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, passes through to Treasury market prices, and explains a significant portion of the flow-effects of LSAP programs, 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 plays no role. In the special collateral repurchase agreement (SC repo) market, collateralized transactions are security-specific (i.e., the contract precludes the possibility to deliver 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 we also show passes through to Treasury cash market prices, having 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

[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.

of its securities.

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 variation in our sample comes mostly 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

[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.

the repo rate that is solely due to changes in the scarcity of the underlying collateral (i.e., 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 "credit-quality" measures such as maturity, which determines the length of exposure to interest-rate risk and can be thought of as capturing Treasuries' riskiness. 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). The coefficient for the Treasury issued amount is also positive and significant, at 0.4 basis points per billion dollars.[4] In addition, when we quantify the pass-through of these changes in the repo scarcity value to Treasury cash market prices,

[4]This result is consistent with Mazzoleni (2013) estimates of a reduction of 0.55 basis points in the yield premium of a two- or a five-year note for an additional issuance of one billion dollars.

our estimates suggest that a one basis point increase in the predicted repo scarcity premium translates on average into a cash premium of about 0.4 basis points.

This pass-through of the SC repo scarcity premium to Treasury cash market prices, explains 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.[5] Since we show that part of this repo 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). Specifically, the estimated pass-through explains a significant portion of the Treasury price reactions to the Fed's actual purchase operations as estimated in D'Amico and King (2013), also known in the QE literature as flow- or pace-effects.

Our findings also have potentially important implications for both the future conduct of monetary policy through fixed-rate full-allotment (FRFA) reverse repos and the Treasury's management of the auction cycles of its securities.[6] If the Fed decides to fully employ FRFA reverse repos, 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). 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

[5] 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), Goldreich et al. (2005), Musto et al. (2011), Fontaine and Garcia (2012), and Banerjee and Graveline (2013).

[6] The September 2013 FOMC meeting authorized the New York Fed to start operational tests of fixed-rate overnight reverse repos. The FRFA reverse repo facility allows a wide range of market participants to deposit unlimited amounts of 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.

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 (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 I describes the data and the variables used in the empirical analysis, whose results are discussed in detail in Section II. In Section III we estimate the pass-through of the repo scarcity premium to Treasury cash prices. In Section IV, we provide updated evidence on the impact of Treasury auction characteristics on SC repo rates. And Section V concludes.

I. Data Background and Description

A. 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

[7]See Potter (2013) for a more detailed discussion on the overnight FRFA 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.

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 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. This implies that anyone who sold that specific collateral short must deliver that bond and not some other bond and therefore will put extra value on that collateral. Mutual and pension funds, custodial agents, and other owners of Treasury securities can then 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. 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 specu-

[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.

lative 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.

B. 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.

To compute this spread, we use two data sources for Treasury GC repo rates. The first

