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The Scarcity Value of Treasury Collateral: Repo-Market Effects of Security-Specific Supply and Demand Factors

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Abstract

We quantify the scarcity value of Treasury collateral by estimating the impact of security-specific demand and supply factors on the specific collateral repurchase agreement (repo) rates of all outstanding U.S. Treasury securities. We find a positive and significant scarcity premium for on- and off-the-run Treasuries that persists for approximately 3 months and is larger in magnitude for shorter-term securities. This scarcity effect seems to pass through to Treasury cash market prices, providing additional evidence for the scarcity channel of quantitative easing (QE). On the contrary, the Federal Reserve's reverse repo operations could help reduce the scarcity premium by alleviating potential shortages of high-quality collateral.

I. Introduction

Over the last 4 decades, and even more so since the 2007–2009 financial crisis, the financial system has increasingly relied on repurchase agreements (repos) backed by government securities.[1] In particular, U.S. Treasury securities account

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[1]See, for example, Gorton, Lewellen, and Metrick (2012) and Copeland, Martin, and Walker (2014), in which government securities include Treasuries; debentures issued by Fannie Mae, Freddie Mac, and Ginnie Mae; and agency mortgage-backed securities (MBSs).

for approximately 80% of the collateral posted in bilateral repos, a major segment of the U.S. repo market (for more details, see Copeland, Davis, Lesueur, and Martin (2014)). The availability of high-quality assets, such as Treasury securities, is widely viewed as crucial in supporting financial stability and price discovery.[2] In the past few years, reduced issuance by the Treasury, the sharp increase in Treasury holdings by the Federal Reserve (Fed), and new financial regulations have reportedly shrunk the availability of Treasury collateral, raising concerns of policy makers and market participants alike.[3]

In this article we use evidence from the bilateral Treasury repo market to show that there is a significant and quite persistent "scarcity premium" on a broader set of Treasury securities than previously thought because it is not limited to on-the-runs and bills. Further, this repo-scarcity premium seems to spill over into the cash market, amplifying the price deviations of these securities from their fundamental values and possibly hindering price discovery. These results have potentially important implications for the functioning of the Treasury repo and cash markets and for a variety of policy issues, including the conduct of central bank operations that change the amount of Treasury collateral and the structure of debt issuance by governments.

The U.S. repo market comprises two segments: bilateral repo and triparty repo. In a bilateral repo, the settlement is handled directly by the trading parties rather than by a third-party clearing bank as in a triparty repo. Most importantly, whereas in triparty repo transactions the acceptable collateral can be any security within an asset class, bilateral repo transactions typically require specific collateral (SC) identified at the individual-security level because these are mainly tools to acquire specific securities rather than funding.[4] The SC repo market constitutes the bulk of the bilateral repo market, the size of which is estimated to range between \$2 and \$3.6 trillion based on recent studies, a giant relative to the Treasury cash market.[5]

The SC repo market constitutes an extremely important link between the traditional banking and shadow-banking systems, allowing hedging, shorting, and derivatives margining. By facilitating these activities, it has been fundamental in ensuring liquidity to cash markets. And in particular, by mitigating leverage constraints (e.g., Gromb and Vayanos (2010)), it has supported arbitrage trading, which is essential to market efficiency. Liquidity and efficiency in the Treasury cash market, in turn, help in avoiding broader mispricings in the economy

[2]For example, when Treasuries are scarce, the amount of privately issued short-term debt backed by lower-quality collateral increases, making a financial crisis more likely (e.g., Carlson et al. (2016), Krishnamurthy and Vissing-Jorgensen (2015), and Sunderam (2015)).

[3]For example, see the *Wall Street Journal* article by Burne (2015) and the Tabb Group report (2012); see Fleming and Keane (2016) for a related discussion of rising settlement fails in seasoned Treasury securities.

[4]Each individual U.S. Treasury security is uniquely identified by a number assigned by the Committee on Uniform Securities Identification Procedures (CUSIP). For simplicity, we use *individual security* and *CUSIP* interchangeably throughout the text.

[5]Copeland et al. (2014) estimate the size of the bilateral repo market to be approximately \$1.9–2.1 trillion based on data from Apr. 2013 to Oct. 2014 and the majority of bilateral transactions to be for specific rather than general collateral. Similar values are reported by Baklanova, Copeland, and McCaughrin (2015). Copeland et al. (2014) estimate a larger size of \$3.6 trillion based on data from July to Aug. 2008.

because the Treasury yield curve provides a benchmark for pricing virtually any other asset, not to mention its role in the transmission of monetary policy.

Still, it was not until the 2007–2009 financial crisis that the systemic importance of the bilateral repo market became evident, for instance, through the risk of fire sales of collateral assets.[6] Gorton and Metrick (2012) suggest that the dramatic increase in bilateral repo margins forced borrowers to delever by fire-selling assets, triggering a generalized run on some asset classes. However, Copeland et al. (2014) show that in both the bilateral and triparty segments, margins for the highest-quality collateral, such as U.S. Treasuries, did not change throughout the crisis, indicating elevated willingness to accept this type of collateral. Nevertheless, concurrent cascades of failures to deliver Treasuries in cash and repo markets suggest that many investors tended to hoard these safer securities, increasing the risk of lending Treasury collateral.[7]

Since the crisis, the focus on minimizing financial fragility has brought the amount and quality of repo collateral to the center of policy debates and research efforts (see, for instance, the comments of Chair Yellen (2013) and Vice-Chair Fisher (2015)). And yet, due in part to the lack of data, the value of Treasury collateral has not been quantified; therefore, the cost of its scarcity and the cost of spillovers to the Treasury cash market are not clear. To fill this gap, we investigate supply effects using novel security-level data in the Treasury SC repo market, where substitution across assets is limited by the contract specification, which precludes the possibility of delivering substitutes, creating an extreme form of imperfect substitutability. This provides an ideal testing ground because the scarcity of the underlying collateral should be the main determinant of the transaction cost, that is, the repo rate.

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.[8] Thus, we do not limit our attention to just a few on-the-run securities. Exploiting the daily cross-sectional variation of these security-level data over a period of almost 4 years, we estimate panel regressions to carefully pin down supply effects. Quantity variations in our sample mostly come from purchases and sales of Treasury securities under various Fed programs.[9] Because these programs targeted longer-term yields in the Treasury cash market rather than overnight rates in the repo market, it is safe to assume that they were not directly responding to changes in SC repo rates. By tracking

[6]See Acharya and Öncü (2013) for a more detailed discussion of the systemic risk posed by the bilateral and triparty repo markets.

[7]In Sept. and Oct. 2008, the daily average of primary dealer settlement fails in the Treasury market was above $200 billion (Garbade, Keane, Logan, Stokes, and Wolgemuth (2010)).

[8]Except for Jordan and Jordan (1997), who use Treasury auction results on 39 distinct notes from Sept. 1991 to Dec. 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).

[9]From Mar. 2009 to Dec. 2012, the Fed conducted two large-scale asset purchase programs by removing $900 billion of Treasury securities from the market and conducted two maturity extension programs by purchasing a total of $667 billion of Treasury securities with a maturity between 6 and 30 years and selling an equal amount of securities with a remaining maturity of 3 years or less.

cumulative 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.

