with Treasury auction announcements.

As shown in Figure 2, not only on-the-run securities but also off-the-run securities can have positive specialness spreads. The upper panel of Figure 2 displays the daily average repo spread across off-the-run securities with remaining maturities between 7 and 10 years, together with a smoothed line fitted to those averages. As can be seen, this off-the-run repo spread is always positive in our sample and exhibits a significant amount of fluctuations, at times jumping above 15 basis points. It is important to note that this is not negligible for overnight transactions. In addition, comparison to the bottom panel of Figure 2, which plots the Fed purchased amounts in this maturity sector, shows that the repo specialness spreads tended to be higher and more volatile in periods when Fed purchases were larger, while

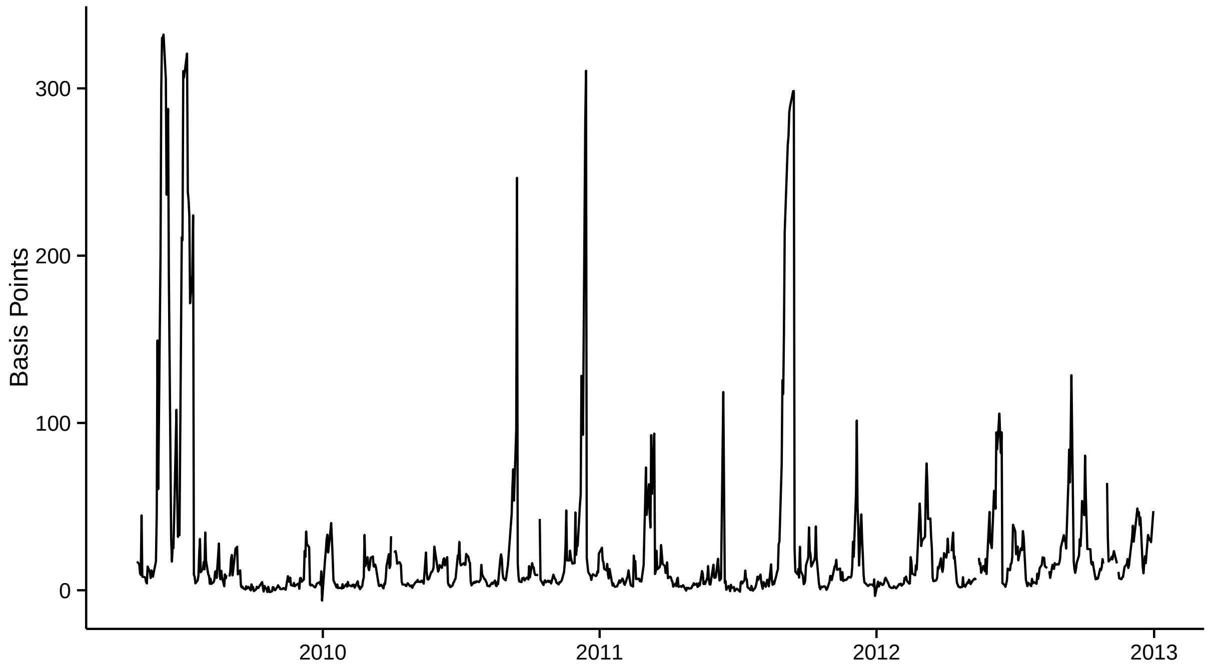

Figure 1: Repo specialness spread for the on-the-run 10-year Treasury security.

they seemed lower and less volatile from October 2009 and October 2010 when there were no asset purchases. Interestingly, security-level data from the Depository Trust & Clearing Corporation (DTCC) show that fails to deliver in well off-the-run Treasury securities were increasing in early 2011 through late 2012 from previously-negligible levels, the same period in which we observe higher average repo spreads for off-the-run securities.[11]

To compute the specialness spread, we use Treasury GC repo rates from the General Collateral Finance (GCF) Repo Index, which is a tri-party repo platform maintained by the DTCC.[12] This market is characterized as being primarily inter-dealer, although some

[11]See Fleming et al. (2014) for more details.

[12]DTCC GCF rate data are publicly available at `http://www.dtcc.com/charts/dtcc-gcf-repo-index.aspx`.

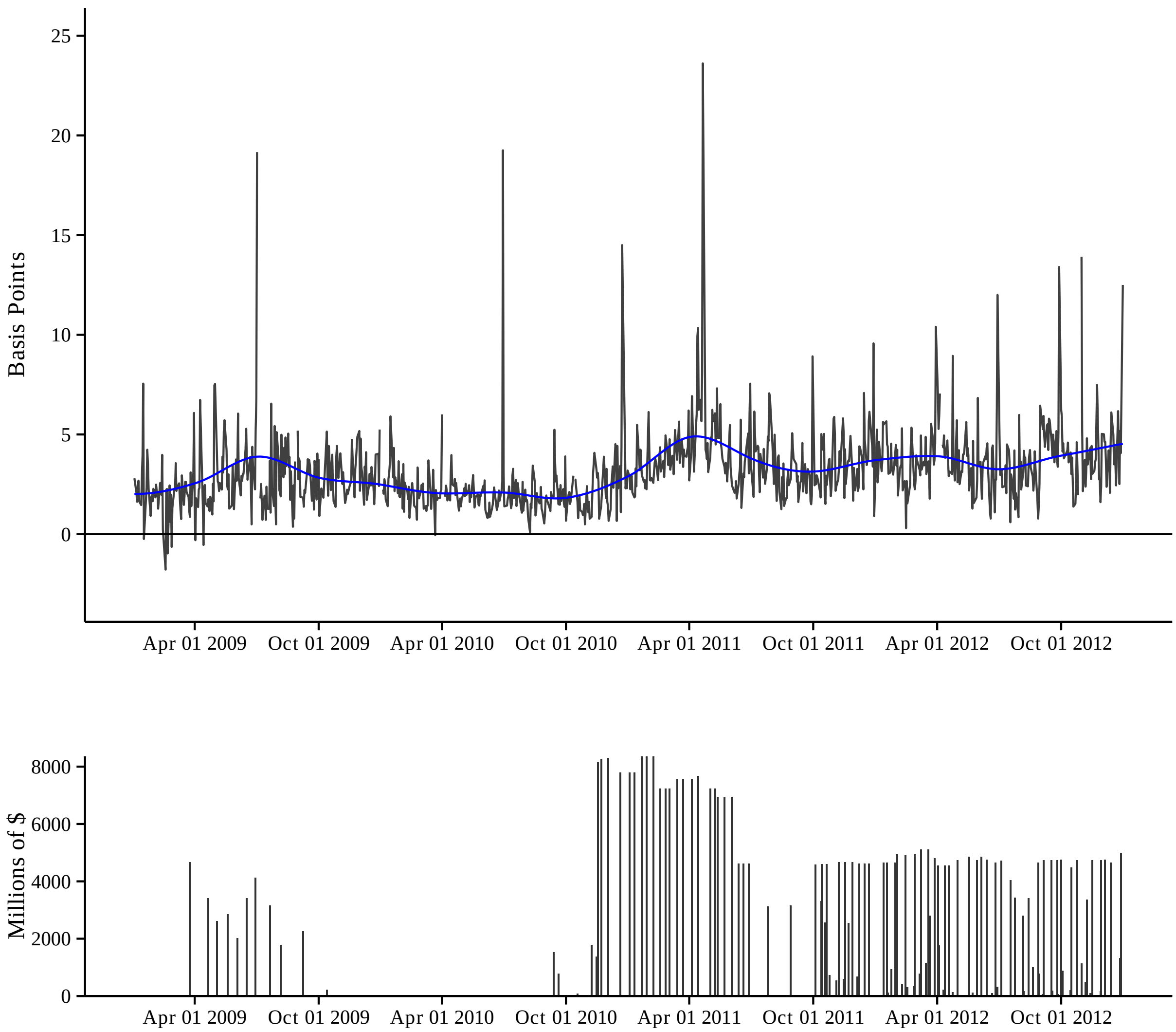

Figure 2: The top panel shows the daily average repo spread across off-the-run securities with remaining maturities of 7 to 10 years. The blue line shows a fitted LOESS curve to the averages. The bottom panel shows total daily Fed purchases of these securities over time.

commercial banks and Fannie Mae also participate. It is a fairly active market although its size is still small compared to that of the overall tri-party repo market.[13] In this study, the specialness spread is mainly used for graphical purposes and comparisons to previous studies, as time dummies in our panel specification control for market-wide effects such as variation in the GC repo rate.

1.3 Quantity Factors Data

During our sample period, from March 2009 to December 2012, the Fed conducted two Large-Scale Asset Purchase (LSAP) programs, one Reinvestment program, and two Maturity Extension Programs (MEPs).[14] These programs have significantly altered the available supply and maturity composition of collateral in the Treasury repo market. Thus, some of the most relevant explanatory variables used in this study are the security-level daily amounts purchased and sold by the Fed under these programs, obtained from the New York Fed.[15] In our regressions, to better account for the relative scarcity of each CUSIP, we use the Fed's purchased/sold amount as a percentage of the privately-held amount outstanding.[16]

Summary statistics of the Fed operations are shown in Table 1. In our sample, the Fed has conducted 3162 purchases and 810 sales of securities across various operations, where most of the CUSIPs have been purchased or sold multiple times. The average purchase's size is $420 million or 1.68% of the security's privately-held amount outstanding; while, the

[13] For more detail about the GCF Repo Index see Fleming and Garbade (2003).

[14] For more details on these programs, see Cahill et al. (2013).

[15] SOMA operation and holding data by CUSIP are publicly available on the New York Fed's website: `http://www.ny.frb.org/markets/pomo/display/index.cfm`.

[16] "Privately held" Treasury securities are defined here as any security not held by the Federal Reserve and is calculated by subtracting the par value held in the SOMA portfolio from the total outstanding par value, which are obtained from CRSP. Source: CRSP®, Center for Research in Security Prices, Booth School of Business, The University of Chicago. Used with permission. All rights reserved. `http://www.crsp.uchicago.edu`.

Table 1: Summary Statistics - Fed Operations

		Mean	Std. Dev.	N
Total	percent_bought	1.68	2.57	3162
	amt_bought	4.2e+08	7.4e+08	
	percent_sold	2.86	4.56	810
	amt_sold	7.1e+08	9.2e+08	
On-The-Run	percent_bought	7.91	6.45	127
	amt_bought	2.3e+09	1.9e+09	
	percent_sold	1.24	1.37	15
	amt_sold	4.2e+08	4.8e+08	
Off-The-Run	percent_bought	1.42	1.86	3035
	amt_bought	3.4e+08	5.2e+08	
	percent_sold	2.89	4.59	795
	amt_sold	7.1e+08	9.3e+08	

Notes: Amounts bought and sold are measured in dollars. Percents bought and sold are measured as a percentage of privately-held amount outstanding.

average sale's size is about $710 million or 2.86% of the security's privately-held amount outstanding. The majority of operations were concentrated in off-the-run securities (about 96% of purchases and 98% of sales). However, the average size of on-the-run purchases is well above the average size of off-the-run purchases.