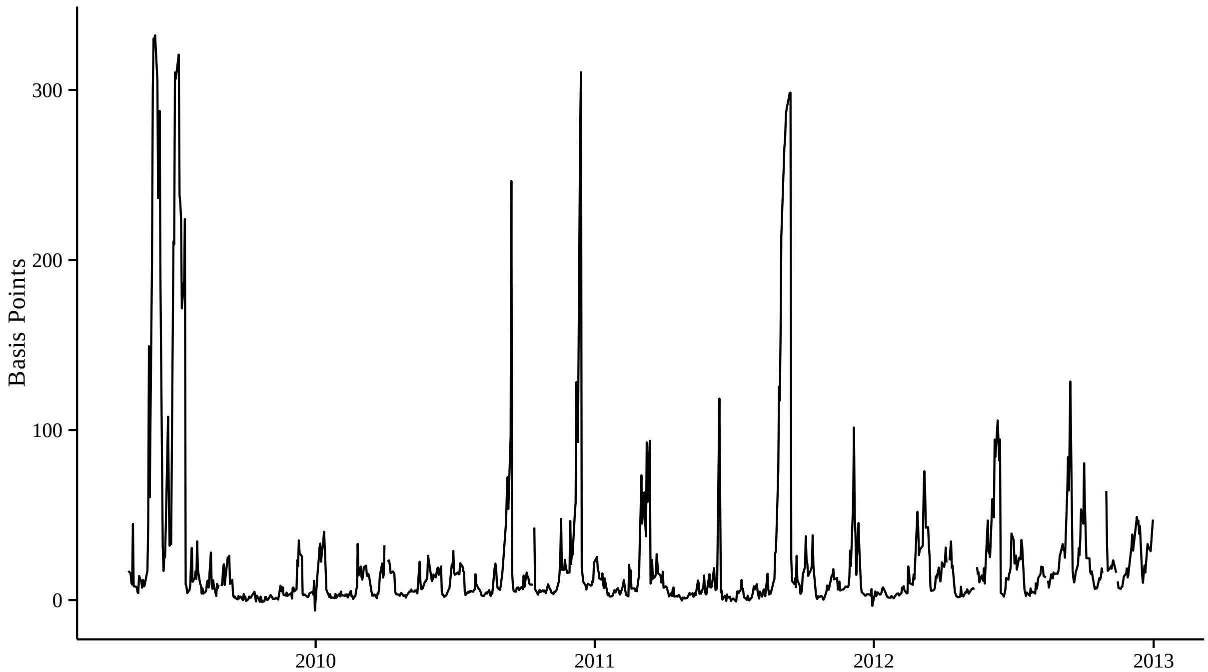

Figure 1: Repo specialness spread for the on-the-run 10-year Treasury security.

source is the General Collateral Finance (GCF) Repo Index, which is a tri-party repo platform maintained by the Depository Trust & Clearing Corporation (DTCC).[11] 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.

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

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.[12] 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.

C. 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).[13] 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.[14] 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.[15]

Summary statistics of the Fed operations are shown in Table I. 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

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

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

[14]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`.

[15]"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 I: 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.

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 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).[16] 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 to borrow securities whose SC repo rates are 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.

D. *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,

[16]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`.

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 2 and 3 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 2, it is easy to note the same pattern documented by Keane (1995) for securities with a monthly auction cycle. In contrast, Figure 3 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 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.

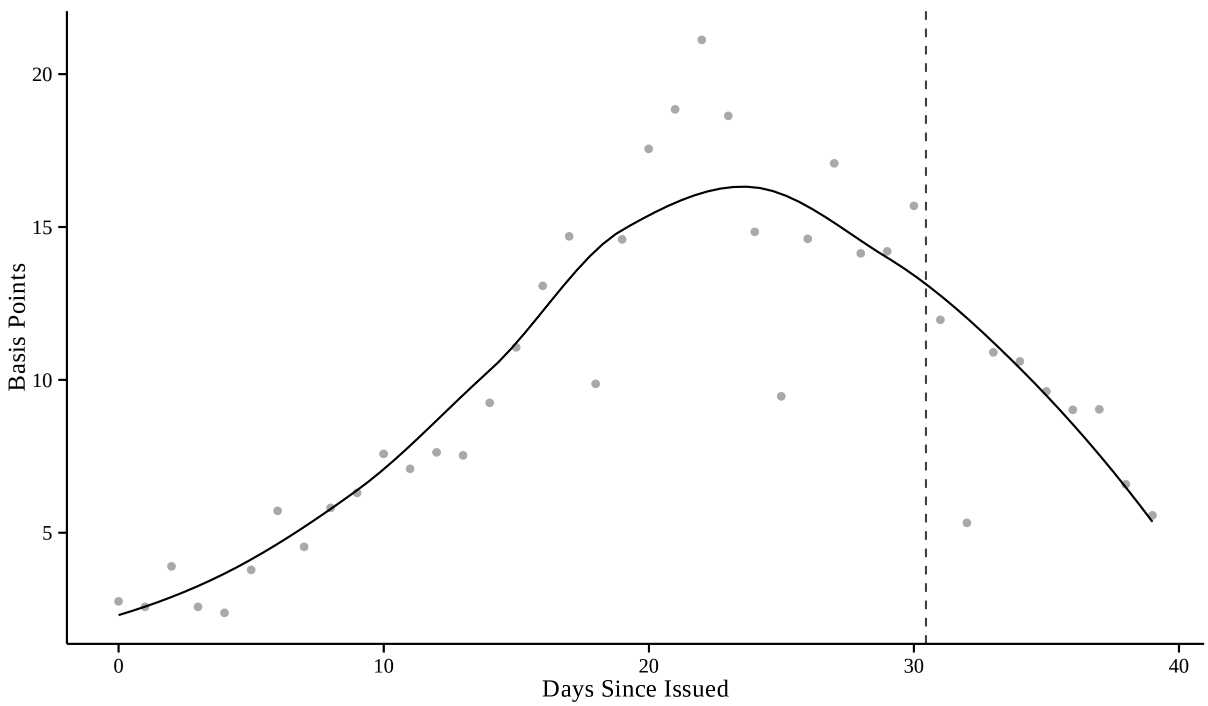

Figure 2: Average daily repo specialness spread for Treasury securities with a 1-month auction cycle (2-, 3-, 5-, and 7-year maturities). Grey dots are the average specialness spread on each day since the issue date, and the line is a fitted LOESS curve. The vertical dashed line marks the average time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