We find that 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 3 months. This suggests the presence of a scarcity premium: 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* because they must lend money at relatively lower interest rates. These effects are also found to be important for off-the-run securities, a result that, to the best of our knowledge, has never been documented before in the repo market and is somewhat puzzling in light of existing theories of specialness (e.g., Vayanos and Weill (2008)). In addition, these impacts are larger in shorter-term securities, with average effects of −1.8 and −0.5 basis points (bps) per billion dollars for on- and off-the-run securities, respectively.[10]

Because the estimated repo-rate responses come from changes in the provision of public, safe, and liquid collateral made by the Fed, our evidence has the key ingredients for there to be potentially important implications for monetary policy. In particular, during the normalization process, if the Fed decides to gradually redeem maturing Treasury securities to reduce the size of its balance sheet, it will effectively increase the availability of on-the-run Treasury collateral, which in turn will put upward pressure on SC repo rates and related money market rates. Further, because the Fed is using overnight reverse repos as a supplementary policy tool, it could in theory become the largest (and most creditworthy) borrower in the repo market, with the power to set a floor on repo rates (Martin, McAndrews, Palida, and Skeie (2013)).[11] Our estimates indeed suggest that by changing the net supply of Treasury collateral, the Fed's reverse repos could potentially both help control money market rates and alleviate shortages of high-quality collateral.[12]

Our findings also have potentially important implications for Treasury debt management. For example, they suggest that increasing the issuance of shorter-term debt or reopening a security in high demand could reduce the scarcity premium and allow the Treasury to capture some savings.[13] Finally, our results can help quantify the impact on the repo market of new financial regulations that might affect the net supply of high-quality collateral. 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. Likewise, the mandatory central clearing of standardized over-the-counter derivatives

[10]This is consistent with the findings of a "money premium" on short-term and safe instruments, as in, for example, Greenwood, Hanson, and Stein (2015) and Carlson et al. (2016).

[11]As announced at the Sept. 2014 Federal Open Market Committee (FOMC) meeting in "Policy Normalization Principles and Plans."

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

[13]Greenwood, Hanson, Rudolph, and Summers (2014) suggest similar benefits to the Treasury from adopting a shorter debt-maturity profile.

will increase the demand for high-quality assets by requiring an initial margin on these transactions.[14]

In addition, because bonds that trade special in the repo market should trade at a premium in the cash market (e.g., Duffie (1996), Jordan and Jordan (1997), and Buraschi and Menini (2002)), we also analyze the relation between security-specific Treasury cash market premia, measured by the yield-curve fitting errors, and repo-specialness spreads. We find that this relation is significantly stronger on the days of the Fed operations and only for securities eligible for the Fed's purchases. This suggests that, on these days, the SC repo-scarcity premium gets discounted into higher Treasury cash prices and thus lower yields, providing additional evidence in favor of the scarcity channel of quantitative easing (QE) and explaining how recurrent and fairly predictable changes in supply can still affect Treasury prices when they occur (see, e.g., Krishnamurthy and Vissing-Jorgensen (2011) and D'Amico, English, López-Salido, and Nelson (2012)). That result, known as the flow or pace effect of QE, is one of the puzzling findings of D'Amico and King (2013), who estimate the price impact of the Fed's purchases in the Treasury cash market but do not account for their direct effects in the repo market. In contrast, our analysis shows that taking into account the repo- and cash-market effects of the Fed's operations provides a more complete picture of this policy's cumulative price impact across Treasury markets.

Our article is related to a growing literature that finds significant price responses to expected and unexpected changes in the net supply of various securities, including stocks (e.g., Shleifer (1986), Kaul, Mehrotra, and Morck (2000), Wurgler and Zhuravskaya (2002), and Greenwood (2005)) and bonds (e.g., Brandt and Kavajecz (2004), Lou, Yan, and Zhang (2013), and D'Amico and King (2013)). In these very liquid cash markets, the price impacts of anticipated and repeated supply shocks are typically shown to be temporary because the scarcity premium is quickly arbitraged away.[15] 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. Our study shows that when the pool of substitutes is virtually reduced to 0 by the contract specification, not only can the quantity impact be identified more precisely, but also it persists longer, amplifying price deviations from fundamental values, which could hinder price discovery.

The remainder of the article is organized as follows: Section II describes the SC repo market, the data, and the variables used in the empirical analysis, the results of which are discussed in detail in Section III, including some important robustness checks. In Section IV, we estimate the relation between Treasury cash prices and the repo-scarcity premium. Section V concludes.

[14]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 the availability of collateral assets.

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

II. Market Background and Data Description

A. SC Repo-Market Background

A repo is a transaction involving the spot sale of a security coupled with a simultaneous forward agreement to buy back the same security, usually on the next day. Thus, it is similar to a collateralized overnight loan where the party providing the funds earns interest at the repo rate. In SC repos the underlying collateral is a specific issue or CUSIP; hence, the SC repo market is a market for collateral rather than for funding.[16] The value of a specific security in this market can fluctuate depending on supply and demand dynamics, prompting some securities to become "special." Special securities trade at very low or even negative repo rates because investors are willing to pay to lend their cash so that they can have access to these securities. All SC repo transactions are conducted on a bilateral basis and are often open; that is, the agreement has an overnight tenor but continues until one of the counterparties decides to close it (Adrian, Begalle, Copeland, and Martin (2011)).

In the SC Treasury repo market, the high quality of the collateral attracts many market participants. Leveraged accounts, such as hedge funds, private equity firms, real estate investment trusts, exchange-traded funds, and broker-dealers, use these SC repos for a number of purposes, including to engage in hedging activity requiring a certain type of collateral; to obtain the cheapest to deliver (CTD) in futures contracts; and most commonly, to establish short positions (Duffie (1996)), that is, to borrow securities when prices are high in order to return them when prices are low. Broker-dealers, mutual and pension funds, money-market funds, custodial agents, and other owners of Treasury securities can borrow cash at an advantageous rate by lending specific securities and eventually re-lend the money at a higher rate, capturing a positive spread. Because all large broker-dealers are banks, the SC repo market constitutes a very important link between banks and shadow banks.

Overall, the SC Treasury repo market, by facilitating market making, hedging, arbitrage trading, and speculative activities, has been fundamental in ensuring efficiency and liquidity in the Treasury cash market. Conversely, the smooth functioning of the SC Treasury repo market and the 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 7:30AM and 10AM (Eastern time). This time window is chosen because trading in the repo market begins at approximately 7AM, remains active until approximately 10AM, and then becomes light until the market closes at 3PM. Repo transactions with specific collateral are executed on a delivery versus payment basis (i.e., same-day settlement).

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

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.

The repo-specialness spread is defined as the difference between the overnight repo rate for general collateral (GC) 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 occur around the time of Treasury auction announcements.

As shown in Figure 2, not only on-the-run securities but also off-the-run securities can have positive specialness spreads. Graph A 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. This off-the-run repo spread is always positive in our sample and exhibits significant fluctuations, at times jumping above 15 bps. It is important to note that this is not negligible for overnight money market rates. In addition, a comparison with Graph B, which plots the Fed purchase amounts in this maturity sector, shows that the repo-specialness spreads tend to be higher and more volatile in periods when Fed purchases were larger, whereas they seem lower and less volatile from Oct. 2009 and Oct. 2010 when there were no asset purchases. Interestingly, security-level data from the Depository Trust & Clearing Corporation (DTCC) show that fails to deliver in seasoned Treasury securities, defined as securities issued more than 180 days prior, 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. Further, seasoned fails continued to rise steadily from 2012 to 2016, reaching a daily average of $40 billion, possibly indicating increasing scarcity of high-quality collateral (see Fleming, Keane, Martin, and McMorrow (2014) and Fleming and Keane (2016) for more details.).

