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

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Abstract

In the special 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 should not play any role once contracts are established. In the special 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. 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. This 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.

[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 few days.

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.[2] Exploiting 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 purchased and sold amounts of Treasury securities under various Federal Reserve (Fed) programs.[3] Since these programs were targeting yields in the Treasury cash market rather than the repo market, it is safe to assume that they were not directly responding to changes in SC repo rates and are therefore exogenous. 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 a lower bound on the total supply effect; this bound is shown to be significant and quite persistent.

The estimated average elasticities of SC repo rates to collateral supply factors capture how the borrowing cost of a loan collateralized by a specific bond changes as that bond becomes more or less scarce. Therefore, these elasticities should measure the portion of the repo rate that is solely due to changes in the scarcity of the underlying collateral (i.e.,

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

[3] 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.

its scarcity value) and not other idiosyncrasies of the specific security such as a change in liquidity and/or credit quality. This is also ensured by explicitly controlling for security-level measures of liquidity such as the bid-ask spread and proxies for interest rate risk exposure such as maturity. Finally, we estimate separate effects for on- and off-the-run securities.

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, implying an average effect of -0.8 and -0.3 basis points per billion dollars, respectively. 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* since they must lend money at relatively lower interest rates. In addition, these impacts are larger in shorter-term securities, with an average effect of -1.8 and -0.5 basis points per billion dollars, for on- and off-the-run securities, respectively. The estimated effects are quite persistent, staying significant for about three months. Conversely, the coefficient on the amount of off-the-run securities sold at the Fed's operations is positive and significant, implying an average effect of 0.2 basis points per billion dollars. This indicates that an increase in the available supply of Treasury securities pushes repo rates up (and specialness spreads down).

Our estimates also suggest that this SC repo scarcity premium passes through to Treasury cash market prices, explaining how perfectly anticipated changes in supply can still affect Treasury prices when they occur. As shown by Duffie (1996) and confirmed by Jordan and Jordan (1997) and Buraschi and Menini (2002), bonds that trade special in the repo market should trade at a premium in the cash market.[4] Since we show that part of this repo

[4]Other important studies that examine the relationship between price differentials in the Treasury cash market and funding conditions in the repo market in various contexts include Krishnamurthy (2002), Gol-

scarcity premium originates from the Fed purchase operations and is priced in the Treasury cash premium, our results provide additional evidence in favor of the scarcity channel of quantitative easing (QE) (e.g., Krishnamurthy and Vissing-Jorgensen, 2011; D'Amico et al., 2012).

Our findings also have potentially important implications for both the future conduct of monetary policy through the overnight reverse repo facility and the Treasury's management of the auction cycles of its securities.[5] Since the Fed intends to use overnight reverse repos as a supplementary policy tool to help control the federal funds rate during the normalization process, 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 suggest that, indeed, by changing the net supply of Treasury collateral, the Fed's reverse repos could potentially be successful in both controlling money market rates and alleviating shortages of high-quality collateral.[7] Regarding Treasury auction cycle management, our results indicate that available options such as increasing the issuance at auction and/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

dreich et al. (2005), Musto et al. (2011), Fontaine and Garcia (2012), and Banerjee and Graveline (2013).

[5]The September 2013 FOMC meeting authorized the New York Fed to start operational tests of fixed-rate overnight reverse repos. 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.

[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.

(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. In Section 3 we estimate the pass-through of the repo scarcity premium to Treasury cash prices. And Section 4 concludes.

1 Data Background and Description

1.1 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 or special collateral (SC) repos the contract is specific to the particular asset that serves as collateral.[9] In this study, we limit our attention to Treasury collateral. The Treasury repo market is a vast market where the high quality of the collateral attracts many market participants and over the past decades has grown dramatically in size and popularity.[10]

In particular, GC repos are used by dealers and other levered accounts (such as hedge

[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.

[9]For more details on the special collateral repo market see Fisher (2002).

[10]For example, as of November 14, 2013, the total amount of U.S. Treasury overnight repos and reverse repos entered into by primary dealers was about $1.6 trillion (FR-2004 data); for comparison, the average daily traded volume in the Treasury cash market over the week ending on November 6 was about $500 billion.

funds) as an inexpensive way to fund much of their activity. Money market mutual funds, corporate treasuries, and municipalities are among the most frequent cash providers in this market, as GC repos represent a relatively safe and liquid money-market instrument (Gorton and Metrick, 2012).

SC repos are used by dealers and hedge funds to establish short positions (Duffie, 1996), that is, to borrow a specific security, which they then sell short in the secondary market in anticipation of a price reduction by the settlement date. However, as pointed out in Vayanos and Weill (2008), when choosing in which securities to establish these positions, short-sellers also consider other factors such as the cost of borrowing the security (SC repo rate) and the future ability to deliver the asset back, which in turn depends on the security's future liquidity and available supply. These factors should be reflected in the current cash prices and repo rates. Once the SC repo contract is established, given that short-sellers must deliver the same asset they borrowed, if some of these factors change differently than expected, then the prices in the cash and repo market will adjust. For example, if the effective supply of the borrowed security declines more than expected, say due to a LSAP purchase operation, then the short-seller could face higher prices in the cash market that might reduce his willingness to deliver back the security, and perhaps increase his willingness to roll over the repo position. And the higher scarcity of the security may induce collateral lenders to extract higher rental fee from short sellers.

Mutual and pension funds, custodial agents, and other owners of Treasury securities can borrow cash at an advantageous rate by lending specific securities in the SC repo market, and eventually re-lend the money at a higher GC repo rate, capturing the spread between the two rates. 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).

Overall, the 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 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.

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 bilateral and 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.