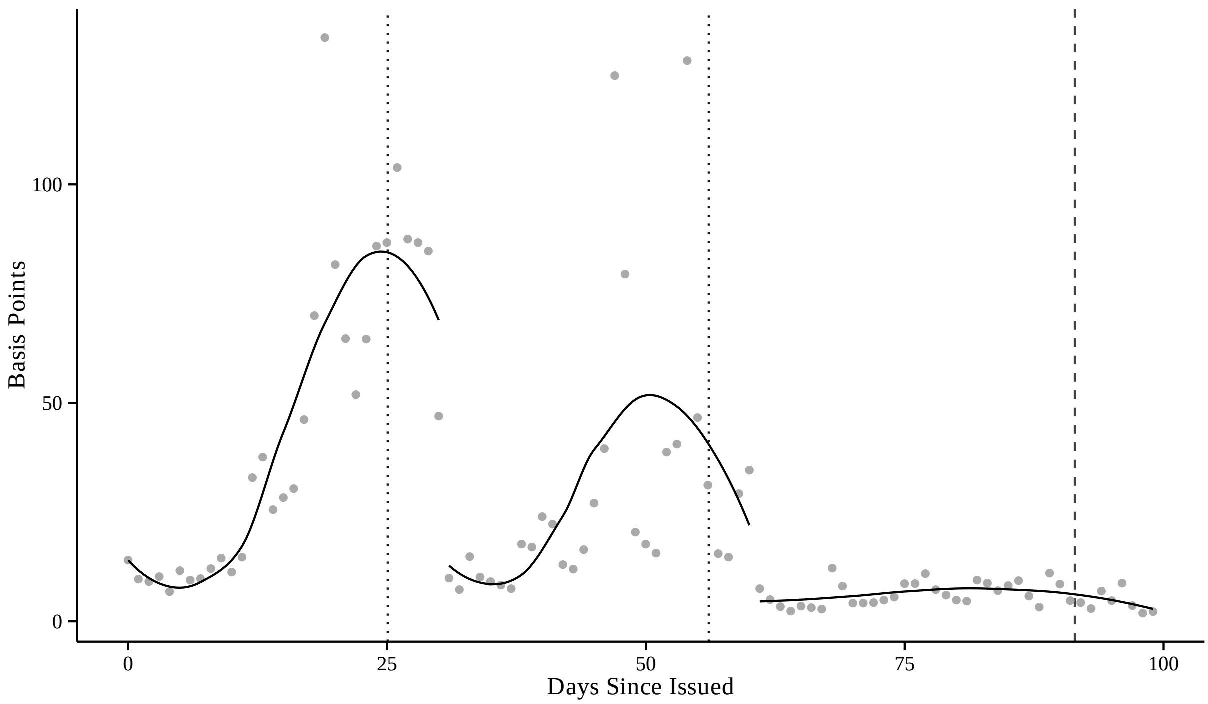

Figure 3: Average daily repo specialness spread for 10-year Treasury securities. Grey dots are the average specialness spread on each day since the issue date, and the line is a fitted LOESS curve. Vertical dotted lines mark the average times of reopening auctions, while the vertical dashed line denotes the average time of the auction of the next 10-year security.

E. 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.[17] Securities with lower bid-ask spreads are more liquid, therefore we expect them to have lower repo rates and higher specialness spreads.

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

Table II: 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	

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.

II. 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. 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 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.

Our sample starts 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.[18] However, due to data availability, specifications that include information on whether transactions were initiated as repos or reverse repos are estimated on a 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.

A. Regression Specification

Our basic panel regression specification is:

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

[18] 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 I.D; 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.[19]

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

B. Results

The results from the SC repo rate panel regression estimated starting on May 1, 2009 are reported in the first column of Table III, while the second column shows the results for the two-day change in the same dependent variable.[20,21] 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 -0.234 suggests that buying one percent of a security's outstanding par value would decrease the SC repo rate by 0.234 basis points, implying that on average a $1 billion purchase of on-the-run securities would decrease the SC repo rate by 0.81 basis points. In contrast, the coefficient for the off-the-run securities implies a decline of 0.33 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 0.048 suggests that selling one percent of a security's outstanding would increase the SC repo rate by 0.048 basis points, implying that a $1 billion sale would increase the

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

[21] 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 III: SC Repo Rate Regressions, from May

	(1) 1-day	(2) 2-day
percent_bought_offtherun	-0.0792***	-0.103***
	(-6.50)	(-6.64)
percent_sold_offtherun	0.0480***	0.0542***
	(3.90)	(5.32)
percent_bought_ontherun	-0.234***	-0.281***
	(-5.09)	(-4.23)
percent_sold_ontherun	-0.153	-0.305
	(-0.38)	(-0.46)
SLP_pct_uncovered_off	-0.00302	0.00498
	(-0.94)	(1.34)
SLP_pct_uncovered_on	-0.0115	0.0642
	(-0.34)	(1.63)
delta_bidaskspread	0.000166	0.000728
	(0.03)	(0.09)
maturity	0.0175***	0.0190***
	(3.86)	(3.45)
maturity2	-0.00123***	-0.00132**
	(-3.63)	(-3.28)
N	89614	88821
R^2	0.730	0.729
adj. R^2	0.729	0.728

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

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 I.C, each dealer's participation is capped, making this tool less effective in releasing demand pressure.