To compute the specialness spread, we use Treasury GC repo rates from the General Collateral Finance (GCF) Repo Index, which is a triparty repo platform

FIGURE 1

Repo-Specialness Spread for On-the-Run 10-Year Treasury Security

To compute the specialness spread, we use Treasury general collateral (GC) repo rates from the General Collateral Finance (GCF) Repo Index, which tracks average daily interest rates on a triparty repo platform maintained by the Depository Trust & Clearing Corporation (DTCC).

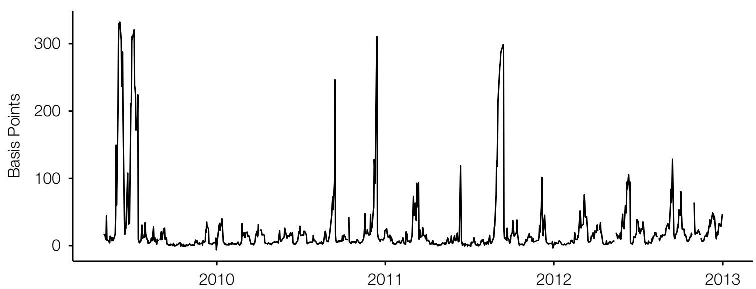
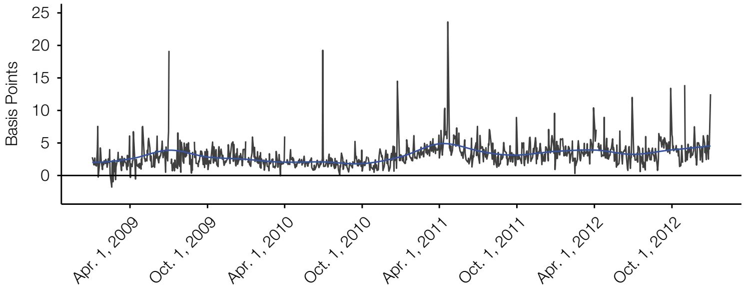


FIGURE 2

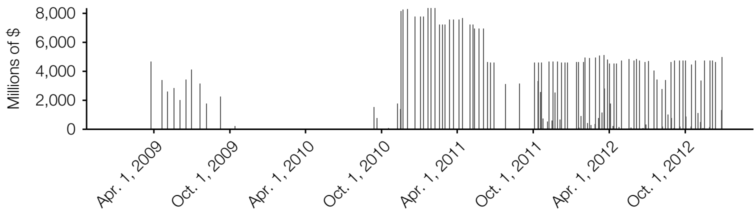
Repo-Specialness Spread for Off-the-Run 10-Year Treasury Securities

Graph A of Figure 2 shows the daily average repo spread across off-the-run securities with remaining maturities of 7–10 years. The smooth line shows a local-weighted scatterplot smoother (LOESS) curve fitted to the averages. Graph B shows the total daily Fed purchases of these securities over time.

Graph A. Average Repo-Specialness Spread



Graph B. Fed Purchases



maintained by the DTCC.[17] This market is characterized as being primarily interdealer, although some commercial banks and Fannie Mae also participate. It is a fairly active market, although its size is still small compared with that of the overall triparty repo market (for more detail about the GCF Repo Index, see Fleming and Garbade (2003)). In this study, the specialness spread is mainly used for graphical purposes and comparisons to previous studies because the time dummies in our panel specification control for market-wide effects such as variation in the GC repo rate.

C. Quantity-Factor Data

During our sample period, from Mar. 2009 to Dec. 2012, the Fed conducted two large-scale asset purchase (LSAP) programs, one reinvestment program, and two maturity extension programs (MEPs) (for more details on these programs, see Cahill, D'Amico, Li, and Sears (2013)). These programs 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

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

programs, obtained from the New York Fed.[18] 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.[19]

Summary statistics of the Fed operations are shown in Table 1. In our sample, the Fed conducted 3,162 purchases and 810 sales of securities across various operations, where most of the CUSIPs were purchased or sold multiple times. The average purchase size is $420 million or 1.68% of the security's privately held amount outstanding; the average sale size is approximately $710 million or 2.86% of the security's privately held amount outstanding. The majority of operations were concentrated in off-the-run securities (approximately 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 because short sellers value the ability to quickly buy back those securities to cover or unwind their positions (Duffie, Gârleanu, and Pedersen (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, although the small number of Fed operations in on-the-run securities limits our statistical power. By reducing the collateral available to the repo market, Fed purchases

TABLE 1
Summary Statistics: Fed Operations

Table 1 reports summary statistics of quantities of Treasury securities purchased and sold at the Fed's operations conducted during our sample period. Amounts bought and sold are measured in dollars. Percentages bought and sold are measured as a percentage of the privately held amount outstanding.

Variable	Mean	Std. Dev.	*N*
Panel A. Total			
PERCENT_BOUGHT	1.68	2.57	3,162
AMOUNT_BOUGHT	4.2e+08	7.4e+08	
PERCENT_SOLD	2.86	4.56	810
AMOUNT_SOLD	7.1e+08	9.2e+08	
Panel B. On-the-Run			
PERCENT_BOUGHT	7.91	6.45	127
AMOUNT_BOUGHT	2.3e+09	1.9e+09	
PERCENT_SOLD	1.24	1.37	15
AMOUNT_SOLD	4.2e+08	4.8e+08	
Panel C. Off-the-Run			
PERCENT_BOUGHT	1.42	1.86	3,035
AMOUNT_BOUGHT	3.4e+08	5.2e+08	
PERCENT_SOLD	2.89	4.59	795
AMOUNT_SOLD	7.1e+08	9.3e+08	

[18] System Open Market Account (SOMA) operation and holding data by CUSIP are publicly available on the New York Fed's Web site: http://www.ny.frb.org/markets/pomo/display/index.cfm.

[19] "Privately held" Treasury securities are defined here as any security not held by the Federal Reserve and are calculated by subtracting the par value held in the SOMA portfolio from the total outstanding par value; the par values are obtained from the Center for Research in Security Prices (CRSP).

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 in SOMA on an overnight basis. But the SLP is limited to primary dealers and has constraints on both the amount of an individual issue a dealer can borrow (25% of the lendable holdings) and the daily amount a dealer can borrow in aggregate across all issues ($5 billion).[20] The program works through an auction mechanism to make loan pricing a market-driven process as primary dealers bid, specifying the quantity and the loan fee. The minimum fee is imposed to provide an incentive to borrow only 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 because any dealer who was not able to obtain the desired amount at the SLP to cover its positions would then have to seek the securities in the repo market, potentially pushing up demand for certain securities. We also control for the total amount borrowed at each SLP auction because it might better capture a security's demand.

D. 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*. This imbalance, which should capture the security's excess demand, can create price pressures in the specific security and might make it run special.

As we discuss in detail in the Supplementary Material, Treasury repo rates and spreads exhibit periodic patterns associated with Treasury auctions (Keane (1995)). We control for these auction-cycle effects by including in our regressions a set of dummy variables that track the time elapsed since issuance for both the monthly and quarterly cycle securities.