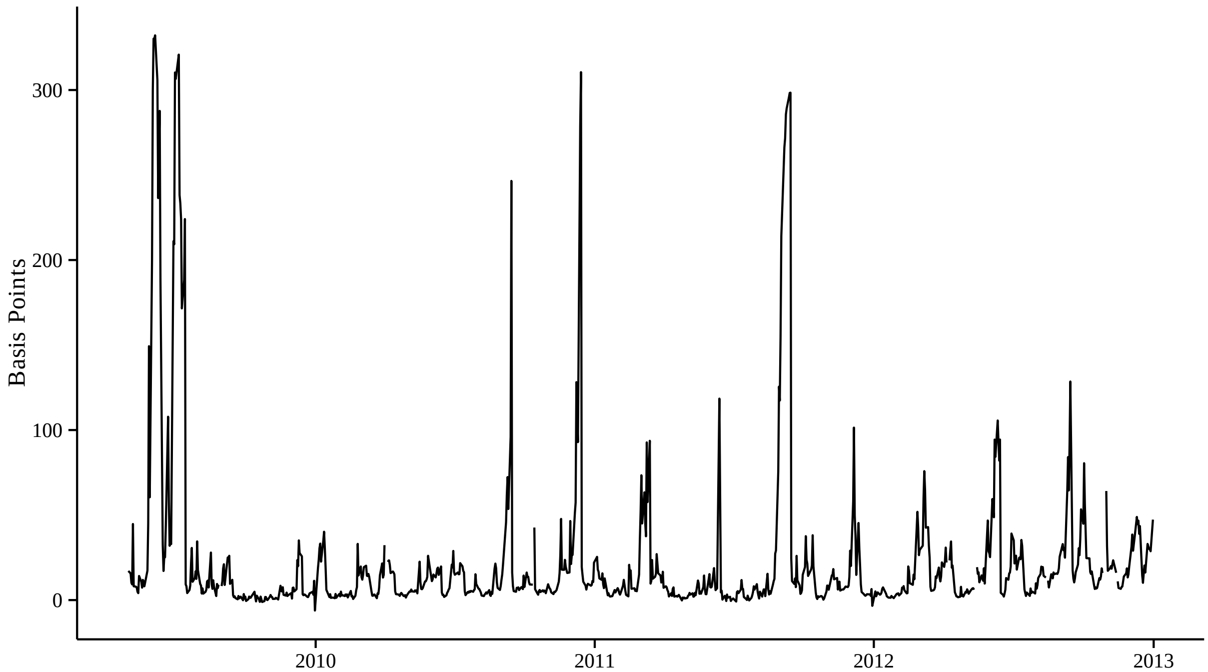

Figure 1: Repo specialness spread for the on-the-run 10-year Treasury security.

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 mean 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 purchased amounts in this maturity sector, shows that the repo specialness spreads tended to be higher and more volatile in periods when LSAP purchases were larger, while they seemed lower and less volatile from October 2009 and October 2010 when there were no asset purchases. Interestingly, as discussed in the New York Fed's Liberty Street Economics blog on September 19, 2014, the data provided by the Depository Trust & Clearing Corporation (DTCC) show that the 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 two data sources for Treasury GC repo rates. The first source is 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 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. The second source for the Treasury GC repo rate is the daily survey of primary dealers conducted by the New York Fed. Dealers are instructed to report overnight GC repo activity with non-affiliated entities such as money market funds (Bartolini et al., 2011). The survey does not specify the market segment in which dealers' repo transactions take place, thus the data capture tri-party, GCF and bilateral transactions.

Since results are very similar using both the GCF and GC repo rates, we only report those based on the GCF repo rate as the primary dealer survey data are restricted.[13] Overall, in this study, the specialness spread is mainly used for graphical purposes and comparisons to previous studies, as time dummies in our specification control for market-wide effects such as variation in the GC repo rate.

[11] The Liberty Street Economics blog post is titled "What explains the June Spike in Treasury Settlement Fails?", by Michael Fleming, Frank Keane, Antoine Martin, and Michael McMorrow. Available at `http://libertystreeteconomics.newyorkfed.org/2014/09/what-explains-the-june-spike-in-treasury-settlement-fails.html#.VJSfR2cAAA`.

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

[13] For more detail about the differences between GC repo rate and the GCF Repo see Fleming and Garbade (2003).