The results from the same specification but augmented with the proxy for short positions and therefore estimated starting on June 23, 2009 are reported in Table IV. 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. Since all the other coefficients remain practically unchanged when estimated in this slightly shorter sample period, for the remainder of this section we focus only on the results obtained using this sample period.

Table V reports the same regression as Table IV, 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.

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 VI presents

Table IV: SC Repo Rate Regressions

	(1) 1-day	(2) 2-day
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

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

Table V: Repo Specialness Spread Regressions

	(1) 1-day	(2) 2-day
percent_bought_offtherun	0.0851***	0.107***
	(6.62)	(6.42)
percent_sold_offtherun	-0.0486***	-0.0552***
	(-3.94)	(-5.46)
percent_bought_ontherun	0.227***	0.240***
	(4.51)	(3.50)
percent_sold_ontherun	0.272	0.142
	(0.66)	(0.26)
SLP_pct_uncovered_off	0.00312	-0.00489
	(0.97)	(-1.32)
SLP_pct_uncovered_on	-0.00362	-0.0390
	(-0.10)	(-1.03)
repo_volume_sprd_std	0.0363*	0.0321
	(2.17)	(1.34)
delta_bidaskspread	-0.00427	0.00180
	(-0.70)	(0.24)
maturity	-0.0143**	-0.0175**
	(-3.17)	(-3.14)
maturity2	0.000930**	0.00119**
	(2.76)	(2.92)
N	87321	86546
R^2	0.686	0.668
adj. R^2	0.684	0.666

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

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 VII 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.

As before, in Table VIII we report the same subsample results as in Table VI 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.

To account for possible correlations across the regression errors of collateral with comparable maturities, we also run the analysis with clustered standard errors. Table IX shows the results of this robustness exercise. The first column shows estimates from the same model as the first column in Table IV, 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 VI and VII and obtain similar results (not shown). This is not surprising if, in the SC repo market, substitution across securities does not play any role. Therefore, quantity

Table VI: SC Repo Rate Regressions; 1-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

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

Table VII: SC Repo Rate Regressions; 2-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	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

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

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

	(1) 0-3 Years	(2) 3-7 Years	(3) 7-15 Years
percent_bought_offtherun	0.138**	0.0701***	0.0787***
	(3.25)	(3.48)	(3.58)
percent_sold_offtherun	-0.0465***		
	(-3.77)		
percent_bought_ontherun	0.554***	0.0955**	0.414
	(3.98)	(3.04)	(0.94)
percent_sold_ontherun	0.308		
	(0.63)		
SLP_pct_uncovered_off	0.00395*	-0.0109	-0.00558
	(2.05)	(-0.16)	(-0.41)
SLP_pct_uncovered_on	0.00544	-0.0329	-0.00705
	(0.12)	(-0.22)	(-0.12)
repo_volume_sprd_std	0.0778*	0.0274	-0.0109
	(2.55)	(1.20)	(-0.32)
delta_bidaskspread	-0.0143	-0.00413	0.0127
	(-1.53)	(-0.40)	(0.86)
maturity	-0.0870**	0.0380	0.00245
	(-2.79)	(0.41)	(0.04)
maturity2	0.0170	-0.00466	-0.0000485
	(1.95)	(-0.53)	(-0.02)
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
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

shocks would not be transmitted to similar securities, reducing cross-sectional correlations.

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

	(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	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

Heteroskedasticity-consistent or clustered t statistics in parentheses

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

C. 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 4 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.[22] In the dynamic specification, in addition to the variables used in the baseline regressions (see Section II.A), 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 4, 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