In addition, because 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 at the close of business and

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

reported in cents per hundred dollars.[21] Securities with lower bid–ask spreads are more liquid; therefore, we expect them to have lower repo rates and higher specialness spreads.

Finally, if individual specialness spreads are not persistent and therefore mean-reverting, the SC repo 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 program purchases. In other words, if omitted when estimating the relation between SC repo rates and Fed purchases, the initial specialness spreads might be correlated with the regression error term. Further, there may be other information embedded in the specialness spread before each operation that reflects expectations of future scarcity. To control for these possibilities, we include the initial level of the specialness spread, that is, the spread on the day preceding each operation, as a regressor.

To conclude, Table 2 reports the variables' main statistics on the days of the Fed operations (excluding the supply factors that are summarized in Table 1). In particular, the first two columns show those statistics for on-the-run securities, the third and fourth columns show those statistics for the off-the-run securities, and the last two columns report them for all securities in the sample. Not surprisingly, on-the-run Treasuries are characterized by much lower and more volatile SC repo rates than off-the-run Treasuries, and hence they have much larger and more volatile specialness spreads. Similarly, as indicated by the smaller and less volatile bid–ask spread, on-the-run securities are consistently more liquid than off-the-run securities. More importantly, the repo-volume spread, which we employ as a proxy for the securities' excess demand, is negative and 10 times larger for on-the-run securities, suggesting that, indeed, it could be capturing demand for short positions because those would be mainly concentrated in the most liquid securities.

TABLE 2

Summary Statistics: Operation Days

Table 2 reports summary statistics for selected variables of interest on the days of the Fed operations. Specific collateral (SC) repo rates and repo-specialness spreads are measured in basis points. Repo-volume spread is our proxy for short positions and is standardized and measured in standard deviations. Bid–ask spreads are measured in cents. The Δ variables are 1-day changes in values.

	On-the-Run		Off-the-Run		Total	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
REPO_RATE	5.6	21.8	14.2	7.49	14	8.21
ΔREPO_RATE	−0.213	6.75	0.0177	2.97	0.0123	3.11
REPO_SPREAD	11.1	20.9	2.77	3.29	2.97	4.72
ΔREPO_SPREAD	0.152	6.65	−0.0821	2.73	−0.0766	2.88
REPO_VOLUME_SPREAD	−0.261	3.33	−0.0264	0.91	−0.0319	1.03
BID_ASK_SPREAD	1.35	0.559	3.15	2.42	3.1	2.41
ΔBID_ASK_SPREAD	0.0027	0.574	−0.00573	0.921	−0.00553	0.914
N	2,029		85,308		87,337	

[21]Composites of bid and ask prices for individual Treasury securities quoted across electronic platforms are obtained from the New York Fed.

III. Empirical Results

We now turn to estimating the impact of the previously described security-specific demand and supply factors on SC repo rates through a series of panel regressions. Various empirical specifications are estimated at a daily frequency, where the dependent variable is the change in the SC repo rate for all outstanding nominal Treasury coupon securities maturing within 15 years because the repo market in longer-term securities is very thin. Consequently, our unbalanced panel consists of 347 CUSIPs. Unlike previous studies, we use changes rather than levels because these variables exhibit a high degree of serial correlation.

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

We start our sample after the introduction of the repo-fail charge by the Treasury Market Practices Group on May 1, 2009, to avoid a structural break in the series.[22] Furthermore, because before June 23, 2009, we cannot observe whether individual transactions were initiated as repos or reverse repos, we use the slightly shorter sample starting on that date.

A. Regression Specification

Our basic panel regression specification is the following:

$$
\begin{aligned}
(1)\qquad \Delta \mathrm{SCR}^{\mathrm{am}}_{i,t,t+j} \;=\; & \alpha + \sum_{m=1}^{2} \beta_{1m} \Delta \mathrm{SF}_{m,i,t} + \sum_{n=1}^{2} \beta_{2n} \Delta \mathrm{DF}_{n,i,t} \\
& + \sum_{k=1}^{2} \beta_{3k} \mathrm{IF}_{k,i,t-1} + \beta_4 \tau_{i,t} + \beta_5 D_{i,t} + \gamma_t + \epsilon_{i,t},
\end{aligned}
$$

where for each security i on day t, $\Delta \mathrm{SCR}_{t,t+j}$ is the change in the SC repo rate in basis points from day t to $t+j$, where $j=1$ in the baseline specification; $\Delta \mathrm{SF}_m$ represents the change in the mth supply factor, specifically, the amount purchased and sold at each Fed operation rescaled by the security's privately

[22] See http://www.newyorkfed.org/tmpg/tmpg_faq_033109.pdf for details on the implementation of the fail charge. Fleming, Krishnan, and Reed (2012) show that this triggered striking changes in the willingness to receive negative interest rates on cash pledged to secure borrowing of certain securities.

held amount outstanding; $\Delta\mathrm{DF}_n$ represents the change in the nth demand factor, specifically, our proxy for short positions rescaled by the security's privately held amount outstanding and the amount of uncovered bids at the SLP auctions; IF_k denotes the kth control for idiosyncratic factors, that is, liquidity characteristics measured by the lagged change in the bid–ask spread, as well as repo-financing advantages measured by the lagged level of the specialness spread; τ consists of maturity and maturity squared; D represents dummies that control for the auction cycle, as discussed in the Supplementary Material; and γ_t represents daily time dummies that control for the evolution over time of common market-wide factors.

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, changes in supply and demand factors are interacted with a dummy that divides the sample into two mutually exclusive subsamples: on-the-run versus off-the-run securities. Furthermore, because Fed operations settle on the following day, we also use the 2-day change in the SC repo rate (i.e., we set $j=2$ in equation (1)) as the dependent variable in our regressions. The rationale is that the impact of these operations might not be felt until the day on which the investors have to actually deliver or receive the security to or from the Fed. Throughout our empirical analysis, equation (1) is estimated using only days when Fed operations were conducted.[23]

B. Results

The results from the panel regression using the 1-day change in the SC repo rate are reported in the first column of Table 3, whereas the second column shows the results for the 2-day change in the same dependent variable.[24,25] Both on- and off-the-run Fed purchases have negative and statistically significant effects on SC repo rates, although their size appears to be considerably larger for on-the-run securities. The coefficient of −0.224 suggests that buying 1% of a security's outstanding would decrease the SC repo rate by 0.224 bps, implying that on average a \$1 billion purchase of on-the-run securities would decrease the SC repo rate by 0.8 bps.[26] In contrast, the coefficient for the off-the-run securities implies a decline of 0.35 bps for a purchase of the same size.

This suggests the existence of a scarcity premium because 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 security, facing an additional cost. And owners of the same security would obtain

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

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

[25]In our regressions, we discard observations for which the 1-day change in the SC repo rate exceeds 40 bps or the 2-day change exceeds 60 bps. These threshold choices seem reasonable because in our full sample, over 99.9% of observations are within each threshold.

[26]The reported value is obtained as follows: Based on the average purchased amount and fraction of the on-the-runs reported in Table 1, 7.9% of the outstanding corresponds to \$2.3 billion, and therefore, 1% of the outstanding corresponds to \$0.29 billion, implying that to obtain the impact for \$1 billion, the coefficient has to be multiplied by 3.48.