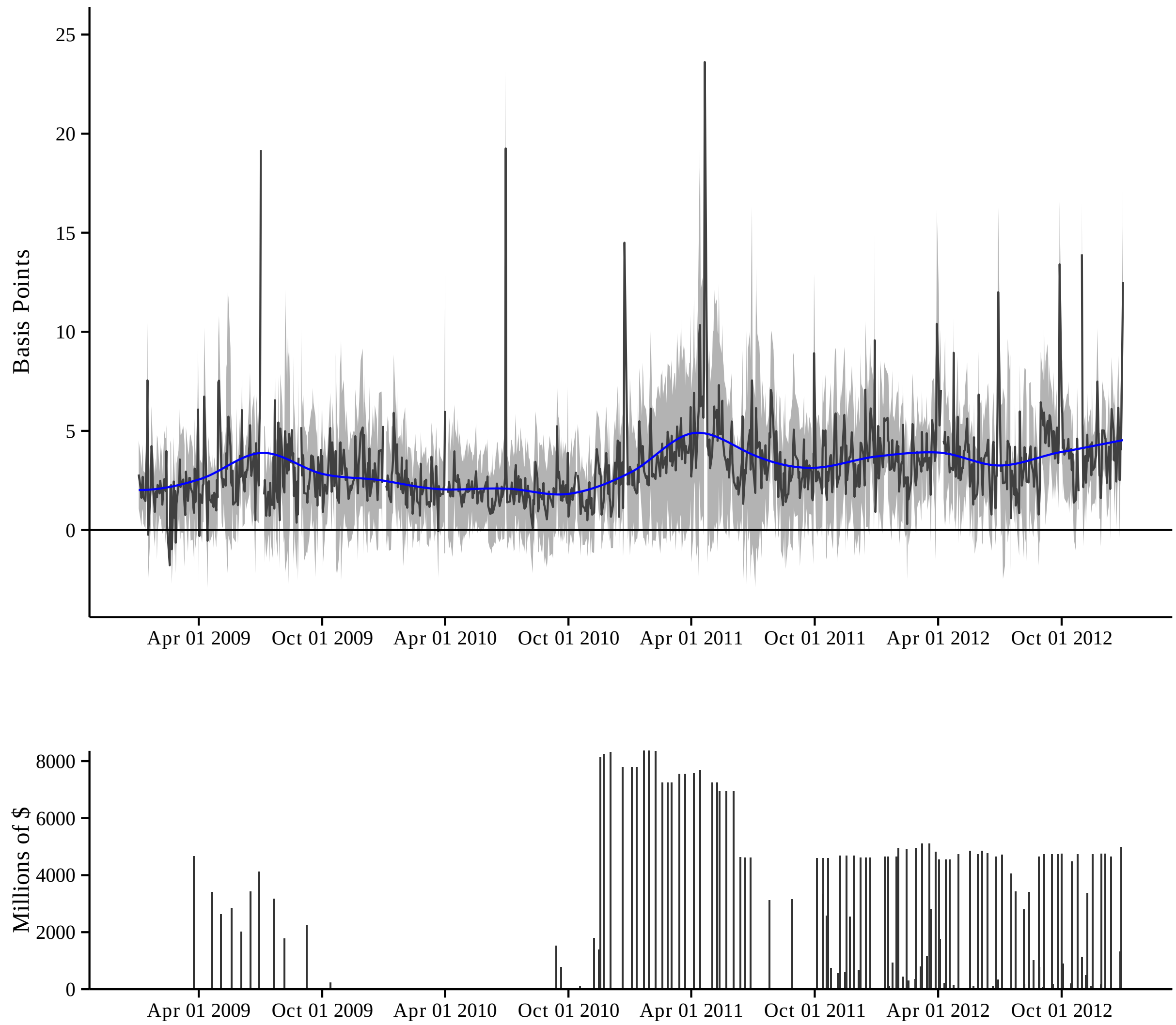

Figure 2: The top panel shows the daily average repo spread across off-the-run securities with remaining maturities of 7 to 10 years. The shaded region shows one standard deviation of the daily cross-section of repo spreads. The blue line shows a fitted LOESS curve to the averages. The bottom panel shows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

1.3 Federal Reserve Operations

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 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

[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	

Amounts bought and sold are measured in dollars.

(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 sales of 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 has constraints on 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.

[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 announcement date (when-issued trading opens), 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 repo specialness 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) for securities with a monthly auction cycle. 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

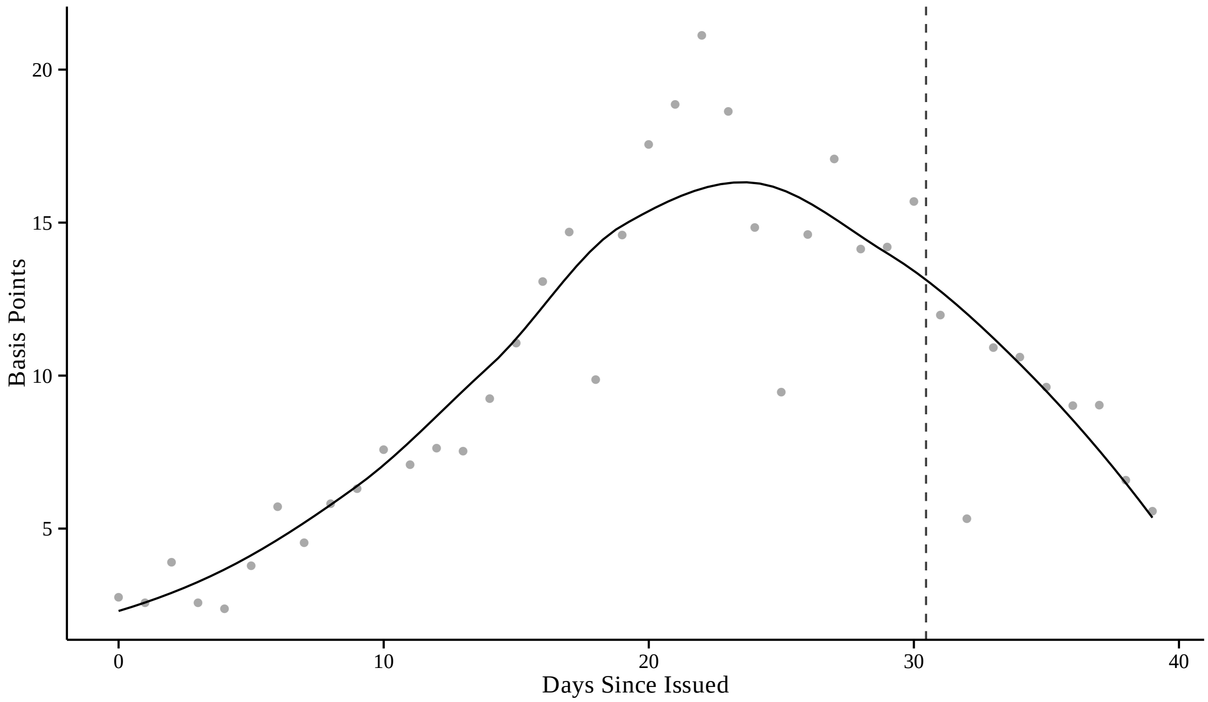

Figure 3: Average daily repo specialness spread for Treasury securities with a 1-month auction cycle (2-, 3-, 5-, and 7-year maturities). Grey dots are the average specialness spread on each day since the issue date, and the line is a fitted LOESS curve. The vertical dashed line marks the average time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

sub-cycle the specialness spread is practically 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.