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

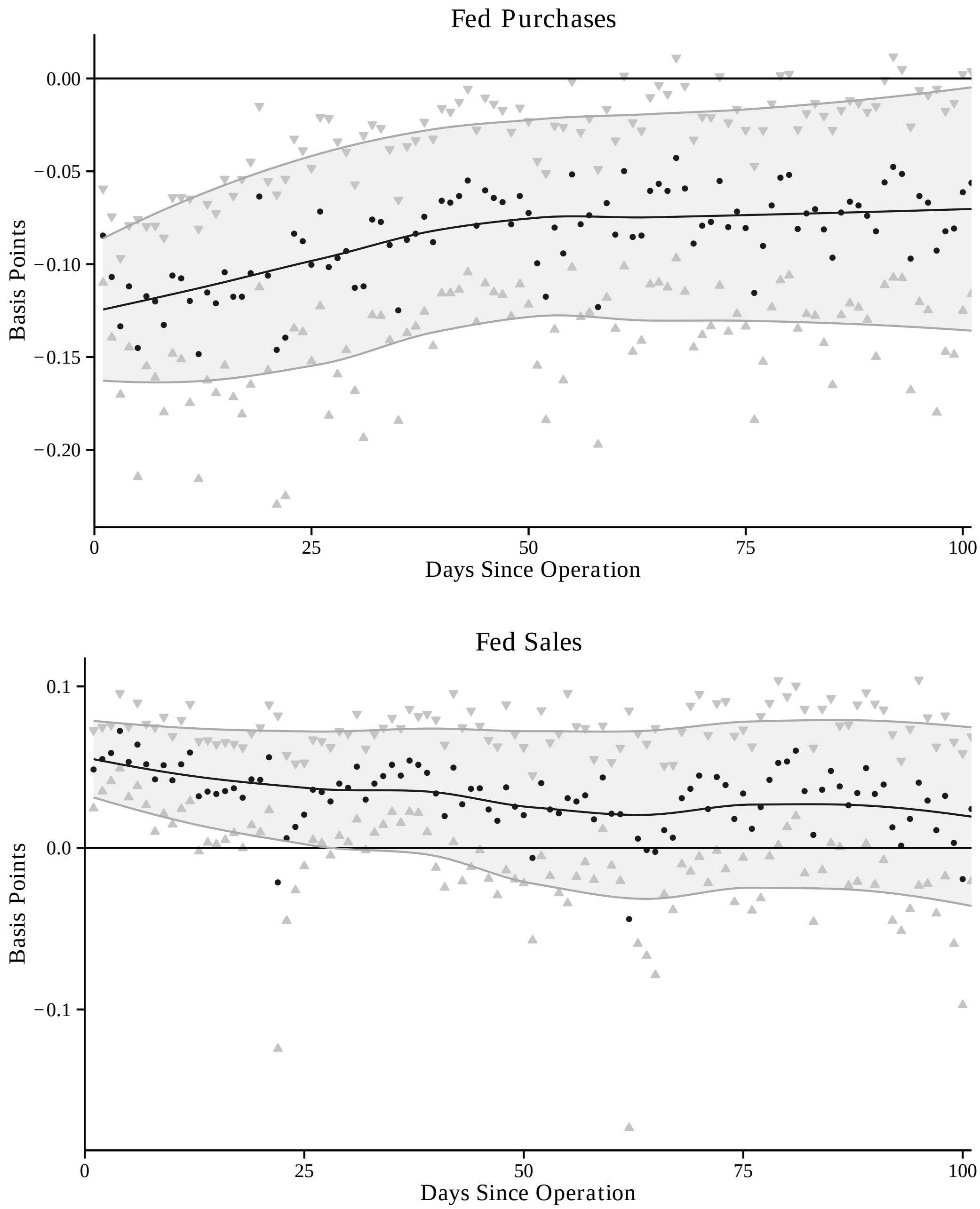

Figure 4: Coefficients on the percentage bought or sold by the Fed from regressions using, as the dependent variable, cumulative changes in the SC repo rate over the N-day period following each operation. Black points indicate the estimated coefficients for each period. Grey triangles indicate the 95% 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.

III. 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 II.B. In this section, we attempt to test this conjecture.

We begin 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 X 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.[23] 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.[24] Further, this coefficient becomes larger if we restrict the sample to the days of the Fed operations, shown in the second column.

In addition, we quantify the pass-through of fluctuations in the repo scarcity value to cash market prices by regressing changes in securities' cash market premia on the changes in specialness spreads solely explained by the amounts purchased and sold by the Fed. The results of this exercise are presented in Table XI. Each column presents the estimated coefficients from a panel regression in which daily changes in cash price premia (within each of the four maturity groups) are regressed on the portion of daily changes in repo specialness spreads that our baseline regressions attribute to the Fed's sale and purchase operations

[23]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.

[24]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 X: 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
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

(using the coefficients reported in Tables V and VIII). Additionally, we control for changes in the security-level bid-ask spreads, include time fixed effects, and we divide the sample into off- and on-the-run securities.