We expect the impact of a sale or purchase operation to differ between on-the-run and off-the-run securities. For example, demand for short positions, a significant driver of repo rates (Duffie, 1996), is usually concentrated in the most liquid securities, as short sellers value the ability to quickly buy back those securities to cover or unwind their positions (Duffie et al., 2007; Vayanos and Weill, 2008). Therefore, the repo rates of on-the-run securities should be more sensitive to quantity factors. For this reason, we separately estimate the effects of the

Fed operations for on- and off-the-run securities, though the small number of Fed operations in on-the-run securities limits our statistical power. By reducing the collateral available to the repo market, Fed purchases should decrease the SC repo rate and increase the specialness spread of the CUSIP purchased. Fed sales should have the opposite effect.

It is, however, important to take into account that once the purchased securities entered in the SOMA portfolio, they then became available through the Fed's Securities Lending Program (SLP), under which at noon of each business day the Fed offers to lend up to 90% of the amount of each Treasury security owned by SOMA on an overnight basis. But the SLP is limited to primary dealers and has constraints on both the amount of an individual issue a dealer can borrow (25% of the lendable holdings) and the daily amount a dealer can borrow in aggregate across all issues ($5 billion).[17] The program works through an auction mechanism to make loan pricing a market-driven process. Primary dealers bid for a security's loan specifying the quantity and the loan fee. The minimum fee is imposed to provide an incentive only to borrow securities whose SC repo rates are sufficiently far below the GC repo rate.

In our regressions, we control for security-level uncovered bids at the SLP auctions, as any dealer who was not able to obtain the desired amount at the SLP to cover its positions would then have to seek the securities in the repo market, potentially pushing up demand for certain securities. We also control for the total amount borrowed at each SLP auction, as it might better capture a security's demand.

[17]See Fleming and Garbade (2007) for more details on the SLP. Data are publically available at the New York Fed's website: `http://www.newyorkfed.org/markets/securitieslending.html`.

1.4 Treasury Auction Cycle

There are three important periodic dates in the Treasury auction cycle: the auction announcement date, the auction date, and the issuance date. There is usually about one week from the announcement to the auction. During a typical auction cycle, the supply of Treasury collateral available to the repo market is at its highest level when the security is issued, therefore the repo specialness spread should be close to zero. As time passes, more and more of the security may be purchased by holders who are not very active in the repo market, consequently the security's availability may decline over time and the repo specialness spread may increase. When forward trading in the next security begins on the auction announcement date, holders of short positions will usually roll out of the outstanding issue, implying that demand for that specific collateral should decrease and that the repo specialness spread will rapidly decline (see Fisher, 2002). Keane (1995) documents that the repo specialness spread for on-the-run securities exhibits this repeated pattern, that is, it climbs with the time since the last auction until around the announcement of the next auction, after which it declines sharply.

Figures 3 and 4 show the auction cycle patterns in our sample for securities auctioned monthly (2-, 3-, 5-, and 7-year maturities) and quarterly (10-year maturities), respectively. In Figure 3, it is easy to note the same pattern documented by Keane (1995). In contrast, Figure 4 shows that the quarterly auction cycle of the 10-year note looks quite different, mainly because the Treasury has introduced two regular reopenings following each 10-year note auction. Therefore, it is possible to observe three separate auction sub-cycles: the most dramatic run-up in specialness spread takes place before the first reopening; a second run-up, similar in shape but smaller in magnitude, immediately follows and peaks just before the second reopening; and finally, during the third sub-cycle the specialness spread is practically

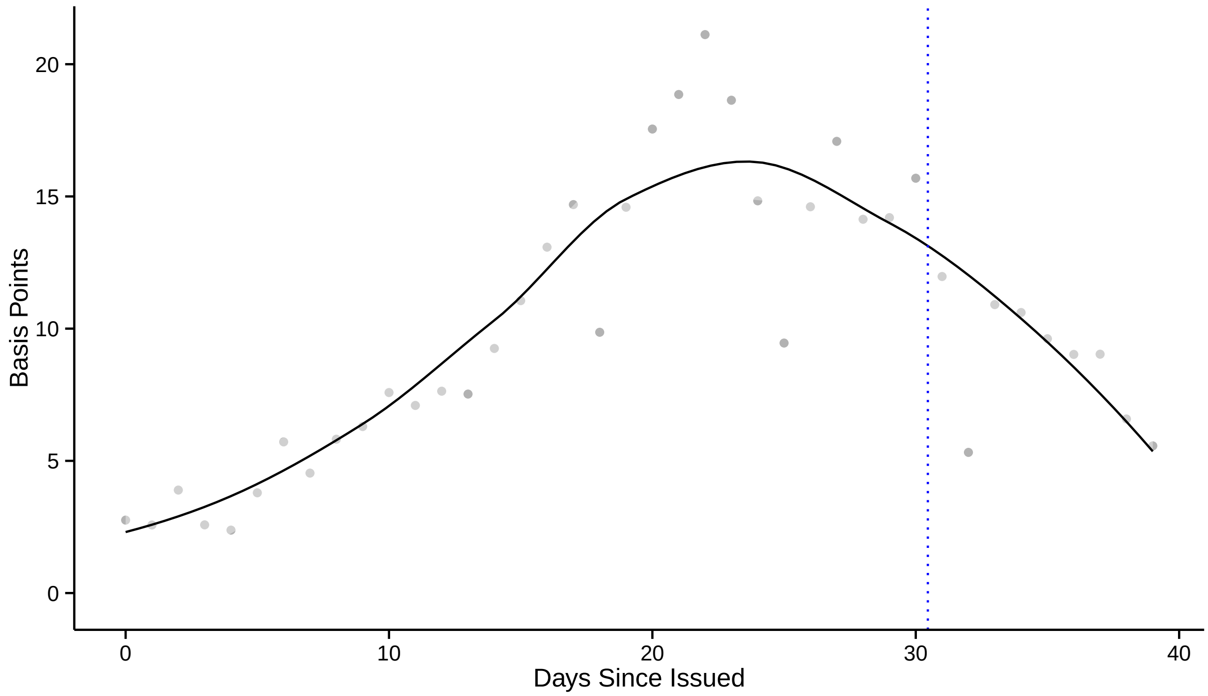

Figure 3: Average daily repo specialness spread for Treasury securities with a 1-month auction cycle (2-, 3-, 5-, and 7-year maturities). Grey dots are the average specialness spread on each day since the issue date, and the line is a fitted LOESS curve. The vertical dashed line marks the average time of the auction of the next security with the same maturity.

flat. This would suggest that the increased availability of the on-the-run security after each reopening strongly diminishes the impact of the seasonal demand for short positions around these dates (Sundaresan, 1994).

In order to control for these auction-cycle effects, we construct a set of dummy variables that track the time elapsed since issuance for both the monthly and quarterly cycles.

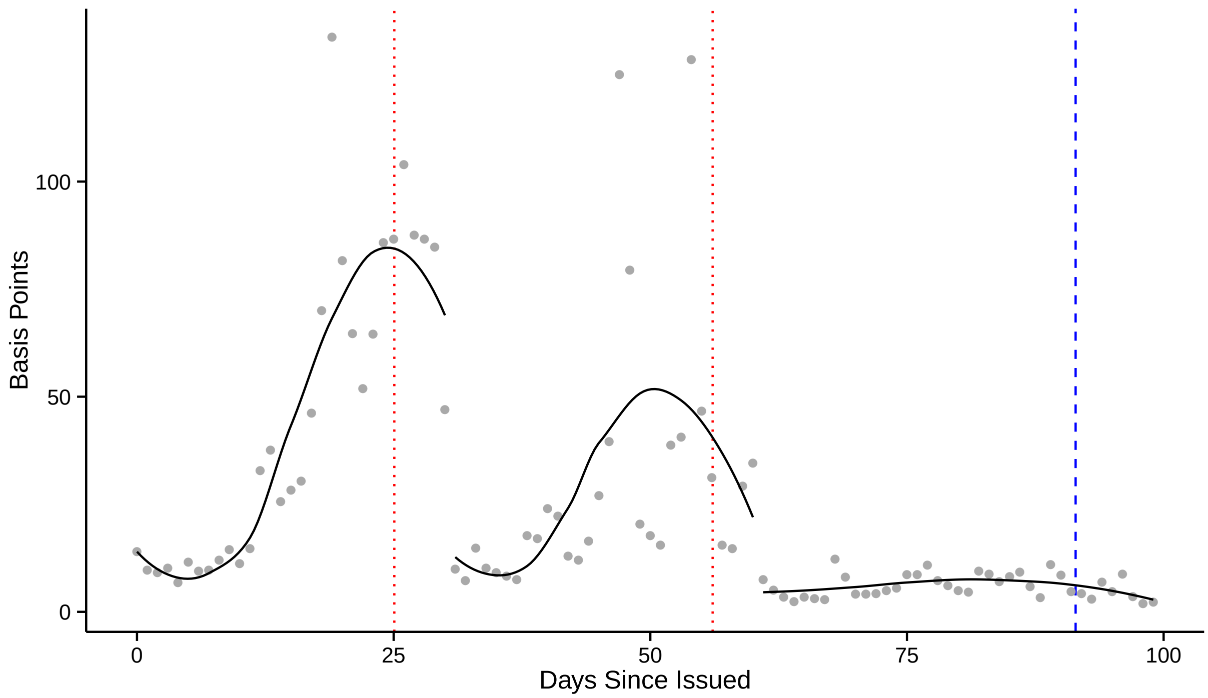

Figure 4: Average daily repo specialness spread for 10-year Treasury securities. Grey dots are the average specialness spread on each day since the issue date, and the line is a fitted LOESS curve. Vertical dotted lines mark the average times of reopening auctions, while the vertical dashed line denotes the average time of the auction of the next 10-year security.

1.5 Demand for Short Positions and Other Controls

In addition to quantifying changes in the available supply of collateral, we also aim to capture one of the most important demand factors in the repo market: demand for short positions. Duffie (1996), Duffie et al. (2007), and Vayanos and Weill (2008) all suggest that agents who create short positions prefer to trade securities that are expected to be liquid in the future, and often use reverse repo contracts to create these positions because they are less expensive than other options. Therefore, for a given supply of the security, the extent of specialness should be increasing in the demand for short positions.

Table 2: Summary Statistics - Operation Days

	On-The-Run		Off-The-Run		Total	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
repo_avgrate	5.54	21.9	14.2	7.48	14	8.22
delta_repo	-.188	6.83	.017	2.95	.0123	3.1
repo_spread	11.1	21.1	2.77	3.22	2.96	4.69
delta_repo_spread	.136	6.56	-.0779	2.67	-.0729	2.82
repo_volume_sprd_std	-.261	3.33	-.0263	.91	-.0318	1.03
bidaskspread	1.35	.56	3.15	2.42	3.1	2.41
delta_bidaskspread	.00231	.573	-.00579	.921	-.0056	.914
N	2028		85293		87321	

Notes: SC repo rates and repo specialness spreads are measured in basis points. Repo volume spread is our proxy for short positions and is standardized and measured in standard deviations. Bid-ask spreads are measured in cents. Δ-variables are one-day changes in values.

To control for daily demand for short positions at the security level, on any given day and for each CUSIP, we compute the total amount of transactions initiated as *reverse repos* and subtract the total amount of transactions initiated as *repos* over the same period. This imbalance, which should capture the security's excess demand, can create price pressures in the specific security and might make it run special.