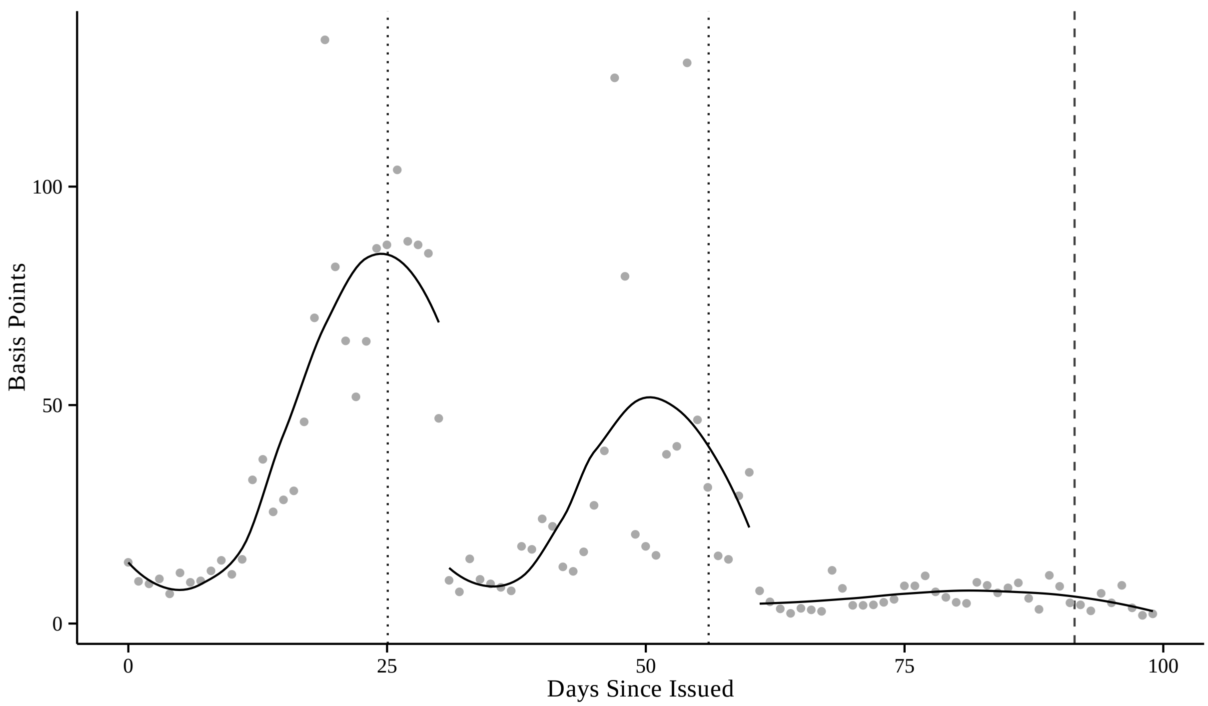

Figure 4: Average daily repo specialness spread for 10-year Treasury securities. Grey dots are the average specialness spread on each day since the issue date, and the line is a fitted LOESS curve. Vertical dotted lines mark the average times of reopening auctions, while the vertical dashed line denotes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

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 by the New York Fed.

Table 2: Summary Statistics - Operation Days

	On-The-Run		Off-The-Run		Total	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
repo_avgrate	5.6	21.8	14.2	7.49	14	8.21
delta_repo	-.213	6.75	.0177	2.97	.0123	3.11
repo_spread	11.1	20.9	2.77	3.29	2.97	4.72
delta_repo_spread	.152	6.65	-.0821	2.73	-.0766	2.88
repo_volume_sprd_std	-.261	3.33	-.0264	.91	-.0319	1.03
bidaskspread	1.35	.559	3.15	2.42	3.1	2.41
delta_bidaskspread	.0027	.574	-.00573	.921	-.00553	.914
N	2029		85308		87337	

SC repo rates and repo specialness spreads are measured in basis points.
Repo volume spreads are standardized and measured in standard deviations.
Bid-ask spreads are measured in cents.

2 Empirical Results

We now turn to estimating the impact of the previously described security-specific demand and supply factors on SC repo rates (and repo specialness spreads) through a series of panel regressions. Various empirical specifications are estimated at a daily frequency where the dependent variable is the change in either the SC repo rate or the specialness spread for all outstanding nominal Treasury coupon securities.[19] 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

[19]Only regressions using the SC repo rate are shown here. All of the results using the specialness spreads are shown in Appendix A.

this is based on the time at which repo rates are collected 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 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 make sure to start out sample after the introduction of a repo fail charge by the Treasury Market Practices Group on May 1, 2009 to avoid a structural break in the series.[20] However, 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:

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

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

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.

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 changes in the SC repo rate and specialness spread as dependent variables 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.

The above specification is estimated using only days when Fed operations were conducted.[21]

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

2.2 Results

The results from the SC repo rate panel regression 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.[22,23] 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 purchases. The coefficient of -0.227 suggests that buying one percent of a security's outstanding par value 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. And owners of that security would obtain financing at a more attractive rate, enjoying an extra profit. The coefficients for the same variables 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

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

[23]In our regressions, we discard observations for which the 1-day change in the SC repo rate exceeds 40 basis points or the 2-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	(2) d2_repo
percent_bought_offtherun	-0.0843***	-0.106***
	(-6.54)	(-6.40)
percent_sold_offtherun	0.0489***	0.0551***
	(3.96)	(5.43)
percent_bought_ontherun	-0.227***	-0.270***
	(-4.51)	(-3.68)
percent_sold_ontherun	-0.170	-0.141
	(-0.41)	(-0.24)
repo_volume_sprd_std	-0.0370*	-0.0268
	(-2.21)	(-1.22)
delta_bidaskspread	0.00325	0.00119
	(0.52)	(0.15)
SLP_pct_uncovered_on	-0.00925	0.0457
	(-0.27)	(1.19)
SLP_pct_uncovered_off	-0.00312	0.00483
	(-0.97)	(1.30)
maturity	0.0156***	0.0175**
	(3.41)	(3.16)
maturity2	-0.00103**	-0.00118**
	(-3.02)	(-2.92)
N	87337	86551
R^2	0.735	0.737
adj. R^2	0.733	0.736

Heteroskedasticity-consistent t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

the SC repo rate by 0.2 basis points. The cumulative impact is again slightly bigger on the settlement day. None of the other variables shown, except for maturity, are statistically significant. One possible explanation for the lack of significance of the SLP coefficient is that, as explained in Section 1.3, each dealer's participation is capped, making this tool less effective in releasing demand pressure.

The demand for short positions (*repo_volume_sprd*) has a negative and statistically significant impact on SC repo rates, although the coefficient's size is much smaller than that one of the Fed purchases. In this case, the split in on- and off-the-run securities (not shown) does not affect its magnitude.

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 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

Table 4: SC Repo Rate Regressions; 1-day Changes

	(1) 0-3 Years	(2) 3-7 Years	(3) 7-15 Years
percent_bought_offtherun	-0.138**	-0.0697***	-0.0766***
	(-3.24)	(-3.51)	(-3.42)
percent_sold_offtherun	0.0463***		
	(3.78)		
percent_bought_ontherun	-0.553***	-0.101**	-0.405
	(-3.98)	(-3.19)	(-0.92)
percent_sold_ontherun	-0.303		
	(-0.62)		
repo_volume_sprd_std	-0.0781*	-0.0273	0.0101
	(-2.56)	(-1.26)	(0.29)
delta_bidaskspread	0.0117	0.00411	-0.0125
	(1.19)	(0.40)	(-0.85)
SLP_pct_uncovered_on	-0.00543	-0.128	0.00723
	(-0.12)	(-1.17)	(0.13)
SLP_pct_uncovered_off	-0.00395*	0.0111	0.00557
	(-2.05)	(0.16)	(0.41)
maturity	0.0935**	-0.00608	0.00491
	(2.95)	(-0.07)	(0.07)
maturity2	-0.0186*	0.00156	-0.000246
	(-2.11)	(0.18)	(-0.08)
N	45886	30194	11257
R^2	0.766	0.749	0.641
adj. R^2	0.764	0.745	0.625