We find that the pass-through is significant only for off-the-run securities, which is not surprising considering the smaller amount of observations for the on-the-run securities. In particular, a one basis point increase in the predicted repo specialness spread translates, on average, into a cash price premium of about 0.4 basis points (column 4). However, the magnitude and importance of the estimated pass-through differs across maturities. For the off-the-run securities with 3 to 7 years left to maturity, it has a similar magnitude of about 0.4 basis points and is statistically significant at a 1% level, while for the off-the-run securities with 7 to 15 years to maturity, it is positive but smaller in magnitude and is barely significant at a 5% level. The coefficient for off-the-run securities with maturities less than 3 years is

Table XI: Cash Market Premia: Pass-through from Fed Operations; 1-Day Changes

	(1) 0-3 Years	(2) 3-7 Years	(3) 7-15 Years	(4) All Mat.
Pred. Repo Spread (Off-the-Run)	0.106	0.386***	0.118*	0.378**
	(0.42)	(5.55)	(1.96)	(3.13)
Pred. Repo Spread (On-the-Run)	-0.0146	0.00560	0.0589	0.0224
	(-0.42)	(0.16)	(0.76)	(0.74)
Observed Bid-Ask Spread	-0.589***	-0.0964***	-0.0402***	-0.269***
	(-4.90)	(-36.37)	(-13.76)	(-6.09)
N	45691	30187	11241	87119
R^2	0.016	0.470	0.579	0.009
adj. R^2	0.006	0.462	0.562	0.004

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

positive but statistically insignificant, although results in this sector are harder to interpret because the corresponding predicted repo spreads reflect effects of both asset purchases and sales.

Overall, these findings suggest that, at least for longer-term off-the-run securities, 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 is part of the so-called flow-effect that D'Amico and King (2013) find to be about 3.5 basis points per \$5 billion of Treasury securities purchased under the first LSAP. In Section II.B, we show that a Fed purchase of the same size would increase the repo specialness spread by about 2.5 basis points, and here we show that this increase would cause the cash market premium to rise by about one basis point (0.4×2.5bp), a significant portion of the

3.5 basis point effect.

IV. Treasury Auction-Level Regressions

Similar to Jordan and Jordan (1997), we also run regressions at Treasury-auction frequency to examine the impact of issued amounts and demand at auctions on future specialness spreads. In particular, they show that both the auction tightness and the issue's distribution of ownership have significant effects on on-the-run specialness spreads and that these effects can last as long as four weeks after the auction.

Again, we omit the 30-year Treasury auctions because long-term treasuries are rarely traded on the repo market. This leaves us with 257 Treasury auctions (including reopenings) from May 1, 2009 to Dec 31, 2012. The data on Treasury auctions are from the Treasury Direct website.[25] For each auction in our sample, we construct the average specialness spread in the jth week ($j = 1, 2, 3, 4$) after the security is issued and the average for the month after issuance.

To measure an unexpectedly large demand for the auctioned security, we use the spread between the 1 p.m. when-issued (WI) rate and the yield at the auction. The WI market is a forward market in which trading begins approximately two weeks before the security's auction and contracts are settled when the security is issued. As Duffie (1996) notes, short positions created in this market are often covered with securities obtained at the auction. An auction yield lower than the prevailing WI rate indicates an unexpectedly strong demand at the auction. Short-sellers unable to cover their positions at the auction will turn to the cash or repo markets, which can potentially push SC repo rates lower and specialness spreads

[25]See `http://www.treasurydirect.gov/RI/OFGateway`. When-issued rate data are obtained from Tradeweb.

higher. Previous studies have used the bid-to-cover ratio, which is defined as the total dollar amount of received bids divided by the total dollar amount of accepted bids. This measure does not, however, necessarily measure the unexpected auction tightness. Instead, since the 1 p.m. WI rate is a reliable measure of the rate expected to prevail at the auction, the spread between the WI rate and the auction yield better captures the unexpected component of the auction demand.

Duffie (1996) also notes that some institutional investors are unable or reluctant to lend their securities in the repo market (e.g., insurance companies, pension funds, and foreign central banks), while other investors like dealers and brokers are major participants in the repo market and routinely use it to finance their positions. Therefore, similarly to Jordan and Jordan (1997), we expect a high fraction of issuance awarded to dealers to be readily available as collateral in the repo market, though this supply may decrease over time as dealers sell their inventories to clients and no longer need repo financing.

In contrast, foreign official investors usually buy and hold their securities and are often legally prohibited from supplying them as collateral to the repo market. In recent years, many foreign governments and central banks, particularly those with elevated current accounts surpluses, have held substantial international reserves in the form of Treasuries. Foreign holdings of U.S. Treasury securities amount to about $5.5 trillion, roughly half of the total marketable Treasury debt. This suggests that a significantly smaller portion of Treasury collateral is available to more active investors in the repo market, such as dealers.