TABLE 3
Specific Collateral Repo-Rate Regressions

Table 3 reports the estimation results of our baseline specification outlined in equation (1). Heteroscedasticity-consistent t-statistics are reported in parentheses. Repo rates are measured in basis points. Percentages bought and sold are measured as a percentage of the privately held amount outstanding. Repo-volume spread is our proxy for short positions and is standardized and measured in standard deviations. Bid–ask spreads are measured in cents. Bids left uncovered at the Securities Lending Program (SLP) are measured as a percentage of the privately held amount outstanding. Repo spreads are measured in basis points. The Δ variables are 1-day changes in values. We also control for time and auction-cycle dummies, maturity, and maturity squared, which are not shown for brevity. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	1-Day Changes	2-Day Changes
Variable	1	2
PERCENT_BOUGHT_OFF_THE_RUN	−0.0846***	−0.114***
	(−6.54)	(−6.83)
PERCENT_SOLD_OFF_THE_RUN	0.0492***	0.0583***
	(3.93)	(5.56)
PERCENT_BOUGHT_ON_THE_RUN	−0.224***	−0.264***
	(−4.43)	(−3.60)
PERCENT_SOLD_ON_THE_RUN	0.0342	0.353
	(0.08)	(0.71)
REPO_VOLUME_SPREAD	−0.0279*	−0.00817
	(−1.71)	(−0.38)
LAGGED_ΔBID_ASK_SPREAD	0.00433	0.00388
	(0.69)	(0.51)
SLP_UNCOVERED_BIDS_ON_THE_RUN	−0.0218	0.0139
	(−0.62)	(0.37)
SLP_UNCOVERED_BIDS_OFF_THE_RUN	−0.00429	0.00212
	(−1.35)	(0.61)
LAGGED_REPO_SPREAD	0.0422***	0.0978***
	(3.25)	(7.71)
N	85,257	84,464
R^2	0.745	0.750
Adj. R^2	0.743	0.749

financing at a more attractive rate, enjoying an extra profit. The coefficients when using the 2-day changes (shown in the second column of Table 3) 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 0.0492 suggests that selling 1% of a security's outstanding would increase the SC repo rate by 0.0491 bps, implying that a \$1 billion sale would increase the SC repo rate by 0.2 bps.[27] The cumulative impact is again slightly bigger on the settlement day.

Conversely, our proxies for demand factors seem to be less important. The demand for short positions (repo-volume spread) has no significant effect on SC repo rates. In this case, the split in on- and off-the-run securities (not shown) does not affect its statistical significance. The SLP coefficient is also not statistically significant. One possible explanation is that, as mentioned in Section II.C, each dealer's participation is capped, making this tool less effective in releasing demand pressure.

[27]The reported value is obtained as follows: Based on the average purchased amount and fraction of the off-the-runs reported in Table 1, 2.9% of the outstanding corresponds to \$0.7 billion, and therefore, 1% of the outstanding corresponds to \$0.24 billion, implying that to obtain the impact for \$1 billion, the coefficient has to be multiplied by 4.14.

Finally, as shown by the estimated coefficient of the last variable in Table 3, the lagged level of the specialness spread is highly significant. Interestingly, when we include this variable, maturity and maturity squared lose their marginal predictive power (not shown), suggesting that the initial level of the specialness spread already captures most of the relevant information specific to each security.

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 (3–7 years), and securities with longer maturities (7–15 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 −1.8 and −0.5 bps 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. Similarly, in this subsample, the demand

TABLE 4

Specific Collateral Repo-Rate Regressions by Maturity Subsample: 1-Day Changes

Table 4 reports the estimation results of our baseline specification in subsamples based on the securities' maturity, with the 1-day change in the repo rate on the left-hand side. Heteroscedasticity-consistent t-statistics are reported in parentheses. Repo rates are measured in basis points. Percentages bought and sold are measured as a percentage of the privately held amount outstanding. Repo-volume spread is our proxy for short positions and is standardized and measured in standard deviations. Bid–ask spreads are measured in cents. Bids left uncovered at the Securities Lending Program (SLP) are measured as a percentage of the privately held amount outstanding. Repo spreads are measured in basis points. The Δ variables are 1-day changes in values. We also control for time and auction-cycle dummies, maturity, and maturity squared, which are not shown for brevity. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	0–3 Years	3–7 Years	7–15 Years
Variable	1	2	3
PERCENT_BOUGHT_OFF_THE_RUN	−0.146***	−0.0644***	−0.0759***
	(−3.31)	(−3.31)	(−3.33)
PERCENT_SOLD_OFF_THE_RUN	0.0472***		
	(3.78)		
PERCENT_BOUGHT_ON_THE_RUN	−0.562***	−0.0906***	−0.441
	(−4.04)	(−2.85)	(−0.98)
PERCENT_SOLD_ON_THE_RUN	−0.130		
	(−0.26)		
REPO_VOLUME_SPREAD	−0.0671**	−0.0226	0.0228
	(−2.43)	(−1.00)	(0.65)
LAGGED_ΔBID_ASK_SPREAD	0.0145	−0.000507	−0.00720
	(1.45)	(−0.05)	(−0.49)
SLP_UNCOVERED_BIDS_ON_THE_RUN	−0.0142	−0.171	−0.00298
	(−0.31)	(−1.42)	(−0.05)
SLP_UNCOVERED_BIDS_OFF_THE_RUN	−0.00484**	−0.00722	0.00746
	(−2.38)	(−0.11)	(0.54)
LAGGED_REPO_SPREAD	0.0426	0.0554***	0.0330***
	(1.38)	(3.18)	(3.43)
N	44,838	29,455	10,964
R^2	0.773	0.764	0.648
Adj. R^2	0.770	0.760	0.632

TABLE 5

Specific Collateral Repo-Rate Regressions by Maturity Subsample; 2-Day Changes

Table 5 reports the estimation results of our baseline specification in subsamples based on the securities' maturity, with the 2-day change in the repo rate on the left-hand side. Heteroscedasticity-consistent t-statistics in parentheses. Repo rates are measured in basis points. Percentages bought and sold are measured as a percentage of the privately held amount outstanding. Repo-volume spread is our proxy for short positions and is standardized and measured in standard deviations. Bid–ask spreads are measured in cents. Bids left uncovered at the Securities Lending Program (SLP) are measured as a percentage of the privately held amount outstanding. Repo spreads are measured in basis points. The Δ variables are 1-day changes in values. We also control for time and auction-cycle dummies, maturity, and maturity squared, which are not shown for brevity. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	0–3 Years	3–7 Years	7–15 Years
Variable	1	2	3
PERCENT_BOUGHT_OFF_THE_RUN	−0.241*** (−4.05)	−0.0850*** (−3.67)	−0.0865*** (−3.47)
PERCENT_SOLD_OFF_THE_RUN	0.0565*** (5.38)		
PERCENT_BOUGHT_ON_THE_RUN	−0.654*** (−3.25)	−0.103* (−1.90)	−0.00370 (−0.01)
PERCENT_SOLD_ON_THE_RUN	0.138 (0.22)		
REPO_VOLUME_SPREAD	−0.0337 (−0.81)	−0.0487** (−2.24)	0.0999** (2.12)
LAGGED_ΔBID_ASK_SPREAD	0.00246 (0.21)	0.00118 (0.09)	0.0160 (0.88)
SLP_UNCOVERED_BIDS_ON_THE_RUN	0.0413 (0.89)	−0.000674 (−0.01)	−0.00233 (−0.04)
SLP_UNCOVERED_BIDS_OFF_THE_RUN	−0.00280 (−0.94)	0.0821* (1.71)	0.00971 (0.51)
LAGGED_REPO_SPREAD	0.131*** (4.69)	0.0883*** (4.75)	0.0774*** (4.68)
N	44,421	29,198	10,845
R^2	0.790	0.754	0.664
Adj. R^2	0.788	0.750	0.649

for short positions is also statistically significant and carries the expected negative sign. Table 5 shows results from the same regressions but using the 2-day change in the SC repo rate, confirming that on the settlement day, the magnitude of all the significant coefficients is a bit bigger.