Heteroskedasticity-consistent t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: SC Repo Rate Regressions; 2-day Changes

	(1) 0-3 Years	(2) 3-7 Years	(3) 7-15 Years
percent_bought_offtherun	-0.212***	-0.0834***	-0.0869***
	(-3.52)	(-3.53)	(-3.49)
percent_sold_offtherun	0.0538***		
	(5.26)		
percent_bought_ontherun	-0.625**	-0.119*	0.119
	(-3.07)	(-2.20)	(0.26)
percent_sold_ontherun	-0.349		
	(-0.51)		
repo_volume_sprd_std	-0.0688	-0.0509*	0.0718
	(-1.50)	(-2.28)	(1.56)
delta_bidaskspread	0.00241	0.00304	0.00769
	(0.20)	(0.24)	(0.39)
SLP_pct_uncovered_on	0.0625	0.0475	0.0306
	(1.28)	(0.52)	(0.46)
SLP_pct_uncovered_off	-0.000236	0.104	0.0142
	(-0.08)	(1.90)	(0.72)
maturity	0.145***	0.0655	0.170
	(3.79)	(0.51)	(1.92)
maturity2	-0.0293**	-0.00550	-0.00735
	(-2.66)	(-0.44)	(-1.88)
N	45474	29963	11114
R^2	0.775	0.745	0.648
adj. R^2	0.773	0.741	0.632

Heteroskedasticity-consistent t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

bit bigger.

2.3 Robustness Checks

Our main assumption for the existence and, more importantly, for the persistence of a significant scarcity effect is that, unlike the Treasury cash market, in the Treasury SC repo market substitution across securities is precluded by the contract specification. To provide additional evidence for this assumption we also control for the amount of purchases of each security's potential substitutes. If our assumption is correct, changes in quantities of securities with very similar characteristics should not affect the SC rate of that particular security.

For a given security, we construct this variable by taking a weighted sum of the purchase amounts $purc_{it}$ of similar securities. For a security i at time t with remaining maturity m_{it},

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

where h is a bandwidth parameter. W is a weight function, which we choose to be the tricube 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.[24]

To more easily compare these coefficients, we scale the amount of substitutes as a per-

[24] 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.

centage of the security i's amount outstanding.[25] So

$$substitutes\_purc\_pct_{it} = \frac{substitutes\_purc_{it}}{amt\_outstanding_{it}}$$

As shown in the first column of Table 6, we find that the coefficient for the substitute purchases is basically zero and not statistically significant. This result is different from the findings of D'Amico and King (2013), where the purchased amount of very close substitutes is an important driver of the total stock effect in the Treasury cash market. However, even in their study, the decreasing magnitude of the coefficients from near-substitute to far-substitute purchases suggested imperfect substitutability across securities.

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 Desk announced the tentative schedule for the entire upcoming month.[26] 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.[27] Then primary dealers submitted their propositions, specifying the amount of each CUSIP that the dealers were willing to sell to (buy from) the Desk and

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

[26]During the first LSAP the tentative schedule was announced biweekly, every-other Wednesday, and the threshold for each security was 35% rather than 70%.

[27]These exclusion criteria were announced by the Open Market Desk at the New York Fed on March 24, 2009.

Table 6: Robustness Checks; 1-day Changes

	(1) d_repo	(2) d_repo	(3) d_repo	(4) d_repo	(5) d_repo
percent_bought_offtherun	-0.0849***	-0.0843***	-0.0839***	-0.0849***	-0.0837***
	(-6.52)	(-6.53)	(-6.46)	(-6.57)	(-6.45)
percent_sold_offtherun	0.0483***	0.0482***	0.0479***	0.0477***	0.0481***
	(3.92)	(3.94)	(3.88)	(3.91)	(3.89)
percent_bought_ontherun	-0.227***	-0.227***	-0.223***	-0.229***	-0.222***
	(-4.50)	(-4.50)	(-4.42)	(-4.53)	(-4.41)
percent_sold_ontherun	-0.245	-0.245	-0.143	-0.210	-0.153
	(-0.92)	(-0.92)	(-0.55)	(-0.80)	(-0.59)
soma_substitutes_purc_pct	0.000106				
	(0.27)				
l_fit_error		0.00101			
		(0.82)			
l_repo_spread			0.0415**		0.0432**
			(3.17)		(3.14)
SLP_accepted				1.92e-10	-7.30e-11
				(1.83)	(-0.70)
repo_volume_sprd_std	-0.0365*	-0.0365*	-0.0268	-0.0349*	-0.0271
	(-2.12)	(-2.12)	(-1.61)	(-2.06)	(-1.62)
delta_bidaskspread	0.00331	0.00315	0.00446	0.00339	0.00444
	(0.53)	(0.51)	(0.71)	(0.55)	(0.71)
maturity	0.0154***	0.0160***	0.00420	0.0106*	0.00574
	(3.30)	(3.51)	(0.78)	(2.11)	(1.05)
maturity2	-0.00102**	-0.00105**	-0.000451	-0.000697	-0.000559
	(-2.95)	(-3.08)	(-1.21)	(-1.88)	(-1.46)
N	87337	87337	85257	87337	85257
R^2	0.735	0.735	0.744	0.735	0.745
adj. R^2	0.733	0.733	0.743	0.734	0.743

Heteroskedasticity-consistent t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

the price at which they were willing to sell (buy). Given this set of propositions, the Desk then determined which securities to buy based on a confidential algorithm and published the auction results within a few minutes.

Based on the Desk's exclusion criteria, market commentaries by the primary dealers, and results shown in Table 3 of D'Amico and King (2013) for the case of the first LSAP, 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 observed before the operation 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 COB of the day preceding each operation.[28] As shown in second column of Table 6, the level of the fitting error is not statistically significant and it hardly affected any of the coefficients.

In addition, if individual specialness spreads are not persistent, 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

[28]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.

that reflects expectations of future scarcity value. To control for these possibilities, we also try including the initial *level* of the specialness spread, that is, the spread on the day preceding each operation, as a regressor. As shown in the third column of Table 6, this new regressor is highly significant, arguing for its inclusion. The estimated values of the purchased and sold off-the-run coefficients are also slightly lower, but they both retain their statistical significance. Interestingly, when we include this variable, maturity and maturity squared lose their marginal predictive power, suggesting that the initial level of the specialness spread already captures the relevant information specific to that security.