Finally, since liquidity and specialness are often correlated (Duffie, 1996), especially for on-the-run securities, we explicitly control for securities' liquidity using individual bid-ask spreads measured in cents per hundred dollars.[18] Securities with lower bid-ask spreads are more liquid, therefore we expect them to have lower repo rates and higher specialness spreads.

[18] Composites of bid and ask price quotations for individual Treasury securities are obtained from the New York Fed.

2 Empirical Results

We now turn to estimating the impact of the previously described security-specific demand and supply factors on SC repo rates through a series of panel regressions. Various empirical specifications are estimated at a daily frequency where the dependent variable is the change in the SC repo rate for all outstanding nominal Treasury coupon securities. Unlike previous studies, we use changes rather than levels because these variables exhibit a high degree of serial correlation.

Another important advantage of using changes is that they mitigate any additional endogeneity concerns that might affect some of the controls and that are typical of exercises in which a price variable (the repo rate) is regressed on quantity factors. The rationale for this is based on the time at which repo rates are measured relative to when Fed operations, Treasury auctions, and SLP auctions are conducted. The SC repo rates are collected every morning from 7:30 to 10:00 a.m., while the regular Fed purchase and sale operations start at 10:15 a.m. and end at 11:00 a.m. In some cases, there can be a second operation between 1:15 and 2 p.m. of the same day. The SLP auctions start at 12 p.m. and end at 12:15 p.m.; and, the Treasury auction results for notes and bonds are normally announced at 1 p.m. This sequence of events implies that only the average repo rate of the following morning will reflect information from these operations. At the same time, the change in the next day's repo rate cannot be factored into the Fed's and Treasury's operational decisions. Therefore, while the change in the repo rate from the morning of any given day to the next will reflect that day's operations, it will not affect the operations' implementation on the same day.

We start our sample after the introduction of the repo fail charge by the Treasury Market Practices Group on May 1, 2009 to avoid a structural break in the series.[19] Furthermore,

[19]See `http://www.newyorkfed.org/tmpg/tmpg_faq_033109.pdf` for details of the fails charge implemen-

due to limited data availability on whether individual transactions were initiated as repos or reverse repos, we use the slightly shorter sample starting on June 23, 2009. We omit securities maturing in more than 15 years because the repo market in longer-term securities is very thin. As a result, our unbalanced panel consists of 347 CUSIPs.

2.1 Regression Specification

Our basic panel regression specification is the following:

$$\Delta SCR^{morning}_{i,t,t+1} = \alpha + \beta_1 \Delta SF_{i,t} + \beta_2 \Delta DF_{i,t} + \beta_3 \Delta L_{i,t} + \beta_4 \tau_{i,t} + \beta_5 D_{i,t} + \gamma_t + \epsilon_{i,t} \qquad (1)$$

where for each security i at time t, ΔSCR is the change in the SC repo rate in basis points; ΔSF represents changes in supply factors such as amount purchased and sold at each Fed operation rescaled by the security's privately-held amount outstanding; ΔDF represents changes in demand factors such as our proxy for short positions rescaled by the security's privately-held amount outstanding and the amount of uncovered bids at the SLP auctions; ΔL are controls for liquidity characteristics such as the change in the bid-ask spread; τ includes maturity and maturity squared; D are dummies that control for the auction cycle discussed in Section 1.4; and γ_t are daily time dummies that control for the evolution over time of common market-wide factors.

Indeed, the daily time dummies should completely absorb the variation in specialness spreads due to the variation in the Treasury GC repo rate, which summarizes the overall trading conditions in the Treasury repo market. This suggests that regressions with changes in SC repo rates or in specialness spreads are equivalent under this specification.

tation. Fleming et al. (2012) show that this triggered striking changes in the willingness to receive negative interest rates on cash pledged to secure borrowing of certain securities.

In addition, some variables are interacted with a dummy that divides the sample into two mutually exclusive subsamples: on-the-run vs. off-the-run securities. Finally, because Fed operations settle on the following day, we also use the two-day change in the SC repo rate as the dependent variable in our regressions. The rationale is that the impact of these operations might not be felt until the day in which the investors have to actually deliver or receive the security to or from the Fed.

Equation 1 is estimated using only days when Fed operations were conducted.[20]

2.2 Results

The results from the panel regression using the one-day change in the SC repo rate are reported in the first column of Table 3, while the second column shows the results for the two-day change in the same dependent variable.[21,22] Both on- and off-the-run Fed purchases have negative and statistically significant effects on SC repo rates, although their size appears to be considerably larger for on-the-run securities. The coefficient of -0.227 suggests that buying one percent of a security's outstanding would decrease the SC repo rate by 0.227 basis points, implying that on average a $1-billion purchase of on-the-run securities would decrease the SC repo rate by 0.79 basis points. In contrast, the coefficient for the off-the-run securities implies a decline of 0.35 basis points for a purchase of the same size.

This suggests the existence of a scarcity premium, as a reduction in the available supply of a specific security would push its repo rate down, indicating that on average investors must lend money at relatively lower rates to obtain that specific security, facing an additional cost.

[20]We obtain very similar results if we use every day in the sample.

[21]For brevity, we do not show the coefficients for the time and auction cycle dummies.

[22]In our regressions, we discard observations for which the one-day change in the SC repo rate exceeds 40 basis points or the two-day change exceeds 60 basis points. These threshold choices seems reasonable, since in our full sample over 99.9% of observations are within each threshold.

Table 3: SC Repo Rate Regressions

	(1) d_repo_spread	(2) d2_repo_spread
percent_bought_offtherun	-0.0847***	-0.107***
	(-6.56)	(-6.43)
percent_sold_offtherun	0.0487***	0.0549***
	(3.95)	(5.41)
percent_bought_ontherun	-0.227***	-0.270***
	(-4.51)	(-3.68)
percent_sold_ontherun	-0.167	-0.138
	(-0.40)	(-0.24)
SLP_pct_uncovered_off	-0.00310	0.00486
	(-0.97)	(1.31)
SLP_pct_uncovered_on	-0.00933	0.0456
	(-0.27)	(1.19)
repo_volume_sprd_std	-0.0369*	-0.0267
	(-2.20)	(-1.21)
delta_bidaskspread	0.00328	0.00119
	(0.53)	(0.15)
maturity	0.0159***	0.0179**
	(3.46)	(3.22)
maturity2	-0.00105**	-0.00122**
	(-3.07)	(-2.98)
N	87337	86551
R^2	0.735	0.737
adj. R^2	0.733	0.736

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Heteroskedasticity-consistent t statistics in parentheses. Repo rates are measured in basis points. Percents bought and sold are measured as a percentage of privately-held amount outstanding. Repo volume spread is our proxy for short positions and is standardized and measured in standard deviations. Bid-ask spreads are measured in cents. Bids left uncovered at the SLP is measured as a percentage of privately-held amount outstanding. Maturity is measured in years. Δ-variables are one-day changes in values. We also control for time and auction-cycle dummies.

And owners of that security would obtain financing at a more attractive rate, enjoying an extra profit. The coefficients when using the two-day changes (shown in the second column) are slightly larger, suggesting that on the settlement day the impact from these operations not only persists but increases.

The impact of Fed sales is positive and significant only for the off-the-run securities, which is not surprising given the small number (15) of on-the-run sales in our sample. The coefficient of 0.0489 suggests that selling one percent of a security's outstanding would increase the SC repo rate by 0.0489 basis points, implying that a $1-billion sale would increase the SC repo rate by 0.2 basis points. The cumulative impact is again slightly bigger on the settlement day.

On the other hand, our proxies for demand factors seem to be less important. The demand for short positions (repo volume spread) has a negative and statistically significant impact on SC repo rates, though the coefficient's size is much smaller than that of the Fed purchases. In this case, the split in on- and off-the-run securities (not shown) does not affect its magnitude. The SLP coefficient is not statistically significant. One possible explanation is that, as mentioned in Section 1.3, each dealer's participation is capped, making this tool less effective in releasing demand pressure.

We next break our data into three subsamples based on the securities' maturity. In particular, we consider possible differences between securities with shorter maturities that were eligible for both sale and purchase operations conducted by the Fed (during the MEP the Fed sold only securities maturing in 3 years or less), those with medium-term maturities (3 to 7 years), and securities with longer maturities (7 to 15 years). Table 4 presents the results for these subsamples. The coefficients for on- and off-the-run Fed purchases are both significantly larger for shorter-term securities, implying an average effect of -1.78 and -0.51

Table 4: SC Repo Rate Regressions by Maturity Subsample; One-Day Changes

	(1) 0-3 Years	(2) 3-7 Years	(3) 7-15 Years
percent_bought_offtherun	-0.139**	-0.0686***	-0.0787***
	(-3.27)	(-3.39)	(-3.58)
percent_sold_offtherun	0.0465***		
	(3.77)		
percent_bought_ontherun	-0.553***	-0.100**	-0.414
	(-3.98)	(-3.19)	(-0.94)
percent_sold_ontherun	-0.306		
	(-0.63)		
SLP_pct_uncovered_off	-0.00395*	0.0110	0.00557
	(-2.05)	(0.16)	(0.41)
SLP_pct_uncovered_on	-0.00539	-0.128	0.00701
	(-0.12)	(-1.17)	(0.12)
repo_volume_sprd_std	-0.0781*	-0.0273	0.0103
	(-2.56)	(-1.26)	(0.30)
delta_bidaskspread	0.0119	0.00419	-0.0126
	(1.21)	(0.41)	(-0.86)
maturity	0.0915**	0.00438	-0.00222
	(2.87)	(0.05)	(-0.03)
maturity2	-0.0174	0.000577	0.0000327
	(-1.96)	(0.06)	(0.01)
N	45886	30194	11257
R^2	0.766	0.749	0.641
adj. R^2	0.764	0.745	0.625

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Heteroskedasticity-consistent t statistics in parentheses. Repo rates are measured in basis points. Percents bought and sold are measured as a percentage of privately-held amount outstanding. Repo volume spread is our proxy for short positions and is standardized and measured in standard deviations. Bid-ask spreads are measured in cents. Bids left uncovered at the SLP is measured as a percentage of privately-held amount outstanding. Maturity is measured in years. Δ-variables are one-day changes in values. We also control for time and auction-cycle dummies.