C. Robustness Checks

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

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

$$(2) \qquad \text{SUB\_PURC}_{it} = \sum_{j \neq i} W\left(\frac{m_{it} - m_{jt}}{h}\right) \text{PURC}_{jt},$$

where h is a bandwidth parameter; m_{it} is the remaining maturity at time t for security i; and W is a weight function, which we choose to be the tri-cube function: $W(u) = (1 - |u|^3)\mathbb{1}_{|u|\leq 1}$. This function is chosen because i) $W(0) = 1$, so purchases of securities with identical maturities are counted at full value; ii) it is bell-curve-shaped, which captures the idea of a gradually decreasing degree of substitution; and iii) it has finite support, so securities with very different maturities will have 0 weight.[28]

Similarly, when we construct the buckets of substitutes based on either liquidity or specialness, we make the weights a function of the distance between the lagged individual yield-curve fitting errors and specialness spreads, respectively.[29] In addition, the weight function can be generalized to allow for a second dimension so that substitutability is defined by two characteristics, either maturity and fitting errors or maturity and specialness. Finally, to more easily compare these coefficients, we scale the amount of substitutes by security i's privately held amount outstanding.[30]

As shown in the first column of Table 6, we find that the coefficient for the close-substitute purchases, defined in terms of maturity distance, is not statistically significant. This result is diametrically opposite to the findings of D'Amico and King (2013), who study the price impact of the first LSAP program in the Treasury cash market and find the coefficient for the close-substitute purchases to be almost as important as that for the purchases of the security itself, indicating a much smaller degree of imperfect substitution in the cash market relative to what we observe in the SC repo market. However, even in their study, the decreasing magnitude of the price impact for securities with increasing maturity distance from the purchased security suggests some degree of segmentation across maturities in the cash market. Our results indicate that this type of imperfect substitutability is extreme in the SC repo market, lending strong support to our hypothesis. Furthermore, as shown in columns 2–5 of Table 6, the coefficient for the close-substitute purchases remains close to 0 and not statistically significant when we measure substitutability with the vicinity of the fitting errors, specialness spreads, a combination of maturity and fitting errors, and a combination of maturity and specialness spreads. This indicates that no matter how one measures substitutability, the absence of substitution effects is evident in the SC repo market, suggesting that this limited substitutability plays an important role in the significance and persistence of the repo-scarcity premium.

[28]To smoothly scale up the bucket size as maturities increase, we transform the raw maturities before applying equation (0). 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.

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

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

TABLE 6
Robustness Checks; Substitutes; 1-Day Changes

Table 6 reports the estimation results of the specifications in which the effects of purchases and sales of substitute securities are considered. Heteroscedasticity-consistent *t*-statistics are reported in parentheses. Repo rates are measured in basis points. Percentages bought and sold are measured as a percentage of the privately held amount outstanding. Fitting errors are measured in cents, where more positive is more expensive. Repo-volume spread is our proxy for short positions and is standardized and measured in standard deviations. Repo spreads are measured in basis points. Bid–ask spreads are measured in cents. The Δ variables are 1-day changes in values. We also control for time and auction-cycle dummies, maturity, and maturity squared, which are not shown for brevity. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	ΔREPO				
Variable	1	2	3	4	5
PERCENT_BOUGHT_OFF_THE_RUN	−0.0790***	−0.0841***	−0.0845***	−0.0810***	−0.0829***
	(−6.03)	(−6.52)	(−6.53)	(−6.22)	(−6.25)
PERCENT_SOLD_OFF_THE_RUN	0.0453***	0.0479***	0.0479***	0.0461***	0.0473***
	(3.68)	(3.88)	(3.88)	(3.72)	(3.82)
PERCENT_BOUGHT_ON_THE_RUN	−0.223***	−0.224***	−0.223***	−0.223***	−0.223***
	(−4.42)	(−4.42)	(−4.41)	(−4.42)	(−4.42)
PERCENT_SOLD_ON_THE_RUN	−0.147	−0.142	−0.145	−0.145	−0.144
	(−0.57)	(−0.55)	(−0.56)	(−0.56)	(−0.56)
SUB_PURC_MATURITY	−0.000857*				
	(−1.65)				
SUB_PURC_FIT_ERR		−0.000140			
		(−0.50)			
SUB_PURC_REPO_SPREAD			0.000156		
			(0.45)		
SUB_PURC_FIT_ERR&MAT				−0.000663	
				(−1.13)	
SUB_PURC_REPO&MAT					−0.000413
					(−0.74)
REPO_VOLUME_SPREAD	−0.0271	−0.0270	−0.0270	−0.0271	−0.0270
	(−1.62)	(−1.62)	(−1.61)	(−1.62)	(−1.62)
LAGGED_ΔBID_ASK_SPREAD	0.00452	0.00446	0.00447	0.00444	0.00445
	(0.72)	(0.71)	(0.71)	(0.71)	(0.71)
LAGGED_REPO_SPREAD	0.0419***	0.0416***	0.0416***	0.0418***	0.0416***
	(3.18)	(3.18)	(3.20)	(3.18)	(3.20)
N	85,257	85,257	85,257	85,257	85,257
R^2	0.745	0.744	0.744	0.744	0.744
Adj. R^2	0.743	0.743	0.743	0.743	0.743

Next, we try to address some of the estimation concerns that might arise because of the mechanics of the Fed's purchase and sale operations. To this end, we provide additional details about the logistics of these operations. At the end of each month, the Open Market Desk at the New York Fed (the Desk) announced the tentative schedule for the entire upcoming month. The announcement of the tentative schedule included the operation type, the 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 CTD in futures contracts, those with high scarcity value in the repo market, and those for which 70% of the issue was already owned by SOMA.[31] Then primary dealers submitted their propositions, specifying the amount and price of each CUSIP at which they were willing to sell to (buy from) the Desk. Given

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

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

Based on the Desk's exclusion criteria, it is plausible that the Desk's algorithm would tend to select, among the submitted bids, those securities that were cheaper relative to the yield curve. This might have introduced a relation between the relative cheapness of each security and the quantity purchased by the Fed. Because 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 address this concern, we augment our baseline specification with the level of the individual yield-curve fitting errors (a proxy of how "expensive" a security is relative to those with same coupon rate and time to maturity) as of the end of the day preceding each operation. As shown in the first column of Table 7, the level of the individual fitting error is not statistically significant and hardly affects any of the coefficients.