Our final robustness check is related to the Securities Lending Program (SLP). Although in our baseline specification we already control for security-level uncovered bids at the SLP auctions for the reasons explained in Section 1.3, it is also plausible that the total amount of borrowing could have been more relevant in capturing the security's heightened demand. In the fourth column of Table 6 we show the results for the regressions augmented with the security-level total amount borrowed at the SLP. The coefficient on the individual SLP borrowed amount is not statistically significant. However, it becomes highly statistically significant on the day following the operation, as illustrated in the fourth column of Table 7. But, as shown in the fifth columns of Tables 6 and 7, if we control for both the initial level of the specialness spread and the SLP borrowed amount the latter loses its marginal explanatory power.

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

Table 7: Robustness Checks; 2-day Changes

	(1) d2_repo	(2) d2_repo	(3) d2_repo	(4) d2_repo	(5) d2_repo
percent_bought_offtherun	-0.103***	-0.107***	-0.108***	-0.109***	-0.107***
	(-6.00)	(-6.41)	(-6.36)	(-6.49)	(-6.34)
percent_sold_offtherun	0.0545***	0.0568***	0.0572***	0.0553***	0.0573***
	(5.27)	(5.54)	(5.52)	(5.46)	(5.52)
percent_bought_ontherun	-0.272***	-0.272***	-0.264***	-0.278***	-0.264***
	(-3.70)	(-3.70)	(-3.60)	(-3.76)	(-3.59)
percent_sold_ontherun	0.231	0.234	0.467	0.335	0.460
	(0.74)	(0.75)	(1.38)	(1.06)	(1.36)
soma_substitutes_purc_pct	-0.000695				
	(-1.19)				
l_fit_error		0.00244			
		(1.63)			
l_repo_spread			0.0987***		0.100***
			(7.77)		(7.31)
SLP_accepted				5.86e-10***	-6.01e-11
				(3.93)	(-0.40)
repo_volume_sprd_std	-0.0292	-0.0288	-0.00835	-0.0247	-0.00851
	(-1.31)	(-1.29)	(-0.39)	(-1.12)	(-0.39)
delta_bidaskspread	0.00109	0.000685	0.00368	0.00114	0.00367
	(0.14)	(0.09)	(0.48)	(0.15)	(0.48)
maturity	0.0194***	0.0180**	-0.0119	0.00136	-0.0106
	(3.41)	(3.26)	(-1.94)	(0.22)	(-1.69)
maturity2	-0.00129**	-0.00120**	0.000369	-0.000114	0.000279
	(-3.13)	(-2.96)	(0.87)	(-0.26)	(0.63)
N	86551	86551	84464	86551	84464
R^2	0.737	0.737	0.750	0.738	0.750
adj. R^2	0.736	0.736	0.749	0.737	0.749

Heteroskedasticity-consistent t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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, in the SC repo market, substitution across securities only plays a limited role. Then quantity shocks would not be transmitted to similar securities, reducing cross-sectional correlations.

Table 8: Clustered Standard Errors

	(1) Robust	(2) 1-yr Cluster	(3) 3-yr Cluster
percent_bought_offtherun	-0.0843***	-0.0843***	-0.0843***
	(-6.54)	(-6.46)	(-6.18)
percent_sold_offtherun	0.0489***	0.0489***	0.0489***
	(3.96)	(3.72)	(3.70)
percent_bought_ontherun	-0.227***	-0.227***	-0.227***
	(-4.51)	(-4.50)	(-4.49)
percent_sold_ontherun	-0.170	-0.170	-0.170
	(-0.41)	(-0.41)	(-0.41)
repo_volume_sprd_std	-0.0370*	-0.0370*	-0.0370*
	(-2.21)	(-2.22)	(-2.19)
delta_bidaskspread	0.00325	0.00325	0.00325
	(0.52)	(0.50)	(0.48)
SLP_pct_uncovered_on	-0.00925	-0.00925	-0.00925
	(-0.27)	(-0.27)	(-0.27)
SLP_pct_uncovered_off	-0.00312	-0.00312	-0.00312
	(-0.97)	(-0.96)	(-0.96)
N	87337	87337	87337
R^2	0.735	0.735	0.735
adj. R^2	0.733	0.733	0.733

Heteroskedasticity-consistent or clustered t statistics in parentheses

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

Regressions are performed on 1-day changes in the SC repo rate

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.[29] 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