Table 5: SC Repo Rate Regressions; Two-Day Changes

	(1) 0-3 Years	(2) 3-7 Years	(3) 7-15 Years
percent_bought_offtherun	-0.215***	-0.0827***	-0.0884***
	(-3.58)	(-3.45)	(-3.58)
percent_sold_offtherun	0.0539***		
	(5.23)		
percent_bought_ontherun	-0.625**	-0.119*	0.112
	(-3.08)	(-2.20)	(0.25)
percent_sold_ontherun	-0.350		
	(-0.51)		
SLP_pct_uncovered_off	-0.000209	0.103	0.0142
	(-0.07)	(1.90)	(0.72)
SLP_pct_uncovered_on	0.0626	0.0474	0.0305
	(1.29)	(0.52)	(0.46)
repo_volume_sprd_std	-0.0688	-0.0509*	0.0719
	(-1.50)	(-2.28)	(1.56)
delta_bidaskspread_pct	0.00279	0.00309	0.00756
	(0.24)	(0.24)	(0.39)
maturity	0.138***	0.0734	0.165
	(3.58)	(0.57)	(1.84)
maturity2	-0.0263*	-0.00625	-0.00718
	(-2.36)	(-0.49)	(-1.81)
N	45474	29963	11114
R^2	0.775	0.745	0.648
adj. R^2	0.773	0.741	0.632

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Heteroskedasticity-consistent t statistics in parentheses. Repo rates are measured in basis points. Percents bought and sold are measured as a percentage of privately-held amount outstanding. Repo volume spread is our proxy for short positions and is standardized and measured in standard deviations. Bid-ask spreads are measured in cents. Bids left uncovered at the SLP is measured as a percentage of privately-held amount outstanding. Maturity is measured in years. Δ-variables are one-day changes in values. We also control for time and auction-cycle dummies.

basis points per billion dollars, respectively. Again, the strong economic and statistical significance of these results confirm the existence of scarcity premia.

Further, in the case of shorter-term securities, the coefficient on off-the-run uncovered bids at the SLP is negative and significant, suggesting that if investors were unable to obtain the desired quantity of a specific security at the SLP, then on average they would lend money in the repo market at a relatively lower rate in exchange of that particular security. Table 5 shows results from the same regressions but using the two-day change in the SC repo rate, confirming that on the settlement day the magnitude of all the significant coefficients is a bit bigger.

2.3 Robustness Checks

Our main hypothesis for the existence of a significant and persistent scarcity effect is that in the SC repo market, because substitution across securities is precluded by the contract specification, there is an extreme form of imperfect substitutability that exacerbates quantity effects. To provide further support to this hypothesis, we control for the amount of purchases of each security's potential substitutes. If our hypothesis is correct, even changes in quantities of securities with very similar characteristics should not affect the SC rate of that particular security.

We measure substitutability across several dimensions such as maturity, liquidity, and specialness. For example, if we choose substitutes based on maturity, for a given security i, we construct this variable by taking a weighted sum of the purchase amounts $purc_{jt}$ of securities with similar remaining maturity:

$$sub\_purc_{it} = \sum_{j \neq i} W\left(\frac{m_{it} - m_{jt}}{h}\right) purc_{jt} \tag{2}$$

where h is a bandwidth parameter and m_{it} is the remaining maturity at time t for security i. W is a weight function, which we choose to be the tri-cube function: $W(u) = (1-|u|^3)\mathbb{1}_{|u|\leq 1}$. This function is chosen because a) $W(0) = 1$, so purchases of securities with identical maturities are counted at full value, b) it is bell-curve shaped, which captures the idea of a gradually decreasing degree of substitution, and c) it has a finite support, so securities with very different maturities will have zero weight.[23]

Similarly, when we construct the buckets of substitutes based on either liquidity or specialness, we make the weights a function of the distance between the lagged individual yield-curve fitting errors and specialness spreads, respectively. [24] In addition, the weight function can be generalized to allow for a second dimension so that substitutability is defined by two characteristics, either maturity and fitting errors or maturity and specialness. Finally, to more easily compare these coefficients, we scale the amount of substitutes by the security i's privately-held amount outstanding.[25]

As shown in the first column of Table 6, we find that the coefficient for the close-substitute purchases, defined in terms of maturity distance, is basically zero and not statistically significant. This result is diametrically opposite to the findings of D'Amico and King (2013), where purchases of a security's close substitutes were almost as important as the purchases of the security itself in the Treasury cash market. However, even in their study, the decreas-

[23]In order to smoothly scale up the bucket size as maturities increase, we transform the raw maturities before applying Equation 2. Maturities are transformed by $T(m) = \log(m + 5)$. This adjustment is chosen so that, along with a bandwidth parameter of $h = 0.2$, the resulting maturity ranges are sensible for various maturities. For instance, 1-year and 20-year securities have positive weights on maturities in (0, 2.3) and (15.5, 25.5), respectively. Note that our results are fairly robust to changes in the weight function, bandwidth, and transformation adjustment.

[24]Throughout the paper, "fitting errors" refer to the residuals that result from fitting a smooth curve, using the functional form proposed by Svensson (1994), to the cross-section of yields on each day. These residuals can be interpreted as a measure of price discrepancies in the Treasury market (Fontaine and Garcia, 2012).

[25]We do not report them, but the results are not significantly changed by using the dollar amount of substitute purchases for each security.

ing magnitude of the coefficients from near-substitute to far-substitute purchases suggested imperfect substitutability across securities. Our results indicate that this type of imperfect substitutability is extreme in the SC repo market, lending strong support to our hypothesis. Furthermore, as shown in columns 2 through 5 of Table 6, the coefficient for the close-substitute purchases remains close to zero and not statistically significant when we measure substitutability with the vicinity of the fitting errors, specialness spreads, a combination of maturity and fitting errors, and a combination of maturity and specialness spreads. This indicates that no matter how you measure substitutability, the absence of substitution effects is evident in the SC repo market, suggesting that this limited substitutability plays an important role in the significance and persistency of the repo scarcity premium.

Next, we try to address some of the estimation concerns that might rise because of the mechanics of purchase operations. To this end, it may be useful to provide additional details about the logistics of these operations. At the end of each month, the Open Market Desk at the New York Fed (the Desk) announced the tentative schedule for the entire upcoming month. The announcement of the tentative schedule included the operation type, targeted maturity range, and the expected operation size. Further, shortly before each operation the Desk published a list of CUSIPs that were eligible for purchase, which generally included nearly all securities in the targeted maturity sector, except for those securities that were the cheapest-to-deliver in futures markets, those with high scarcity value in the repo market, and those for which 70% of the issue was already owned by SOMA.[26] Then primary dealers submitted their propositions, specifying the amount and price of each CUSIP at which they were willing to sell to (buy from) the Desk. Given this set of propositions, the Desk then

[26]These exclusion criteria were announced by the Desk on March 24, 2009. During the first LSAP the tentative schedule was announced biweekly, every-other Wednesday, and the threshold for each security was 35% rather than 70%.

Table 6: Robustness Checks; Substitutes; One-Day Changes

	(1) ΔRepo	(2) ΔRepo	(3) ΔRepo	(4) ΔRepo	(5) ΔRepo
Percent Bought Off-the-run	-0.0853***	-0.0855***	-0.0853***	-0.0867***	-0.0835***
	(-6.48)	(-6.57)	(-6.54)	(-6.62)	(-6.27)
Percent Sold Off-the-run	0.0475***	0.0475***	0.0476***	0.0484***	0.0465***
	(3.86)	(3.90)	(3.89)	(3.92)	(3.80)
Percent Bought On-the-run	-0.227***	-0.226***	-0.227***	-0.227***	-0.227***
	(-4.51)	(-4.50)	(-4.51)	(-4.51)	(-4.51)
Percent Sold On-the-run	-0.234	-0.236	-0.231	-0.233	-0.235
	(-0.87)	(-0.88)	(-0.86)	(-0.87)	(-0.88)
Sub. Purc. (Maturity)	0.00000693				
	(0.02)				
Sub. Purc. (Fit Err.)		0.000271			
		(1.10)			
Sub. Purc. (Repo Spread)			-0.000257		
			(-0.74)		
Sub. Purc. (Fit Err. & Mat.)				0.000345	
				(0.77)	
Sub. Purc. (Repo & Mat.)					-0.000589
					(-1.03)
Repo Volume Spread	-0.0371*	-0.0370*	-0.0371*	-0.0370*	-0.0371*
	(-2.15)	(-2.14)	(-2.15)	(-2.15)	(-2.15)
ΔBid-Ask Spread	0.00427	0.00429	0.00428	0.00428	0.00426
	(0.68)	(0.68)	(0.68)	(0.68)	(0.68)
N	85257	85257	85257	85257	85257
R^2	0.742	0.742	0.742	0.742	0.742
adj. R^2	0.740	0.740	0.740	0.740	0.740

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Heteroskedasticity-consistent t statistics in parentheses. Repo rates are measured in basis points. Percents bought and sold are measured as a percentage of privately-held amount outstanding. Fitting errors are measured in cents, where more positive is more expensive. Repo volume spread is our proxy for short positions and is standardized and measured in standard deviations. Bid-ask spreads are measured in cents. Δ-variables are one-day changes in values. We also control for time and auction-cycle dummies, maturity, and maturity squared, which are not shown for brevity.

determined which securities to buy (sell) based on a confidential algorithm and published the auction results within a few minutes.

Based on the above Desk's exclusion criteria, it is plausible that the Desk's algorithm would tend to select, among the submitted bids, those securities that were cheaper relative to the yield curve. This might have introduced a relation between the relative cheapness of each security and the quantity purchased by the Fed. Since cheaper securities are less likely to be special (i.e., less likely to have low SC rates), if we omit measures of the relative cheapness of each security, we might bias the coefficient estimates of purchased quantities because both SC rates and quantities are correlated with the omitted variable. To this purpose, we augment our baseline specification with the level of the individual yield-curve fitting errors—a proxy of how "expensive" a security is relative to those with same coupon rate and time to maturity—as of the end of the day preceding each operation. As shown in the first column of Table 7, the level of the individual fitting error is not statistically significant and hardly affected any of the coefficients.

In addition, if individual specialness spreads are not persistent and therefore mean-reverting, SC rates of securities that are not running special would tend to fall relative to other securities and those of securities with high scarcity value would tend to rise, even in the absence of LSAP purchases. In other words, initial specialness spreads might be correlated with the regression error term. Further, there may be other information embedded in the specialness spread before each operation that reflects expectations of future scarcity value. To control for these possibilities, we also include the initial level of the specialness spread, that is, the spread on the day preceding each operation, as a regressor. As shown in the second column of Table 7, this new variable is highly significant, arguing for its inclusion. However, the estimated values of the coefficients for purchased and sold amounts

Table 7: Robustness Checks; Other Controls; One-Day Changes

	(1) ΔRepo	(2) ΔRepo	(3) ΔRepo
Percent Bought Off-the-run	-0.0843***	-0.0839***	-0.0849***
	(-6.53)	(-6.46)	(-6.57)
Percent Sold Off-the-run	0.0482***	0.0479***	0.0477***
	(3.94)	(3.88)	(3.91)
Percent Bought On-the-run	-0.227***	-0.223***	-0.229***
	(-4.50)	(-4.42)	(-4.53)
Percent Sold On-the-run	-0.245	-0.143	-0.210
	(-0.92)	(-0.55)	(-0.80)
Lagged Fit Error (Level)	0.00101		
	(0.82)		
Lagged Repo Spread (Level)		0.0415**	
		(3.17)	
SLP Total Amt Borrowed			1.92e-10
			(1.83)
Repo Volume Spread	-0.0365*	-0.0268	-0.0349*
	(-2.12)	(-1.61)	(-2.06)
ΔBid-Ask Spread	0.00315	0.00446	0.00339
	(0.51)	(0.71)	(0.55)
N	87337	85257	87337
R^2	0.735	0.744	0.735
adj. R^2	0.733	0.743	0.734

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Heteroskedasticity-consistent t statistics in parentheses. Repo rates are measured in basis points. Percents bought and sold are measured as a percentage of privately-held amount outstanding. Fitting errors are measured in cents, where more positive is more expensive. Total amount borrowed at the SLP is measured in dollars. Repo volume spread is our proxy for short positions and is standardized and measured in standard deviations. Bid-ask spreads are measured in cents. Maturity is measured in years. Δ-variables are one-day changes in values. We also control for time and auction-cycle dummies, maturity, and maturity squared, which are not shown for brevity.

are barely changed and they both retain their statistical significance. Interestingly, when we include this variable, maturity and maturity squared lose their marginal predictive power (not shown), suggesting that the initial level of the specialness spread already captures all the relevant information specific to that security.