Our next robustness check is related to the SLP. Although in our baseline specification, for the reasons explained in Section II.C, we already control for security-level uncovered bids at the SLP auctions (see Table 3), it is plausible that the total amount of borrowing at each of these auctions could have been more

TABLE 7

Robustness Checks; Other Controls; 1-Day Changes

Table 7 reports on the specifications in which control variables are included. Heteroscedasticity-consistent t-statistics are reported in parentheses. Repo rates are measured in basis points. Percentages bought and sold are measured as a percentage of the privately held amount outstanding. Fitting errors are measured in cents, where more positive is more expensive. The total amount borrowed at the Securities Lending Program (SLP) is measured in dollars. Repo-volume spread is our proxy for short positions and is standardized and measured in standard deviations. Bid–ask spreads are measured in cents. Repo spreads are measured in basis points. The Δ variables are 1-day changes in values. We also control for time and auction-cycle dummies, maturity, and maturity squared, which are not shown for brevity. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	ΔREPO	
Variable	1	2
PERCENT_BOUGHT_OFF_THE_RUN	−0.0843***	−0.0838***
	(−6.52)	(−6.50)
PERCENT_SOLD_OFF_THE_RUN	0.0481***	0.0481***
	(3.89)	(3.89)
PERCENT_BOUGHT_ON_THE_RUN	−0.223***	−0.223***
	(−4.42)	(−4.41)
PERCENT_SOLD_ON_THE_RUN	−0.143	−0.153
	(−0.55)	(−0.59)
LAGGED_FIT_ERROR	0.000686	
	(0.54)	
SLP_TOTAL_AMT_BORROWED		−7.07e−11
		(−0.69)
REPO_VOLUME_SPREAD	−0.0270	−0.0272
	(−1.61)	(−1.63)
LAGGED_ΔBID_ASK_SPREAD	0.00435	0.00444
	(0.70)	(0.71)
LAGGED_REPO_SPREAD	0.0415***	0.0432***
	(3.19)	(3.15)
N	85,257	85,257
R^2	0.744	0.745
Adj. R^2	0.743	0.743

relevant in capturing the security's heightened demand. In the second column of Table 7, we show the results for the regressions augmented with this variable. Similar to the results for the individual amount of uncovered bids, the coefficient on the security-level total amount borrowed at the SLP is also not statistically significant.

Finally, to account for possible correlations across the regression errors of collateral with comparable maturities, we also run the analysis with clustered standard errors. The results are robust to the type of standard error used because the statistical significance of the estimated coefficients is practically unchanged. The corresponding table and discussion can be found in the Supplementary Material.

D. Persistence

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 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, Graph A of Figure 3 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.[32] In the dynamic specification, in addition to the variables used in the baseline regressions (see Section III.A), we also control for any future purchases that took place over the n-day time period. Figure 3 shows that the effect is quite persistent; it converges toward 0 very slowly and stays significant for at least 3 months (60 business days). Further, in the week following the purchase operation, on average, the estimated coefficient increases in magnitude to -0.12 (from -0.085), indicating that a \$1 billion purchase would decrease the SC repo rate by 0.5 bps, and after approximately 2 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 Graph B, the effect is less persistent for sales; it remains significant for approximately 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 dissipate quickly, at least in our sample. This is remarkable if we consider that in our panel, time dummies sweep out any market-wide effects, including Fed and Treasury actions and announcements; hence, 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 in the Treasury cash market, which revert to 0 after 6 days from the day of purchase (D'Amico and King (2013)). This could be due to the security-specific nature

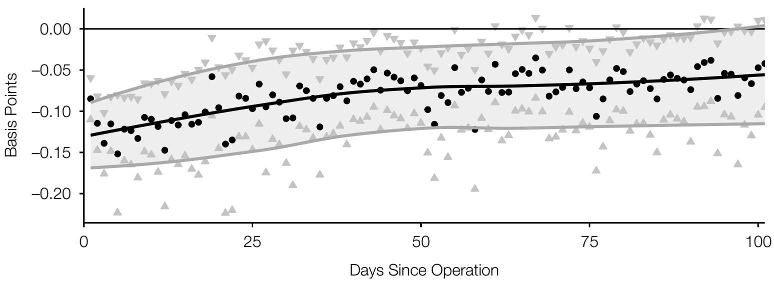
[32]The small sample size for the on-the-run securities limits our ability to test for dynamic effects.

FIGURE 3

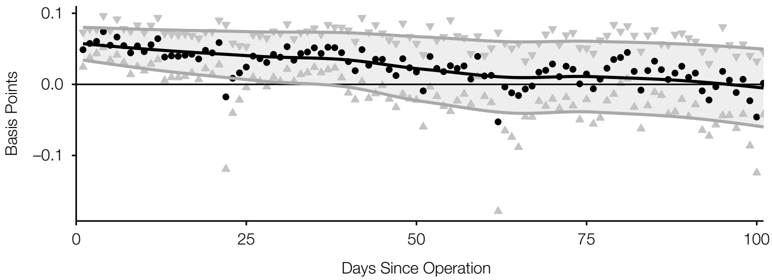
Coefficients on the Percentage Bought or Sold by the Fed

The coefficients in Figure 3 are obtained from regressions using the cumulative changes in the specific collateral (SC) repo rate over the *n*-day period following each operation as the dependent variable. Black points indicate the estimated coefficients for each period. Gray triangles indicate the 95% confidence interval for each of those coefficients. The lines are fitted local-weighted scatterplot smoother (LOESS) curves.

Graph A. Fed Purchases



Graph B. Fed Sales



of SC repo contracts, which prevent the delivery of close substitutes. In other words, anyone who sold collateral short must deliver that specific bond, 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 persistence of the supply effects: If there is a significant amount of open short positions established through reverse repos, and the net supply of the underlying collateral decreases (in this particular case because of the Fed purchases), at impact, the price of the Treasury collateral in the cash market would increase, and the current and expected future repo rates 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), resetting 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 persistence of the supply shock.

IV. Relation to Cash-Market Prices

In light of the recent literature's findings that even repeated and anticipated changes in supply can affect Treasury cash prices (as shown by Lou et al. (2013) for Treasury auctions and by D'Amico and King (2013) for the Fed's Treasury LSAP programs), 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), and Buraschi and Menini (2002)), it is natural to hypothesize that some of the LSAP programs' price effects in the cash market might reflect changes in repo-specialness spreads due to the Fed operations estimated in Section III.B. In this section, we provide evidence supporting this conjecture.

It is well established that securities with higher current and expected future repo specialness tend to be more expensive in the cash market, irrespective of the specific demand–supply imbalance inducing the heightened specialness.[33] This relation also holds in our full sample: Treasury bonds with higher cash price premia (relative to the bonds with the same coupon and maturity) also have larger repo-specialness spreads. However, in contrast to previous studies, we also find that this relation becomes stronger on the days of the Fed purchase/sale operations and only in the subsample of securities that were eligible for purchase/sale in at least one of the operations included in our sample. Because 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, such strengthening in the relation between cash price premia and repo spreads provides some support for our hypothesis. Namely, 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 8 shows results from four panel regressions broadly motivated by the work of Jordan and Jordan (1997), in which levels of the securities' cash price premia measured at the end of the day are regressed on their repo-specialness spreads as of the morning of the same day. We start by analyzing this relation in the full sample, including all days and all available securities, and then progressively zoom in on specific subsamples that help us to better test our conjecture. We also control for the securities' liquidity and risk differentials through the bid–ask spread, on-the-run dummy, and maturity squared. To measure each specific security's price premium in the cash market over an otherwise identical note (i.e., a note with the same coupon rate and time to maturity), we use the deviation of its observed yield from the Svensson (1994) zero-coupon

[33] Studies that examine the relation between price differentials in the Treasury cash market and funding conditions in the repo market include those by Krishnamurthy (2002), Goldreich, Hanke, and Nath (2005), Musto, Nini, and Schwarz (2011), Fontaine and Garcia (2012), and Banerjee and Graveline (2013).