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

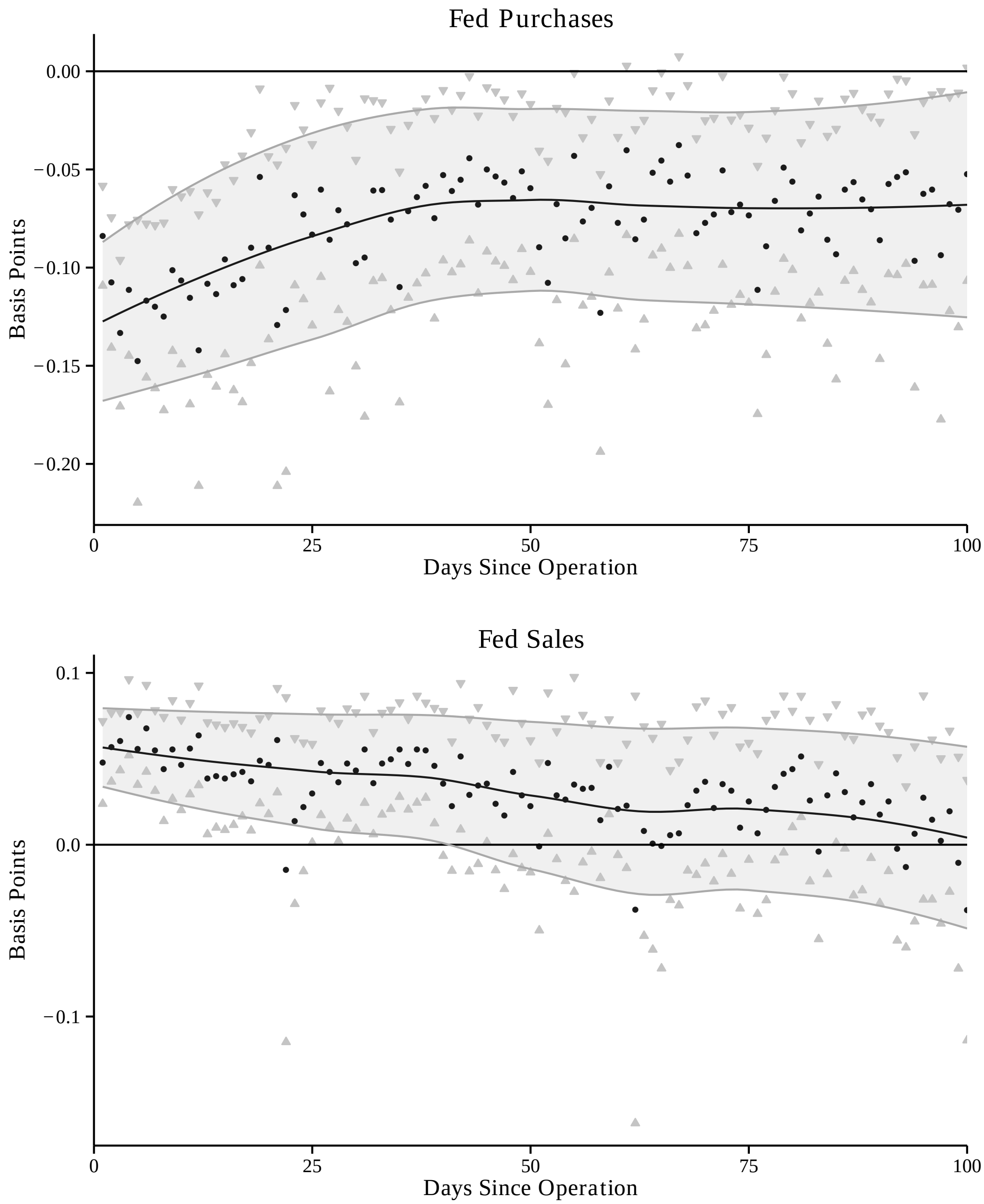

Figure 5: Coefficients on the percentage bought or sold by the Fed from regressions using, as the dependent variable, cumulative changes in the SC repo rate over the N-day period following each operation. Black points indicate the estimated coefficients for each period. Grey triangles indicate the 95% 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 are 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 Pass-Through to Cash Market Prices

In light of the recent literature's findings that even perfectly 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 showing that, in our sample, a specific Treasury bond's cash price premium (relative to securities with the same coupon and maturity) indeed mostly reflects the magnitude of its repo specialness spread, and that this relation becomes stronger on the days of Fed purchase/sale operations. 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 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 are regressed on their repo specialness spreads. We also control for 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.[30] 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.[31] More importantly, this coefficient becomes larger if we restrict the sample to the days of the Fed operations, shown in the second column, and this difference is statistically significant.

These findings suggest that the Fed asset purchase programs could affect Treasury security prices not only directly through the stock effect, 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 in turn reflected (and discounted) in the cash market, leading to higher price premia for relatively scarcer securities on the days of the operations. This indirect effect could be part of the so-called flow-effect

[30] 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.

[31] 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; Levels

	(1) All Days	(2) Operations
Repo Spread	0.0487***	0.0646***
	(10.99)	(9.24)
Bid-Ask Spread	-0.525***	-0.402***
	(-51.74)	(-23.76)
dummy_ontherun	1.019***	0.683***
	(14.46)	(7.05)
maturity2	0.233***	0.248***
	(82.80)	(49.80)
N	170203	92099
R^2	0.283	0.258
adj. R^2	0.277	0.251

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

estimated by D'Amico and King (2013).

4 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 the scarcity value of this collateral 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 quantitative easing.

Since changes in quantities affect the SC repo rate not only of on-the-run but also off-the-run securities, and fails have been steadily rising in well off-the-run securities in recent years, then it is reasonable to conclude that the scarcity effect is a widespread phenomenon and is not confined just to a few "special" securities. This implies that changes in quantities are relevant for the repo rates of many Treasury securities outstanding, and therefore have potentially important implications for the GC repo rate and other money market rates through arbitrage relations. To summarize, if changes in available supply affect the average lowest money market rate (SC repo rate), then by moving the floor they can push all other money market rates higher or lower. At the same time, they can also affect the volatility in the money market. For example, an increase in the availability of high-quality collateral can prevent near-zero or negative SC and GC repo rates, mitigating downward fluctuations in money market rates.

The Fed's overnight reverse repo facility—one of the tools for the policy normalization process—can tighten control over money market rates through a similar mechanism. For example, by increasing the availability of Treasury collateral to a wide range of market participants, it could reduce the scarcity premium embodied in these rates, especially when the appetite for high-quality assets increases. Figure 6 attempts to illustrate this point.

The top panel of Figure 6 shows two of the most relevant overnight money market rates—the federal funds rate and the GCF Treasury repo rate—together with the repo rate set by the Fed for its reverse repo operational tests, which started at the end of September 2013. This panel shows that, although the operations' amounts are capped, the Fed's reverse repo rate has generally been providing a floor for other money market rates during quarter- and year-end periods.[32] These are periods when demand for Treasury securities increases, likely

[32]A clear exception is September 30, 2014, when the $300 billion cap was binding.