Our next robustness check is related to the SLP. Although in our baseline specification, for the reasons explained in Section 1.3, we already control for security-level uncovered bids at the SLP auctions (see Table 3), it is plausible that the total amount of borrowing at each of these auctions could have been more relevant in capturing the security's heightened demand. In the third column of Table 7, we show the results for the regressions augmented with this variable. Similarly to the results for the individual amount of uncovered bids, also the coefficient on the security-level total amount borrowed at the SLP is not statistically significant.

Finally, to account for possible correlations across the regression errors of collateral with comparable maturities, we also run the analysis with clustered standard errors. Table 8 shows the results of this robustness exercise. The first column shows estimates from the same model as the first column in Table 3, using heteroskedasticity-consistent standard errors. The second and third columns show the results from specifications where we allow for clustering within one- and three-year maturity buckets for each security. The results are robust to the type of standard error used, as the statistical significance of the estimated coefficients is practically unchanged. We perform the same exercise for the maturity subsample regressions presented in Tables 4 and 5 and obtain similar results (not shown). This is not surprising if, as already documented in Table 6, there is an extreme form of imperfect substitution that limits the transmission of quantity shocks across similar securities, reducing cross-sectional correlations.

Table 8: Clustered t Statistics; One-Day Changes in SC Repo Rate

	(1) Robust	(2) 1-yr Clust.	(3) 3-yr Clust.
percent_bought_offtherun	-0.0847***	-0.0847***	-0.0847***
	(-6.56)	(-6.49)	(-6.21)
percent_sold_offtherun	0.0487***	0.0487***	0.0487***
	(3.95)	(3.69)	(3.66)
percent_bought_ontherun	-0.227***	-0.227***	-0.227***
	(-4.51)	(-4.50)	(-4.49)
percent_sold_ontherun	-0.167	-0.167	-0.167
	(-0.40)	(-0.40)	(-0.40)
SLP_pct_uncovered_off	-0.00310	-0.00310	-0.00310
	(-0.97)	(-0.95)	(-0.96)
SLP_pct_uncovered_on	-0.00933	-0.00933	-0.00933
	(-0.27)	(-0.27)	(-0.27)
repo_volume_sprd_std	-0.0369*	-0.0369*	-0.0369*
	(-2.20)	(-2.21)	(-2.18)
delta_bidaskspread_pct	0.00328	0.00328	0.00328
	(0.53)	(0.50)	(0.48)
N	87337	87337	87337
R^2	0.735	0.735	0.735
adj. R^2	0.733	0.733	0.733

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: t statistics in parentheses. Repo rates are measured in basis points. Percents bought and sold are measured as a percentage of privately-held amount outstanding. Repo volume spread is our proxy for short positions and is standardized and measured in standard deviations. Bid-ask spreads are measured in cents. Bids left uncovered at the SLP is measured as a percentage of privately-held amount outstanding. Maturity is measured in years. Δ-variables are one-day changes in values. We also control for time and auction-cycle dummies, maturity, and maturity squared, which are not shown for brevity.

2.4 Persistency

In addition to looking at the immediate impact of the security-specific demand and supply factors on SC repo rates, we also investigate their dynamic effects. Because the Fed's purchased (sold) amounts can be perceived by the market participants as a long lasting reduction (increase) in a security's available supply (conditional on their expectations about the time of the potential unwinding of the Fed balance sheet expansion), and because SC repo contracts rule out the possibility of delivering a close substitute security, we would expect these effects to be quite persistent.

To test this hypothesis, the top panel of Figure 5 shows, for the change in the SC repo rates, the cumulative response to the Fed off-the-run purchases in the N-day period following the purchases ($N = 1, \ldots, 100$) and the corresponding 95% confidence interval.[27] In the dynamic specification, in addition to the variables used in the baseline regressions (see Section 2.1), we also control for any future purchases that took place over the N-day time period. It can be seen that the effect is quite persistent, as it converges toward zero very slowly and stays significant for at least three months (60 business days). Further, in the week following the purchase operation, on average, the estimated coefficient increases in magnitude to -0.12 (from -0.08), indicating that a $1 billion purchase would decrease the SC repo rate by 0.5 basis points, and only after about two months (40 business days) it stabilizes around the initial impact value. We repeat the same exercise for the coefficient on the amount sold at the Fed operations. As shown in the bottom panel of Figure 5, the effect is less persistent for sales, as it remains significant for about 15 business days.

Indeed, the estimated impulse response for the coefficient on the Fed's purchases confirms the existence of a significant scarcity premium for Treasury collateral that does not seem to

[27] The small sample size for the on-the-run securities limits our ability to test for dynamic effects.

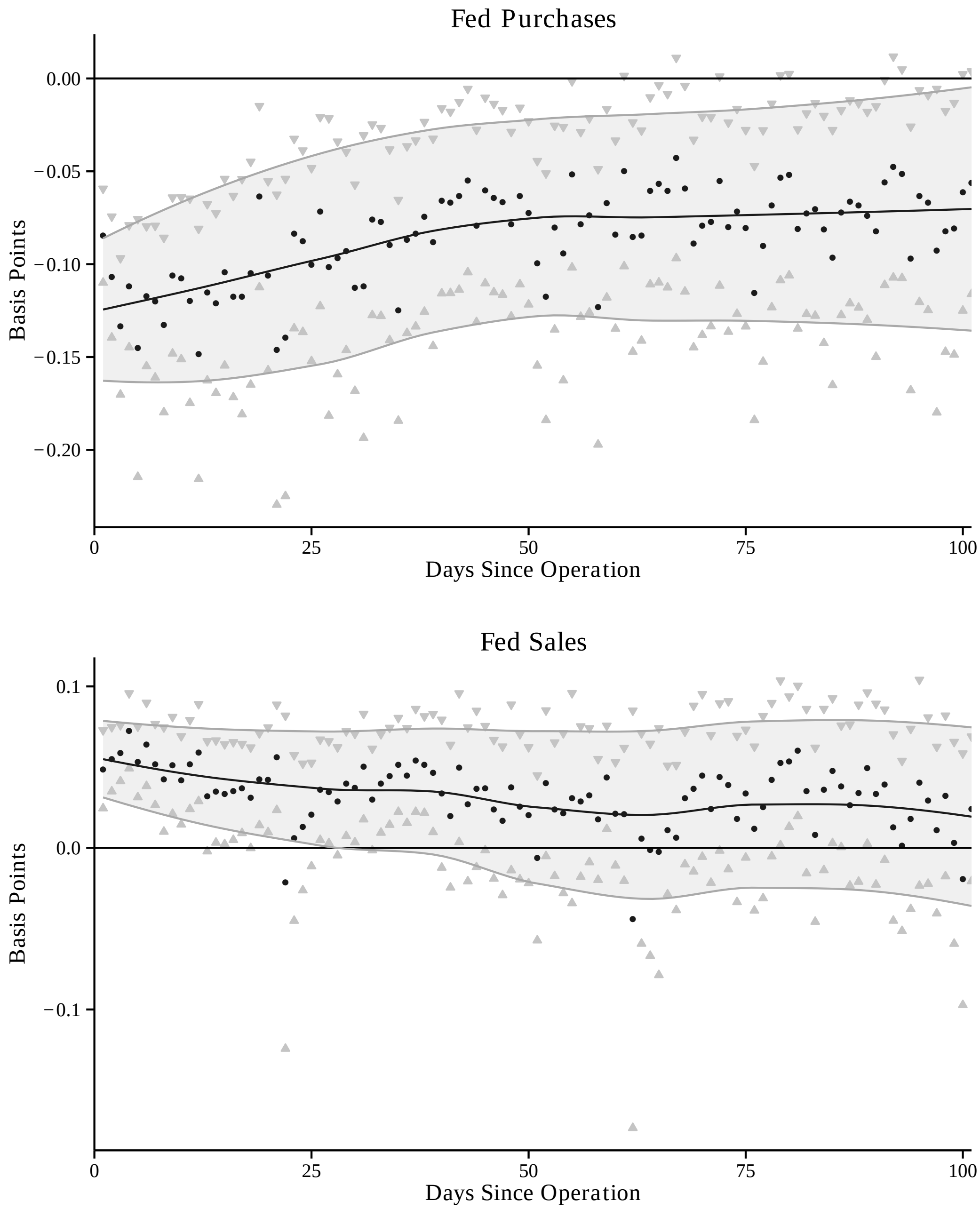

Figure 5: Coefficients on the percentage bought or sold by the Fed from regressions using, as the dependent variable, cumulative changes in the SC repo rate over the N-day period following each operation. Black points indicate the estimated coefficients for each period. Grey triangles indicate the 95% confidence interval for each of those coefficients. The lines are fitted LOESS curves.

dissipate quickly, at least in our sample. This is quite striking if we consider that our panel includes time dummies, thus this coefficient isolates the additional price impact of a change in supply on top of any common factor, measuring a lower bound of the supply effect; this bound is shown to be sizable and fairly persistent.

It certainly persists longer than the purchase effects of the Fed's first LSAP program in the Treasury cash market, which revert to zero after six days from the day of purchase (D'Amico and King, 2013). This can be due to the security-specific nature of SC repo contracts, which prevent the delivery of close substitutes. In other words, anyone who sold collateral short must deliver that specific bond and not some other bond, and therefore would put extra value on that specific collateral. The availability of similar bonds would not affect that value, at least until the position is closed.

The following is one possible mechanism behind the persistency of the supply effects. If there is a significant amount of open short positions established through reverse repos and the net supply of the underlying collateral decreases (in this particular case because of the Fed purchases), at impact the price of the Treasury collateral in the cash market would increase and the current and expected future repo rate would decrease (repo specialness spread would increase). Dealers would now have a few options: they may be forced to repurchase the bond at a significantly higher price and incur a substantial loss, which in aggregate would make the collateral's net supply decrease further; they can roll over in a new reverse repo offering cash at the lower SC repo rate to get that specific security and close the previous position; and, if the current contract is an open repo, they can roll over the same reverse repo contract (subject to changes in margin requirements) re-setting to the lower SC repo rate. All these possibilities, by either making the underlying collateral scarcer and/or by keeping the repo contract rolling, may cause SC repo rates to stay lower for longer, magnifying the persistency of the supply shock.