Using auction allotment data obtained from the Treasury, we control for the security's share awarded to dealers and foreign investors in our regressions.[26] Securities with larger

[26] Investor class auction allotment data are available at `http://www.treasury.gov/resource-center/data-chart-center/Pages/investor_class_auction.aspx`. "Dealers and brokers" includes primary dealers, dealer departments at commercial banks, and other non-bank dealers and brokers. "Foreign investors" includes private foreign investors, foreign central banks, and other non-private foreign entities.

Table XII: Summary Statistics - Treasury Auctions

	Mean	Std. Dev.
foreign_pct	22	10.4
dealer_pct	53.2	9.57
amt_issued (bn)	30	9.3
whenissued_spread	-4.63	1.94
N	257	

fractions awarded to dealers are expected to have lower specialness spreads as they are more readily available in the repo market, while the opposite is expected for securities with larger fractions awarded to foreign participants.

Similarly to Graveline and McBrady (2011), we also include the amount issued at each auction, as larger issues should be in greater supply in the repo market. Finally, we include dummies for auctions of each maturity in our sample (2-, 3-, 5-, 7-, and 10-year) and a dummy variable that tracks if the auction is a reopening. Summary statistics for our dependent variables are shown in Table XII.

Regression results for the average specialness spread are presented in Table XIII. The first column shows the results for the first week after issuance. The coefficients on foreign allotment percentages are largely significant and have the expected signs, with higher dealer allotments resulting in lower specialness and larger foreign allotments resulting in higher specialness. Furthermore, in week four the foreign allotment's effect size quadruples, suggesting that when the demand for on-the-run securities is already high due to the auction cycle (discussed in Section I.D), then this type of supply constraint magnifies the rise in repo specialness spreads. The effect of the amount issued is negative and significant, and persists throughout the inter-auction period, with much larger effect sizes in weeks three and four. In

Table XIII: Treasury Auctions: Average Specialness Spread by Week

	(1) Week 1	(2) Week 2	(3) Week 3	(4) Week 4	(5) Total
dealer_pct	-0.0949$^+$	-0.0723	0.137	0.296	0.0840
	(-1.81)	(-0.81)	(0.56)	(1.11)	(0.58)
foreign_pct	0.139*	0.132	0.140	0.579*	0.252$^+$
	(2.20)	(1.10)	(0.59)	(2.09)	(1.71)
amt_issued (bn)	-0.385**	-0.348$^+$	-1.04$^+$	-1.76*	-0.852*
	(-2.95)	(-1.65)	(-1.78)	(-2.51)	(-2.42)
WI_auction_spread	-0.255	-0.437	-2.071	-2.420	-1.302
	(-1.13)	(-0.78)	(-1.28)	(-1.62)	(-1.52)
dummy_reopening	-2.393*	-3.663	-16.85$^+$	-39.87**	-16.67**
	(-2.19)	(-1.58)	(-1.74)	(-3.12)	(-2.79)
N	257	257	257	257	257
R^2	0.262	0.153	0.136	0.205	0.201
adj. R^2	0.232	0.119	0.101	0.173	0.168

Heteroskedasticity-consistent t statistics in parentheses
$^+$ $p < .10$, * $p < .05$, ** $p < .01$

contrast, the coefficient on the spread between the WI rate and the auction yield is negative but not statistically significant. The coefficient on the reopening dummy shows that, on average, the specialness spread is lower after reopenings than initial auctions, particularly in the third and fourth weeks after the auction. This confirms the patterns shown in Figure 3. This result also has implications for the Treasury's management of auction cycles, as increasing the tradeable supply of highly-demanded securities through reopenings could help alleviate collateral scarcity.

We largely confirm the conclusions of Jordan and Jordan (1997) regarding the effects of Treasury auction characteristics on repo specialness in a much larger sample. Our results also provide support for Duffie's conjecture that repo specialness should exhibit a non-linear behavior due to the determination of its equilibrium value (see Figures 2 and 3 in Duffie, 1996). When collateral supply exceeds its demand, the normal situation, small supply shifts should not affect specialness, which remains in a corner solution close to zero. However, during periods of excess demand, such as at the peak of the auction cycle (week four), we expect supply shifts to have large and significant impacts. Consistent with this theory, we find that the estimated effects of foreign allotments and amounts issued are much stronger during the third and fourth weeks after issuance, when securities are usually on special due to the Treasury auction cycle.

V. 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 demand and supply 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.

Further, we find that for longer-term off-the-run securities this scarcity value is reflected in the Treasury cash market prices. And in particular, we show that the portion of the increase in the repo scarcity premium due to the Fed purchase operations passes through to cash market premia, explaining a significant amount of the flow-effects of these operations. Therefore, our results provide further support for the scarcity channel of quantitative easing.