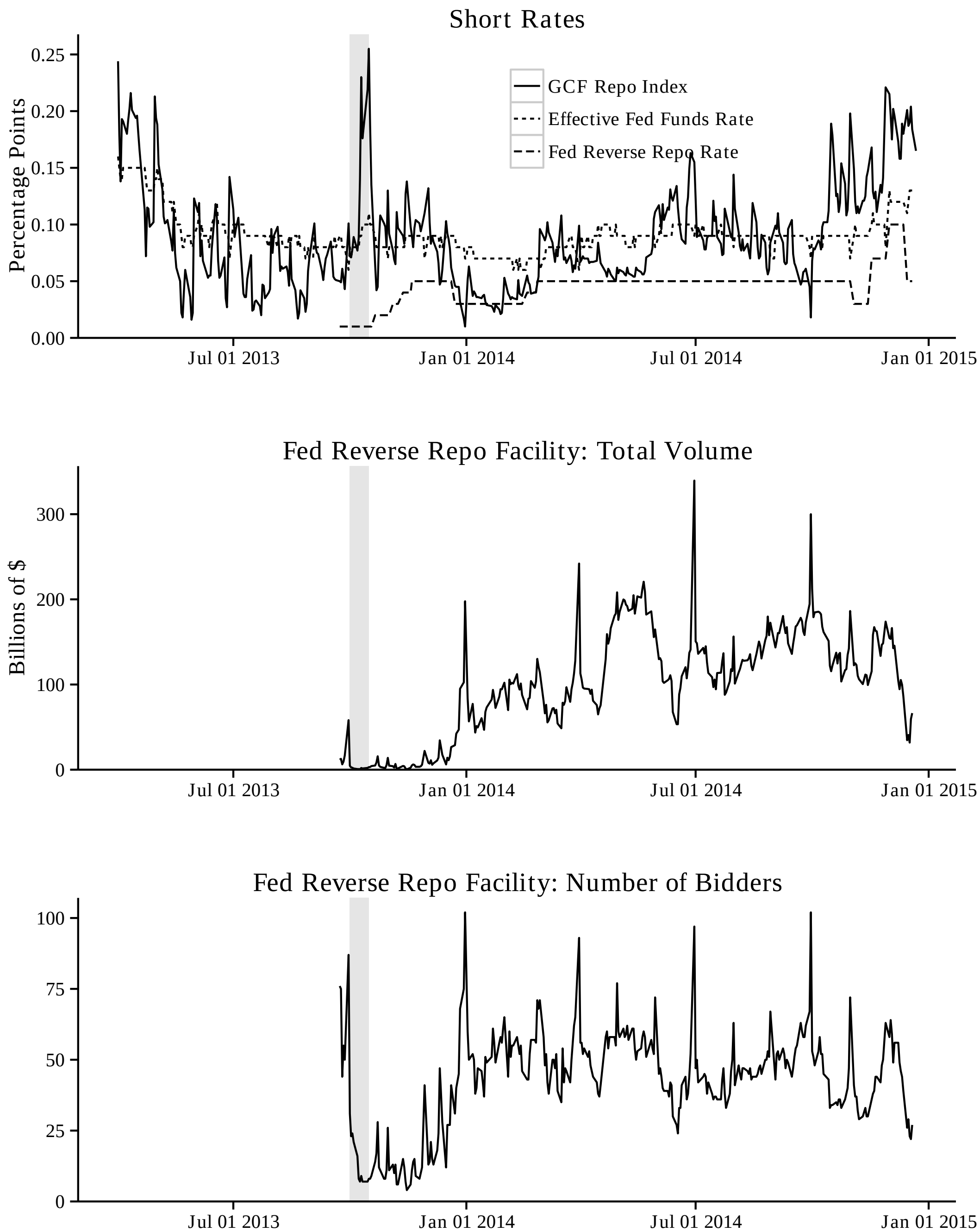

Figure 6: The top panel shows various money market rates as well as the rate offered at the Fed's reverse repo facility. The bottom two panels show some of this facility's statistics. The shaded area denotes the U.S. government shutdown of 2013.

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). Indeed, as shown in the bottom two panels, which plot the aggregate volume and the number of participants at each Fed reverse repo operations, demand for Treasury securities and participation at this facility have spiked at the end of each quarter.

Further, it is important to keep in mind that the impact of the Fed overnight reverse repo facility is similar to, but less direct than the impact of an increase in the amount issued by the Treasury, a Treasury reopening, or a Fed LSAP sale operation.[33]

This discussion is not meant to provide a definite answer regarding the efficacy of this facility as a monetary policy tool 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.

[33] Under a reverse repo with the Fed, the securities sold by the Fed to the counterparty may be held on the counterparty's balance sheet but are in the tri-party system, making them unavailable for the counterparty to satisfy margin requirements (Potter, 2013).

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A Repo Spread Regressions

Table 10 reports the same regression as Table 3, except using the change in the repo specialness spread instead of the SC repo rate as the dependent variable. As discussed earlier, since we include time dummies, it is only the variation in the specific repo rates that drive our estimates. So these results are extremely similar to the previous regression except for the flipped sign. This is because any factor that pushes the SC repo rate down will push the corresponding specialness spread up, and vice versa.

As before, in Table 11 we report the same subsample results as in Table 4 except using the repo specialness spread as the dependent variable. Again, we can see that the coefficients are almost identical except for the flipped sign.

Table 10: Repo Specialness Spread Regressions

	(1) d_repo_spread	(2) d2_repo_spread
percent_bought_offtherun	0.0847***	0.107***
	(6.59)	(6.40)
percent_sold_offtherun	-0.0488***	-0.0554***
	(-3.95)	(-5.48)
percent_bought_ontherun	0.227***	0.240***
	(4.51)	(3.50)
percent_sold_ontherun	0.274	0.145
	(0.67)	(0.26)
repo_volume_sprd_std	0.0364*	0.0322
	(2.17)	(1.34)
delta_bidaskspread_pct	-0.00425	0.00180
	(-0.70)	(0.24)
SLP_pct_uncovered_on	-0.00371	-0.0391
	(-0.10)	(-1.03)
SLP_pct_uncovered_off	0.00314	-0.00487
	(0.98)	(-1.31)
maturity	-0.0140**	-0.0171**
	(-3.12)	(-3.10)
maturity2	0.000907**	0.00117**
	(2.71)	(2.88)
N	87321	86546
R^2	0.686	0.668
adj. R^2	0.684	0.666

Heteroskedasticity-consistent t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 11: Repo Specialness Spread Regressions; 1-day Changes

	(1) 0-3 Years	(2) 3-7 Years	(3) 7-15 Years
percent_bought_offtherun	0.137**	0.0708***	0.0766***
	(3.22)	(3.58)	(3.42)
percent_sold_offtherun	-0.0464***		
	(-3.78)		
percent_bought_ontherun	0.553***	0.0956**	0.405
	(3.98)	(3.04)	(0.92)
percent_sold_ontherun	0.306		
	(0.63)		
repo_volume_sprd_std	0.0778*	0.0274	-0.0107
	(2.55)	(1.20)	(-0.31)
delta_bidaskspread_pct	-0.0141	-0.00408	0.0126
	(-1.51)	(-0.40)	(0.86)
SLP_pct_uncovered_on	0.00548	-0.0331	-0.00727
	(0.12)	(-0.22)	(-0.13)
SLP_pct_uncovered_off	0.00396*	-0.0110	-0.00558
	(2.05)	(-0.16)	(-0.41)
maturity	-0.0891**	0.0443	-0.00467
	(-2.87)	(0.49)	(-0.07)
maturity2	0.0182*	-0.00525	0.000230
	(2.10)	(-0.60)	(0.08)
N	45878	30189	11254
R^2	0.729	0.690	0.578
adj. R^2	0.726	0.685	0.560

Heteroskedasticity-consistent t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$