3 Relation to Cash Market Prices

In light of the recent literature's findings that even repeated and anticipated changes in supply could have effects on Treasury cash prices (as shown by Lou et al., 2013, for Treasury auctions and D'Amico and King, 2013, for the Fed's Treasury LSAPs), and given the existence of well-documented links between a security's cash market price and repo market specialness (Duffie, 1996; Jordan and Jordan, 1997; Buraschi and Menini, 2002), it is natural to hypothesize that some of the LSAPs' price effects in the cash market might reflect changes in repo specialness spreads due to the Fed operations estimated in Section 2.2. In this section, we attempt to test this conjecture.

We shed some light on this issue by conducting a simple empirical exercise. First, similarly to previous studies, we find that also in our sample a specific Treasury bond's cash price premium (relative to securities with the same coupon and maturity) mostly reflects the magnitude of its repo specialness spread.[28] Then, we go a step further and show that this relation is stronger on the days of the Fed operations and mainly in the securities eligible for purchase/sale, many of which are well off-the-run. Since we already showed that the Fed's asset purchases are associated with higher repo specialness spreads (lower SC repo rates) and that these effects are quite persistent, the above relation to the cash price premium provides some support for our hypothesis. Namely, that one channel through which LSAPs affect Treasury prices (on the days of the actual operations) could be by impacting the scarcity value of Treasury collateral in the repo market. This can help explain why purchase/sale

[28] Other important studies that examine the relation between price differentials in the Treasury cash market and funding conditions in the repo market in various contexts include Krishnamurthy (2002), Goldreich et al. (2005), Musto et al. (2011), Fontaine and Garcia (2012), and Banerjee and Graveline (2013).

operations that were announced in advance, and whose total size and targeted securities were fairly predictable, might still trigger statistically significant responses in bond prices, known as pace- or flow-effects in the QE literature.

In particular, Table 9 shows results from a panel regression, motivated by the work of Jordan and Jordan (1997), in which levels of the securities' cash price premia measured at the end of the day are regressed on their repo specialness spreads as of the morning of the same day. We also control for the securities' liquidity and risk differentials through the bid-ask spread, on-the-run dummy, and maturity squared. To measure each specific security's price premium in the cash market over an otherwise identical note (i.e., a note with the same coupon rate and time to maturity), we use the deviation of its observed yield from the Svensson (1994) zero-coupon yield curve.[29] A higher spread implies that a security is more expensive than the curve would predict based on the security's fundamentals, and therefore is embodying a premium related to its specific characteristics, such as liquidity and repo financing advantages.

As shown in the first column, running this regression in the full sample produces a positive and significant coefficient on the specialness spread, confirming the results of Jordan and Jordan (1997) in our sample.[30] More importantly, this coefficient becomes larger on the days of the Fed operations, as indicated by the positive and statistically significant coefficient of the repo spread interacted with a dummy variable accounting for the operation days, shown in the second column. Finally, we split the sample into observations of securities that were

[29] The yield curve is estimated excluding on-the-run and first off-the-run Treasury securities. The deviation is computed as the predicted minus actual yield and is maintained by the staff of the Board of Governors of the Federal Reserve System.

[30] In our regressions, we include security and time fixed-effects and discard observations for which the cash price premium exceeds 50 basis points in absolute value. This threshold choice seems reasonable, since in our full sample the 1% and 99% percentiles of price premium measures are about -16 bps and 22 bps, respectively, while their 0.1% and 99.99% percentiles are -116 and 44 basis points, respectively.

Table 9: Cash Market Premium Regressions; Levels

	(1) All Days	(2) All Days	(3) Ever Eligible	(4) Never Eligible
Repo Spread	0.0458***	0.0326***	0.0335***	0.0203
	(10.26)	(6.41)	(6.43)	(1.12)
Repo Spread x Operation Day		0.0294***	0.0314***	-0.00554
		(3.60)	(3.66)	(-0.28)
Bid-Ask Spread	-0.417***	-0.416***	-0.408***	-0.668***
	(-45.77)	(-45.69)	(-45.43)	(-5.96)
On-the-run	1.191***	1.171***	1.267***	0.337*
	(17.60)	(17.41)	(16.80)	(2.01)
Maturity^2	0.229***	0.229***	0.221***	-0.885***
	(83.67)	(83.76)	(81.70)	(-11.27)
N	165535	165535	157117	8418
R^2	0.294	0.294	0.255	0.711
adj. R^2	0.289	0.289	0.250	0.674

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: t statistics in parentheses. Repo spreads are measured in basis points. Operation days are days that the Fed conducts purchases or sales. Bid-ask spreads are measured in cents. Ever eligible tracks securities that the Fed ever determines to be eligible for purchase or sale. We also control for time dummies.

'never eligible' for purchases (i.e., met the Fed's exclusion criteria mentioned in Section 2.3) and of securities that were instead eligible. The comparison of the results reported in the third and fourth columns indicates that the strengthening of the relation between the cash price premium and the repo spread on operation days is observed only in the subsample of eligible securities. This is quite striking, as the 'never eligible' category includes a higher percentage of on-the-run securities. It is worth noting that these results hold when regressions are run in changes rather than levels (not shown).

These findings suggest that the Fed asset purchase programs could affect Treasury security prices not only directly through the stock effect (e.g., D'Amico et al., 2012), but also indirectly by increasing the scarcity value of the Treasury collateral in the repo market, which translates into higher specialness spreads. These increases in the security's specialness are also reflected (and discounted) in the cash market as indicated by the higher price premia for relatively scarcer securities on the days of the actual operations. This indirect effect could be part of the so-called flow effect, the existence of which was one of the puzzling findings of D'Amico and King (2013).

4 Implications for Monetary Policy

Figure 6 plots the overnight average SC repo rate across the off-the-run (black solid line) and on-the-run (black dashed line) Treasury securities with maturity up to 10 years together with two of the most relevant overnight money market rates–the effective federal funds rate (FFR, red line) and the GCF Treasury repo rate (black dotted line). There are two relevant features worth noticing: First, the average SC repo rate for on-the-run securities provides a lower bound to these key overnight money market rates (it is the rate on loans secured by the highest quality collateral) and second, the average SC repo rate for off-the-run securities strongly commove with the GCF repo rate and the FFR (with a correlation coefficient of 98 and 87 percent, respectively), and it is always a touch below the GCF repo rate as it should be. Any investor who owns an off-the-run security that is running special does not have any incentive to lend it in the GC market instead of the SC market, as by lending it in the SC market can borrow money at a lower rate and reinvest that money in the GC market, capturing the spread between the two rates.[31]

In this study, we provided new evidence that changes in provision of public, safe, and

[31] It is also against TMPG best practices (see `http://www.newyorkfed.org/tmpg/`) to use a security that is trading special to settle a GC transaction, further enforcing the fact that the GC rate should be at least as large as the highest SC rate.

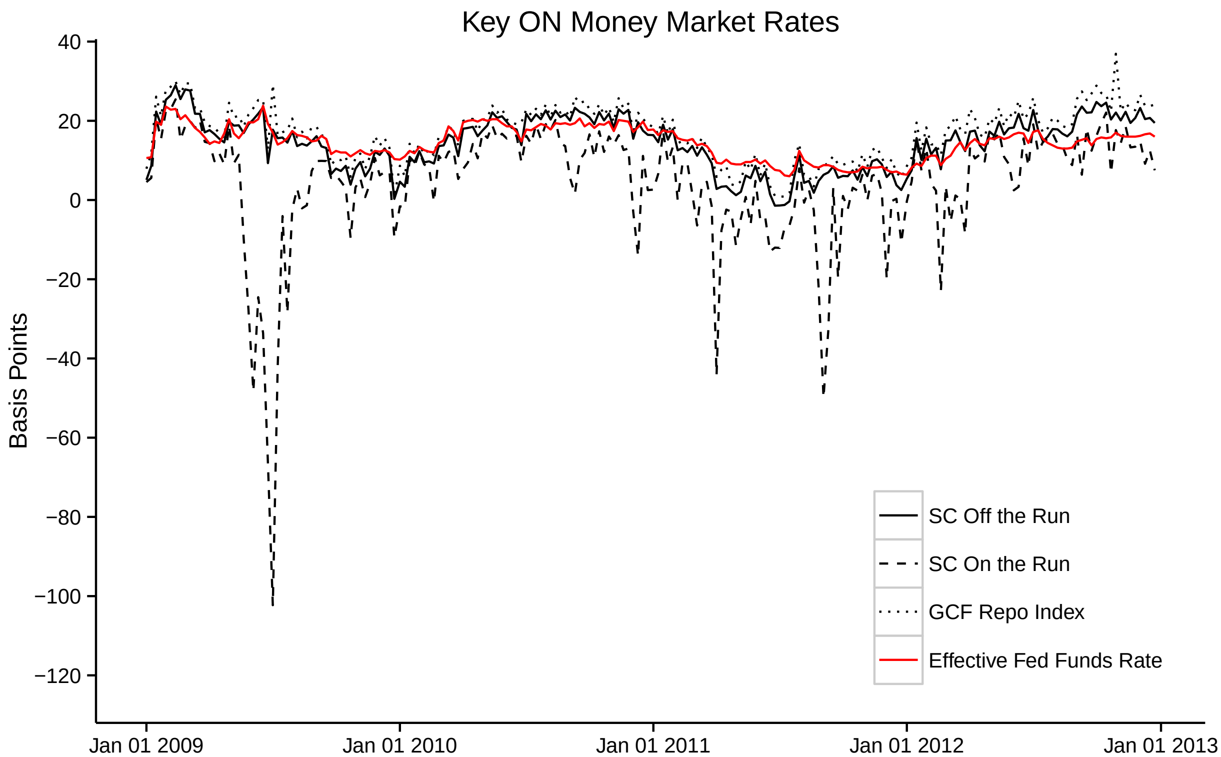

Figure 6: The graph plots four key overnight money market rates. The black solid line is the average SC repo rate across off-the-run Treasury securities with maturity up to 10 years. The black dashed line is the average SC repo rate across on-the-run Treasury securities with maturity up to 10 years. The black dotted line is the GCF Treasury repo rate and the red line is the effective federal funds rate.

liquid collateral by the Federal Reserve have affected SC repo rates for both on-the-run and off-the-run Treasury securities, *which are key ingredients for there to be potentially important implications for monetary policy.* The most direct implication of our findings is that, during the policy normalization process, if the Fed decides to gradually redeem maturing Treasury securities,[32] which has a nearly identical effect as selling those securities,[33] the larger supply of high-quality collateral should reduce the scarcity premium and push up SC repo rates of on- and off-the-run Treasury securities, putting upward pressure on strongly related money market rates such as the GC repo rate and FFR. More generally, as suggested by Figure 6, as long as the usual arbitrage relations are at work, by changing the quantity of Treasury collateral and SC repo rates of most Treasury securities, the Fed could in turn tighten control over other money market rates related to the average SC repo rate. That is, by lifting the lowest money market rate, the Fed would increase the floor for all other short rates.

Additionally, our empirical results may have important implications for other monetary policy tools, where the mechanism outlined above should become more potent as the Fed interacts directly with a broader set of counterparties, including nonbank institutions, in the repo market. In particular, differently from the LSAP/MEP operations and the SLP that were restricted to primary dealers, the Fed's overnight reverse repo (ON RRP) facility one of the tools for the policy normalization process is accessible to money market funds (MMFs) and government-sponsored enterprises (GSEs), two active players in the repo market.[34] In

[32]The FOMCs Policy Normalization Principles and Plans of September 17, 2014, state the Committee intends to reduce the Federal Reserve's securities holdings in a gradual and predictable manner primarily by ceasing to reinvest repayments of principal on securities held in the SOMA.