Our findings also suggest that, through the same mechanism, the Fed's FRFA reverse repo facility—one of the tools under consideration for the policy normalization process—can help tighten control over money market rates. 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 5 attempts to illustrate this point.

The top panel of Figure 5 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 still capped, the Fed's reverse repo rate has generally been providing a floor for other money market rates during quarter- and year-end periods. These are periods when demand for Treasury securities increases, 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). 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 FRFA 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.[27]

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

[27] 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).

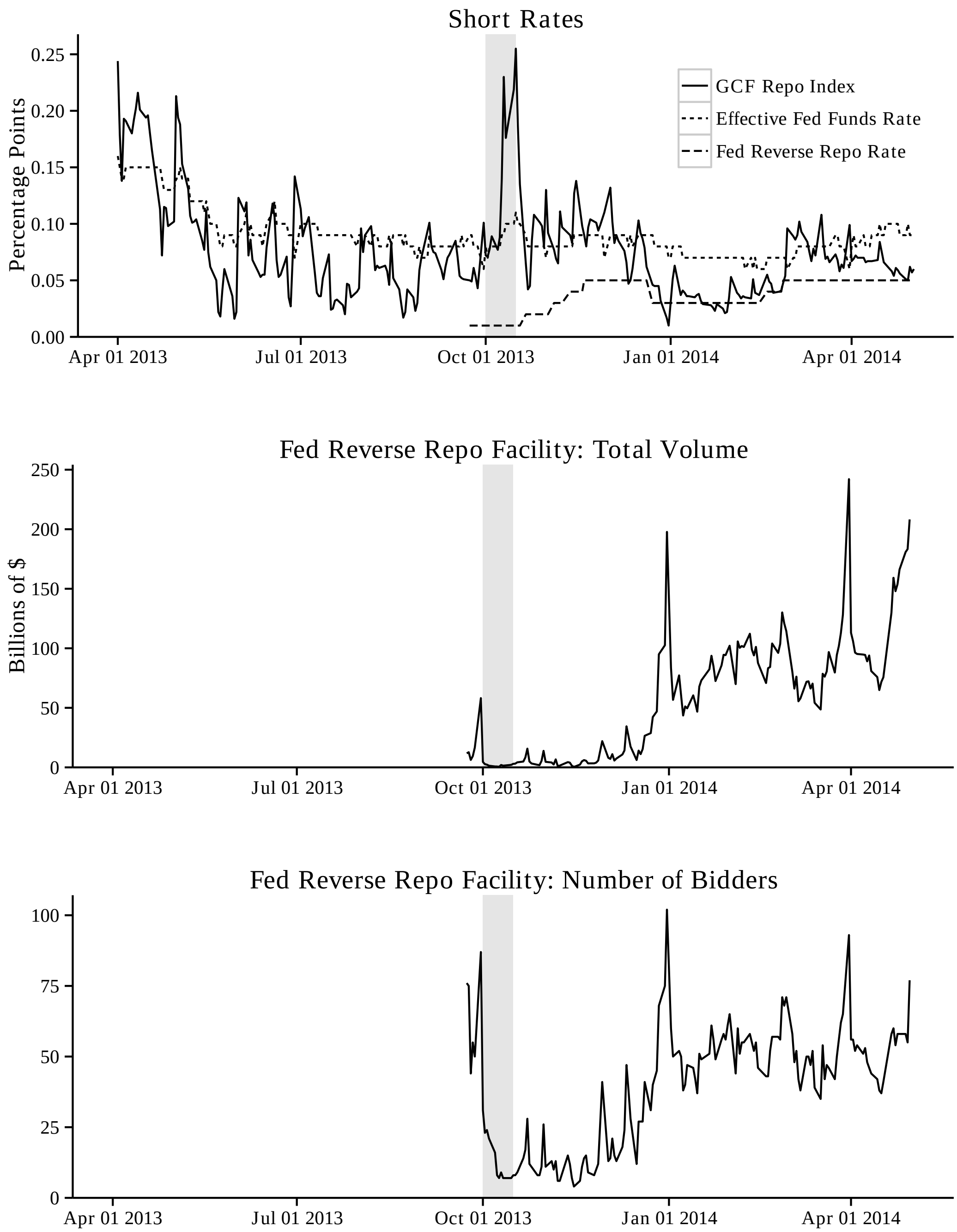

Figure 5: The top panel shows various money market rates as well as the rate offered at the Fed's reverse repo facility. The bottom two panels show some of this facility's statistics. The shaded area denotes the U.S. government shutdown of 2013.

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.

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