TABLE 8
Cash Market Premium Regressions

Table 8 reports the estimation results for specifications in which cash market premiums are regressed on repo spreads and control variables in four (sub)samples. *t*-statistics are shown in parentheses. Repo spreads are measured in basis points. Operation days are days that the Fed conducts purchases or sales. Bid–ask spreads are measured in cents. "Ever Eligible" tracks securities that the Fed ever determines to be eligible for purchase or sale, and "Never Eligible" tracks those that were never eligible for purchase (i.e., met the Fed's exclusion criteria mentioned in Section III.C). We also control for time and security dummies. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	All Days		Ever Eligible	Never Eligible
Variable	1	2	3	4
REPO_SPREAD	0.0458***	0.0326***	0.0335***	0.0203
	(10.26)	(6.41)	(6.43)	(1.12)
REPO_SPREAD × OPERATION_DAY		0.0294***	0.0314***	−0.00554
		(3.60)	(3.66)	(−0.28)
BID_ASK_SPREAD	−0.417***	−0.416***	−0.408***	−0.668***
	(−45.77)	(−45.69)	(−45.43)	(−5.96)
ON_THE_RUN	1.191***	1.171***	1.267***	0.337*
	(17.60)	(17.41)	(16.80)	(2.01)
MATURITY^2	0.229***	0.229***	0.221***	−0.885***
	(83.67)	(83.76)	(81.70)	(−11.27)
N	165,535	165,535	157,117	8,418
R^2	0.294	0.294	0.255	0.711
Adj. R^2	0.289	0.289	0.250	0.674

yield curve.[34] 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 by the first coefficient in the first column in Table 8, in the full sample the Treasury bond's cash price premium is significantly positively related to the specialness spread, confirming that this relation holds on average in our sample irrespective of the LSAP operations.[35] More importantly, this coefficient becomes larger in magnitude on the days of the Fed operations, as indicated by the positive and statistically significant coefficient of the repo spread interacted with a dummy variable accounting for the operation days, shown in the second column. Finally, we split the sample into two subsamples, one containing observations of securities that were never eligible for purchase (i.e., met the Fed's exclusion criteria mentioned in Section III.C) and one including securities that were instead eligible for at least one operation in our sample. The comparison of the results reported in the third and fourth columns indicates that the strengthening of the relation between the cash price premium and the repo spread on operation days is observed only in the subsample of eligible securities. This is quite striking because the never-eligible category includes a higher percentage of on-the-run securities, which usually exhibit larger repo-specialness spreads and price premia in the cash

[34]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 to maturity and is maintained by the staff of the Board of Governors of the Federal Reserve System.

[35]In our regressions, we include security and time fixed effects and discard observations for which the cash price premium exceeds 50 bps in absolute value. This threshold choice seems reasonable because in our full sample, the 1st and 99th percentiles of price premium measures are approximately −16 bps and 22 bps, respectively, whereas their 0.1 and 99.99 percentiles are −116 and 44 bps, respectively.

market. It is also worth noting that these results hold when regressions are run in changes rather than levels (not shown).

These findings suggest that the Fed asset purchase programs could affect Treasury security prices not only directly through the stock effect (e.g., D'Amico et al. (2012)) but also indirectly by increasing the scarcity value of the Treasury collateral in the repo market, which translates into higher specialness spreads. These increases in the security's specialness are also reflected (and discounted) in the cash-market prices, as indicated by the larger-than-average increase in cash premia per unit increase in specialness spreads on the days of the actual operations. This indirect effect could in part explain the so-called flow effect, the existence of which was one of the puzzling findings of D'Amico and King (2013), who focused only on the impact of LSAPs in the Treasury cash market. In contrast, our analysis suggests that considering the propagation of Treasury supply shocks in closely related markets, such as the Treasury cash and repo markets, can provide a more complete picture of the transmission mechanism of this monetary policy tool, including its unintended consequences, such as the heightened scarcity value of safe and liquid assets.

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 quantity effects are economically and statistically significant in the SC repo market. Specifically, we estimate that a $1 billion reduction in the available supply of Treasury collateral can increase its scarcity value by 0.3–1.8 bps depending on the security's characteristics, with the larger effects concentrated in on-the-run and shorter-term securities. These effects are larger than those estimated by D'Amico and King (2013) for the flow effect of the first LSAP program in the Treasury cash market. And because, as in their study, quantity variation in our sample comes mostly from purchased and sold amounts of Treasury securities under various Fed programs, our results provide further support for the scarcity channel of QE.

Similarly, our estimates can help evaluate the impact of a gradual reduction of the Fed's securities holdings during the policy-normalization process.[36] For instance, if the Fed decides to redeem rather than roll over maturing Treasury securities, which is nearly identical to selling on-the-run Treasuries, the larger supply of high-quality collateral should reduce the scarcity premium, putting upward pressure on SC repo rates and related money market rates such as the GC repo rate.[37] This would in turn facilitate the transmission of monetary policy during the tightening cycle.

[36]The FOMC's "Policy Normalization Principles and Plans" of Sept. 17, 2014, states that "the Committee intends to reduce the Federal Reserve's securities holdings in a gradual and predictable manner primarily by ceasing to reinvest repayments of principal on securities held in the SOMA."

[37]For example, during the second MEP (used in our empirical analysis), in order to buy a larger amount of longer-term Treasury securities, the Desk was directed to sell or redeem Treasury securities with remaining maturities of approximately 3 years or less because such redemptions were equivalent to selling those securities. See the MEP operating policy at http://www.newyorkfed.org/markets/opolicy/operating_policy_120620.html.

An additional novel finding presented in this study is that changes in quantities affect the SC repo rate not only of on-the-run but also off-the-run securities, which suggests that in the Treasury market, the scarcity effect is a widespread phenomenon and is not confined just to a few "special" securities. This implies that, in principle, the Fed's overnight reverse repo (ON RRP) facility, one of the supplementary tools to control the federal funds rate (FFR) during the policy-normalization process, could prevent near-zero or negative SC and GC repo rates by increasing the availability of Treasury collateral to a wide range of market participants.[38] This would help in firming the floor for key money market rates, which is crucial to ensure a robust implementation of a floor or corridor system for the FFR.[39] For interested readers, we provide some suggestive evidence on the efficacy of the ON RRP facility in the Supplementary Material; we leave more definitive analysis to future research.

Supplementary Material

Supplementary Material for this article is available at https://doi.org/10.1017/S0022109018000790.

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[38]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.

[39]In the case of a floor system, the ON RRP rate set by the Fed should constitute an effective floor for money market rates; in the case of a corridor system, although this rate would still provide a floor, the interest rate on excess reserves would provide the upper bound of the corridor.

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