[33]For example, during the second MEP (used in our empirical analysis), in order to buy a larger amount of longer-term Treasury securities, the Fed suspended rolling over maturing Treasury securities into new issues at auction, as this was equivalent to selling those securities. See the MEP operating policy at `http://www.newyorkfed.org/markets/opolicy/operating_policy_120620.html`.

[34]This facility allows a wide range of market participants to deposit cash at a fixed rate in exchange for Treasury securities held in the SOMA portfolio. See `http://www.newyorkfed.org/markets/rrp_faq.html` for more information on these operations.

principle, by increasing the availability of Treasury collateral to a wider range of market participants, the Fed could be more effective in reducing the scarcity premium on this collateral, especially when the appetite for high-quality assets increases (see also Gagnon and Sack, 2014). This, in turn, should firm the floor on money market rates, ensuring a robust implementation of a floor or corridor system for the FFR.[35]

To provide some preliminary evidence in favor of the described mechanisms, it can be helpful to examine a number of pertinent aspects of the ON RRP operational tests, which started at the end of September 2013.[36] The top panel of Figure 7 shows again the FFR and the GCF Treasury repo rate this time together with the repo rate set by the Fed for the ON RRP operations. First, note that the Fed's reverse repo rate has generally been providing a floor for the other money market rates, even during quarter- and year-end periods. These are periods when the net supply of Treasury collateral decreases, likely due to risk-shifting window dressing by intermediaries, who alter portfolios at disclosure dates to underrepresent their riskiness. (e.g., Musto, 1997; Griffiths and Winters, 2005) For example, foreign banks trim borrowing against Treasury collateral to reduce the size of their balance sheets at quarter-ends, since bank capital regulations in some countries are based on assets measured at the end of each quarter. Hence, their clients, facing a reduced availability of Treasury collateral and safe investment options around these dates, can shift their demand toward the ON RRP facility. Indeed, as shown in the bottom two panels, which plot the aggregate volume and the number of participants at each ON RRP operation, take-ups and participation at this facility have spiked at the end of each quarter. Second, on September

[35] In the case of a floor system, the ON RRP rate set by the Fed should constitute an effective floor for money market rates; in the case of a corridor system, while this rate would still provide a floor, the IOER would provide the upper bound of the corridor.

[36] This testing exercise was motivated as a matter of prudent advance planning by the Federal Reserve, see the September 2013 FOMC meeting.

30, 2014, when the demand ($407 billion) was above the overall limit of $300 billion (whose introduction is marked by the vertical dashed line), the Treasury GCF rate dropped below the ON RRP offering rate. That is, scarcity of collateral was binding and the ON RRP rate failed to provide a floor. Lastly, take-up increased significantly and hovered near $200 billion around the tax date of April 15, 2014, when Treasury bill issuance was down due to the Treasurys reduced borrowing needs (as it is usually the case during most tax seasons), and investors apparently substituted their demand for Treasury bills with demand for Fed ON RRPs. This prevented the GCF repo rate from falling below the ON RRP rate for the entire period.

Overall, these potentially beneficial effects of the ON RRP facility mainly arise from the increased availability of very safe and liquid assets to investors in the Triparty system. And, even if, unlike the LSAP and MEP operations used in our empirical study, the ON RRP facility prevents the reuse of collateral outside the Triparty system, it can still tighten the arbitrage relations between the Triparty and bilateral repo rates by affecting the activity of investors (such as dealers) that are present in both markets. In other words, the strengthening of the link between the average SC repo rate for on-the-run securities, the average SC repo rate for off-the-run securities, the GC repo rate, and the FFR can happen, for example, through the following channels.

First, since the Fed is engaging directly with MMFs and GSEs in repos against Treasury collateral, it is effectively removing their activity from dealer balance sheets, this can allow dealers to increase the balance sheet space dedicated to investors that do not have access to the ON RRP facility, increasing the availability of Treasury collateral in the bilateral repo market at a rate close to (but above) the ON RRP rate. For example, dealers could increase the balance sheet space dedicated to bilateral transactions with hedge funds that do not have

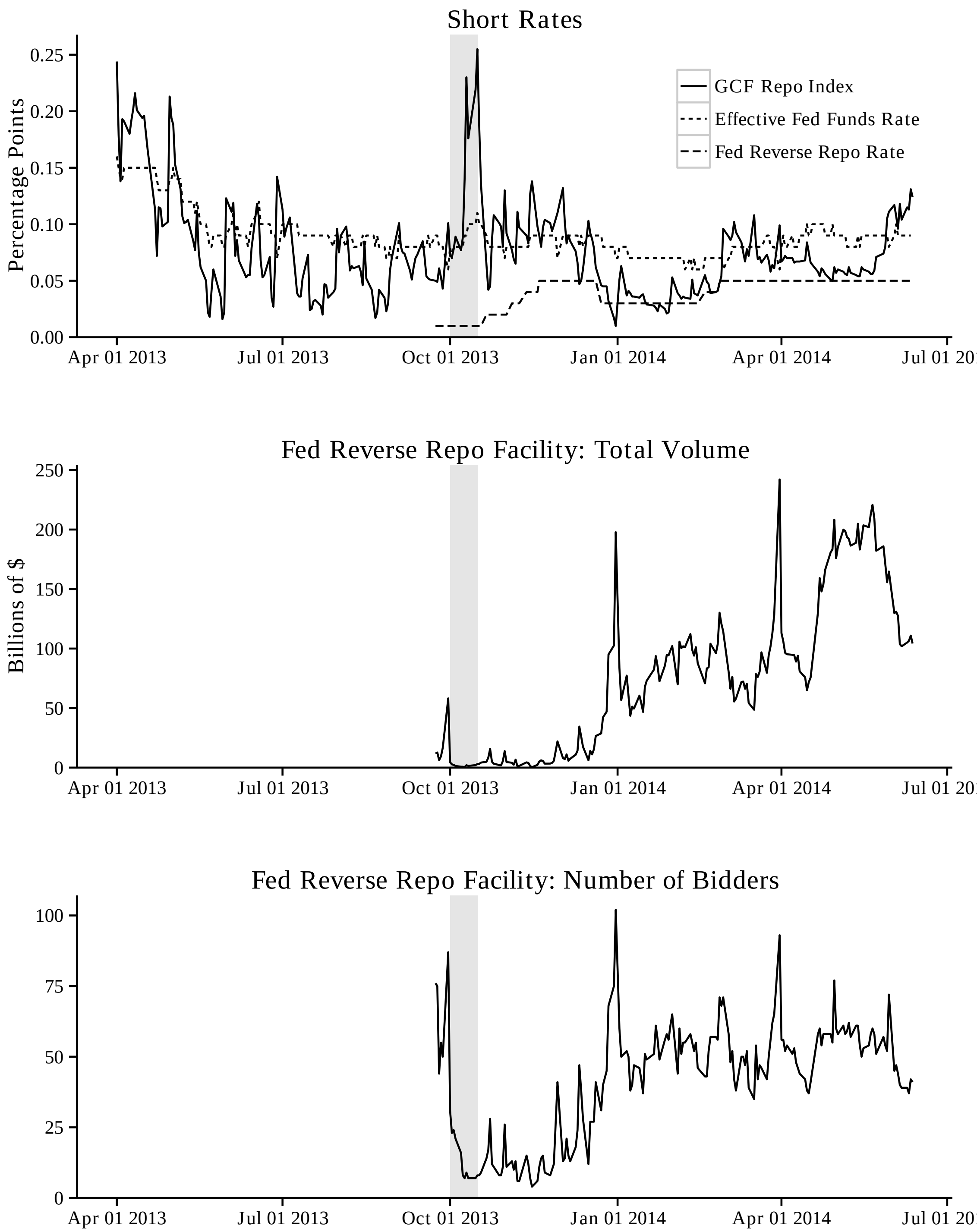

Figure 7: The top panel shows two money market rates together with the rate offered at the Fed's reverse repo facility. The bottom two panels show some of this facility's summary statistics. The shaded area denotes the U.S. government shutdown of 2013. The vertical dashed line in the top panel indicates the time of the introduction of a $300 billion cap on the total daily operation size. The cap's size is indicated by the horizontal dashed line in the middle panel.

access to the ON RRP facility but would like to obtain high-quality collateral to post margin at the central clearinghouses for their OTCD. Second, since dealers can obtain additional Treasury GC at the ON RRP facility, even if this collateral can be reused only within the Triparty system, it still allows them to free inventory space and save the higher quality collateral (e.g., on-the-run and shorter-term Treasury securities) for SC repos with other dealers for the purpose of hedging and shorting, making these activities less costly and again enhancing the link between Triparty and bilateral repo markets. Overall, the Fed entering the repo market directly can lead to dealer banks undertaking more collateral transformation, which is substituting cash on their balance-sheet with RRP general collateral, and RRP general collateral with the highest-quality specific collateral, tightening the links between the GC and SC repo markets and their corresponding rates. Similarly to the MEP operations used in our empirical experiment, which replaced longer-term Treasury securities with shorter-term ones (i.e., securities with less than 3 years to maturity) in investors portfolios, dealers collateral-transformation activity is nothing more than a temporary increase in the available supply of high-quality collateral that reduces the scarcity premium embedded in the SC repo rates, as shown in our results.

5 Conclusion

In this study, we use security-level data to estimate the impact of changes in the demand and supply of Treasury collateral on the SC repo rates of all outstanding U.S. nominal Treasury securities. We find that quantity effects are economically and statistically significant in the SC repo market. Specifically, we estimate that a one-billion-dollar reduction in the available supply of Treasury collateral can increase its scarcity value by 0.3 to 1.8 basis points depending on the security's characteristics, with the larger effects concentrated in on-the-run and shorter-term securities. Since quantity variation in our sample comes mostly from purchased and sold amounts of Treasury securities under various Fed programs, our results provide further support for the scarcity channel of QE, and can help evaluate the impact of a gradual reduction of the Fed's securities holdings during the policy normalization process.

Since changes in quantities affect the SC repo rate not only of on-the-run but also off-the-run securities, it is reasonable to conclude that, in the Treasury market, the scarcity effect is a widespread phenomenon and is not confined just to a few "special" securities. Thus, these changes in quantities by the Fed, being relevant for the SC repo rates of many Treasury securities outstanding, can also affect the Treasury GC repo rate, and other money market rates through arbitrage relations. This implies that the Fed's changes in the available supply of Treasury collateral, by influencing the lowest money market rates (SC repo rates), can move the floor for key money market rates, ensuring a better implementation of monetary policy. At the same time, they could also affect the volatility in money markets. For example, an increase in the availability of high-quality collateral could prevent near-zero or negative SC and GC repo rates, mitigating downward fluctuations in money market rates.

Overall, we provide new evidence that changes in provision of public, safe, and liquid collateral by the Fed have affected the average Treasury SC repo rate, which can have potentially important implications for monetary policy. And, in the previous section, we discussed in more detail how our results can be used to think about monetary policy implementation during the normalization process. That discussion was not meant to provide a definite answer regarding the efficacy of new monetary policy tools, such as the ON RRP facility, and the sample is still too small for in-depth empirical analysis. However, we do think that this topic deserves further investigation, and that the type of analysis presented in this paper is well suited to evaluate some of the tools available to the Fed when implementing monetary policy with a very large balance sheet. This is crucial for understanding the issues surrounding the process of policy normalization and we leave it to future research.

References

Adrian, Tobias, Brian Begalle, Adam Copeland, and Antoine Martin, 2011, Repo and securities lending, Staff Report 529, Federal Reserve Bank of New York, Retrieved from `http://www.nyfedeconomists.org/research/staff_reports/sr529.pdf`.

Ajello, Andrea, Luca Benzoni, and Olena Chyruk, 2012, No-arbitrage restrictions and the U.S. Treasury market, *Economic Perspectives* 36, 55–74, Federal Reserve Bank of Chicago.

Banerjee, Snehal, and Jeremy J. Graveline, 2013, The cost of short-selling liquid securities, *Journal of Finance* 68, 637–664.

Bartolini, Leonardo, Spence Hilton, Suresh Sundaresan, and Christopher Tonetti, 2011, Collateral values by asset class: Evidence from primary securities dealers, *Review of Financial Studies* 24, 248–278.

Brandt, Michael W., and Kenneth A. Kavajecz, 2004, Price discovery in the U.S. Treasury market: The impact of orderflow and liquidity on the yield curve, *Journal of Finance* 59, 2623–2654.

Buraschi, Andrea, and Davide Menini, 2002, Liquidity risk and specialness, *Journal of Financial Economics* 64, 243–284.

Burne, Katy, 2015, Pressure in repo market spreads, *Wall Street Journal*, `http://www.wsj.com/articles/pressure-in-repo-market-spreads-1428013415`.

Cahill, Michael E., Stefania D'Amico, Canlin Li, and John S. Sears, 2013, Duration risk versus local supply channel in Treasury yields: Evidence from the Federal Reserve's asset purchase announcements, Working Paper 35, Finance and Economics Discussion Series, Board of Governors of the Federal Reserve System.

Cherian, Joseph A., Eric Jacquier, and Robert A. Jarrow, 2004, A model of the convenience yields in on-the-run Treasuries, *Review of Derivatives Research* 7, 79–97.

Committee on the Global Financial System, May 2013, Asset encumbrance, financial reform and the demand for collateral assets, *CGFS Papers* 49.

Copeland, Adam, Isaac Davis, Eric Lesueur, and Antoine Martin, 2014, Lifting the veil on the U.S. bilateral repo market, `http://libertystreeteconomics.newyorkfed.org/2014/07/lifting-the-veil-on-the-us-bilateral-repo-market.html`.

D'Amico, Stefania, William English, David López-Salido, and Edward Nelson, 2012, The Federal Reserve's large-scale asset purchase programmes: Rationale and effects, *The Economic Journal* 122, 415–446.

D'Amico, Stefania, and Thomas B. King, 2013, Flow and stock effects of large-scale Treasury purchases: Evidence on the importance of local supply, *Journal of Financial Economics* 108, 425–448.

Duffie, Darrell, 1996, Special repo rates, *Journal of Finance* 51, 493–526.

Duffie, Darrell, Nicolae Gârleanu, and Lasse Heje Pedersen, 2002, Securities lending, shorting, and pricing, *Journal of Financial Economics* 66, 307–339.

Duffie, Darrell, Nicolae Gârleanu, and Lasse Heje Pedersen, 2007, Valuation in over-the-counter markets, *Review of Financial Studies* 20, 1865–1900.

Eldor, Rafi, Shmuel Hauser, Michael Kahn, and Avraham Kamara, 2006, A search-based theory of the on-the-run phenomenon, *Journal of Business* 79, 2067–2097.

Elton, Edwin J., and T. Clifton Green, 1998, Tax and liquidity effects in pricing government bonds, *Journal of Finance* 53, 1533–1562.

Fisher, Mark, 2002, Special repo rates: An introduction, *Economic Review* 87, 27–43, Federal Reserve Bank of Atlanta.

Fleming, Michael, Frank Keane, Antoine Martin, and Michael McMorrow, 2014, What explains the June spike in Treasury settlement fails?, `http://libertystreeteconomics.newyorkfed.org/2014/09/what-explains-the-june-spike-in-treasury-settlement-fails.html`.

Fleming, Michael J., 2002, Are larger Treasury issues more liquid? Evidence from bill reopenings, *Journal of Money, Credit and Banking* 34, 707–735.

Fleming, Michael J., and Kenneth D. Garbade, 2003, The repurchase agreement refined: GCF Repo®, *Current Issues in Economics and Finance* 9, Federal Reserve Bank of New York.

Fleming, Michael J., and Kenneth D. Garbade, 2004, Repurchase agreements with negative interest rates, *Current Issues in Economics and Finance* 10, Federal Reserve Bank of New York.

Fleming, Michael J., and Kenneth D. Garbade, 2007, Dealer behavior in the specials market for US Treasury securities, *Journal of Financial Intermediation* 16, 204–228.

Fleming, Michael J., Warren B. Hrung, , and Frank M. Keane, 2010, Repo market effects of the Term Securities Lending Facility, Staff Report 426, Federal Reserve Bank of New York, Retrieved from http://www.newyorkfed.org/research/staff_reports/sr426.pdf.

Fleming, Michael J., Neel Krishnan, and Adam V. Reed, 2012, The effects of Treasury fails charge on market functioning, Working Paper.

Fleming, Michael J., and Joshua V. Rosenberg, 2007, How do Treasury dealers manage their positions?, Staff Report 299, Federal Reserve Bank of New York, Retrieved from http://www.newyorkfed.org/research/staff_reports/sr299.pdf.

Fontaine, Jean-Sebastien, and Rene Garcia, 2012, Bond liquidity premia, *Review of Financial Studies* 25, 1207–1254.

Goldreich, David, Bernd Hanke, and Purnendu Nath, 2005, The price of future liquidity: Time-varying liquidity in the U.S. Treasury market, *Review of Finance* 9, 1–32.

Gorton, Gary, and Andrew Metrick, 2012, Securitized banking and the run on repo, *Journal of Financial Economics* 104, 425–451.

Graveline, Jeremy J., and Matthew R. McBrady, 2011, Who makes on-the-run Treasuries special?, *Journal of Financial Intermediation* 20, 620–632.

Greenwood, Robin, 2005, Short- and long-term demand curves for stocks: Theory and evidence on the dynamics of arbitrage, *Journal of Financial Economics* 75, 607–649.

Greenwood, Robin, and Dimitri Vayanos, 2013, Bond supply and excess bond returns, *Review of Financial Studies* Forthcoming.

Griffiths, Mark D., and Drew B. Winters, 2005, The turn of the year in money markets: Tests of the riskshifting window dressing and preferred habitat hypotheses, *Journal of Business* 78, 1337–1364.

Gromb, Denis, and Dimitri Vayanos, 2010, Limits of arbitrage: The state of the theory, Working Paper 15821, National Bureau of Economic Research, Retreived from `http://www.nber.org/papers/w15821`.

Heller, Daniel, and Nicholas Vause, June 2011, Expansion of central clearing, *BIS Quarterly Review* .

Jordan, Bradford D., and Susan D. Jordan, 1997, Special repo rates: An empirical analysis, *Journal of Finance* 52, 2051–2072.

Kaul, Aditya, Vikas Mehrotra, and Randall Morck, 2000, Demand curves for stocks do slope down: New evidence from an index weights adjustment, *Journal of Finance* 55, 893–912.

Keane, Frank, 1995, Expected repo specialness costs and the Treasury auction cycle, Research Paper 9504, Federal Reserve Bank of New York, Retrieved from `http://www.newyorkfed.org/research/staff_reports/research_papers/9504.pdf`.

Krishnamurthy, Arvind, 2002, The bond/old-bond spread, *Journal of Financial Economics* 66, 463–506.

Krishnamurthy, Arvind, and Annette Vissing-Jorgensen, 2011, The effects of quantitative easing on interest rates: Channels and implications for policy, Working Paper 17555, National Bureau of Economic Research, Retrieved from `http://www.nber.org/papers/w17555`.

Longstaff, Francis A., 2000, Arbitrage and the Expectations Hypothesis, *Journal of Finance* 55, 989–994.

Lopez, Jorge Cruz, Royce Mendes, and Harri Vikstedt, 2013, The market for collateral: The potential impact of financial regulation, *Financial System Review* 45–53, Bank of Canada.

Lou, Dong, Hongjun Yan, and Jinfan Zhang, 2013, Anticipated and repeated shocks in liquid markets, *Review of Financial Studies* 26, 1891–1912.

Martin, Antoine, James McAndrews, Ali Palida, and David Skeie, 2013, Federal Reserve tools for managing rates and reserves, Staff Report 642, Federal Reserve Bank of New York, Retrieved from `http://www.newyorkfed.org/research/staff_reports/sr642.pdf`.

Mazzoleni, Michele, 2013, Treasury yields and auction cycle management, Job Market Paper.

Moulton, Pamela C., 2004, Relative repo specialness in U.S. Treasuries, *Journal of Fixed Income* 14, 40–47.

Musto, David K., 1997, Portfolio disclosures and year-end price shifts, *Journal of Finance* 52, 1563–1588.

Musto, David K., Greg Nini, and Krista Schwarz, 2011, Notes on bonds: Liquidity at all costs in the Great Recession, Working paper, Retrieved from `http://www.fma.org/Napa/Papers/Notes_on_Bonds.pdf`.

Nautz, Dieter, 1997, How auctions reveal information: A case study on German REPO rates, *Journal of Money, Credit and Banking* 29, 17–25.

Potter, Simon, 2013, Recent developments in monetary policy implementation, Speech delivered before the Money Marketeers of New York University, New York City, December

2. Available at `http://www.newyorkfed.org/newsevents/speeches/2013/pot131202.html`.

Pozsar, Zoltan, 2014, Shadow banking: The money view, Working Paper 2014-04, Office of Financial Research.

Shleifer, Andrei, 1986, Do demand curves for stocks slope down?, *Journal of Finance* 41, 579–590.

Singh, Manmohan, 2014, *Collateral and Financial Plumbing* (Risk Books).

Sundaresan, Suresh, 1994, An empirical analysis of U.S. Treasury auctions: Implications for auction and term structure theories, *Journal of Fixed Income* 4, 35–50.

Sundaresan, Suresh, and Zhenyu Wang, 2009, Y2K options and the liquidity premium in Treasury markets, *Review of Financial Studies* 22, 1021–1056.

Svensson, Lars E.O., 1994, Estimating and interpreting forward interest rates: Sweden 1992-1994, Working Paper 4871, National Bureau of Economic Research, Retreived from `http://www.nber.org/papers/w4871`.

Vayanos, Dimitri, and Pierre-Olivier Weill, 2008, A search-based theory of the on-the-run phenomenon, *Journal of Finance* 63, 1361–1398.

Wurgler, Jeffrey, and Ekaterina Zhuravskaya, 2002, Does arbitrage flatten demand curves for stocks?, *Journal of Business* 75, 583–608.