Collateral Choice*

Benedikt Ballensiefen†

September 26, 2022

Abstract

This is the first paper studying *collateral choices* in one of the main short-term funding markets, the repurchase agreement (repo) market. In general collateral repos, the borrower can choose which bond he delivers as collateral out of a predefined list. Collateral availability and opportunity cost are the two main drivers of this collateral choice. In aggregate, on-the-run bonds are more likely to be delivered than cheapest-to-post securities which is surprising given that the former is more expensive. I rationalize those findings in a theoretical framework and show that bonds with higher repo delivery volumes have lower bond market liquidity.

Keywords: Collateral, Repo, Bond Market, On-the-run, Liquidity.
JEL Classification: E40, E41, E43, G00, G01, G10

A repurchase agreement (repo) is a secured short-term instrument that serves a dual role to obtain funding or collateral. Along those lines, the repo market divides into two broad

*I would like to thank Andrea Barbon (discussant), Philippe van der Beck (discussant), Martin Brown, Darrell Duffie, Sebastian Infante (discussant), Peteris Kloks, Edouard Mattile, Ye Qian (discussant), Angelo Ranaldo, Jurij-Andrei Reichenecker (discussant), Kumar Rishabh (discussant), Fabricius Somogyi, Paul Söderlind, and Hannah Winterberg and conference participants at the 5th Short-Term Funding Markets Conference (2022), the SFI Research Days (2022), the 29th Finance Forum (2022), the FMA European Conference (2022), and the World Finance Conference (2022) as well as seminar participants at the University of St. Gallen (2022) for their valuable comments and suggestions. Scheduled conferences include the 6th SAFE Market Microstructure Conference (2022), the 28th Annual Meeting of the German Finance Association (doctoral workshop, 2022), the GPEF PhD Day (2022), the 17th Central Bank Conference on Microstructure of Financial Markets (2022), and the American Economic Association (poster session, 2023). This work did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The Online Appendix is available upon request. Please do not circulate this paper.

†University of St. Gallen and World Bank Group, Unterer Graben 21, CH-9000 St.Gallen, Switzerland. Tel. +41 (0)79 808 92 56. E-mail: benedikt.ballensiefen@unisg.ch.

segments, the *general collateral (GC)* market in which the borrower can choose which bond he pledges as collateral out of a predefined basket of securities and the *special* market in which a particular bond is specified as collateral.[1] Conventional wisdom says that special repos are collateral-driven while GC trades are funding-based. Still, surprisingly little is known about borrowers' collateral choices in the GC segment. This is different from other markets such as futures where the "cheapest-to-deliver or CTD" concept was developed.

The focus of this paper is to study GC repo collateral choices. I find that banks' willingness to deliver securities as collateral depends on collateral availability (quantity) and opportunity cost (price). Most recently issued ("on-the-run") government bonds are more likely to be chosen as collateral than cheapest-to-post (CTP) securities. This is surprising since posting on-the-run bonds in high demand is generally costly (Krishnamurthy, 2002). The cheapest-to-post idea in the repo market is a new concept developed in this paper; the CTP bond refers to the bond with the highest special repo rate of all bonds that are eligible to be posted as collateral into a GC trade. Delivering the on-the-run bond instead of the CTP security is therefore more expensive since on-the-run rates in the special segment are often lower than prevailing market rates (Duffie, 1996). I find that the intensity of on-the-run deliveries declines in the auction cycle and is smaller for bonds targeted by quantitative easing (QE). The CTP bond is also relatively more likely to be chosen as collateral which highlights the role of collateral opportunity cost. I rationalize the empirical findings in a simple theoretical framework that links the repo market to the underlying bond market for that collateral and show that bonds with higher repo delivery volumes have lower bond market liquidity.

The novelty of this paper is to analyze the specific bond being delivered by the borrower as collateral into GC trades. For this, I employ a novel and highly representative data set of European repo trades for the time period from 2010 until 2020. My setting is particularly well suited to analyzing collateral delivery patterns for at least three reasons. First, the euro repo market is the largest repo market worldwide and the main market for banks in the euro area to obtain short-term funding and rebalance portfolio holdings. Second, euro

[1] A special repo is sometimes referred to as a "specific" repo in the U.S.

repos are mostly secured by government bonds whose supply and demand varies depending on auctions, reopenings, and QE purchases. The large cross-section allows me to disentangle different aspects of collateral choice. And third, the market infrastructure is based on central clearing and anonymous centralized electronic order book platforms which guarantees homogeneous counterparty credit risk and efficient price formation. The market characteristics therefore eliminate many confounding factors, thus buttressing the measurement accuracy of the empirical results.

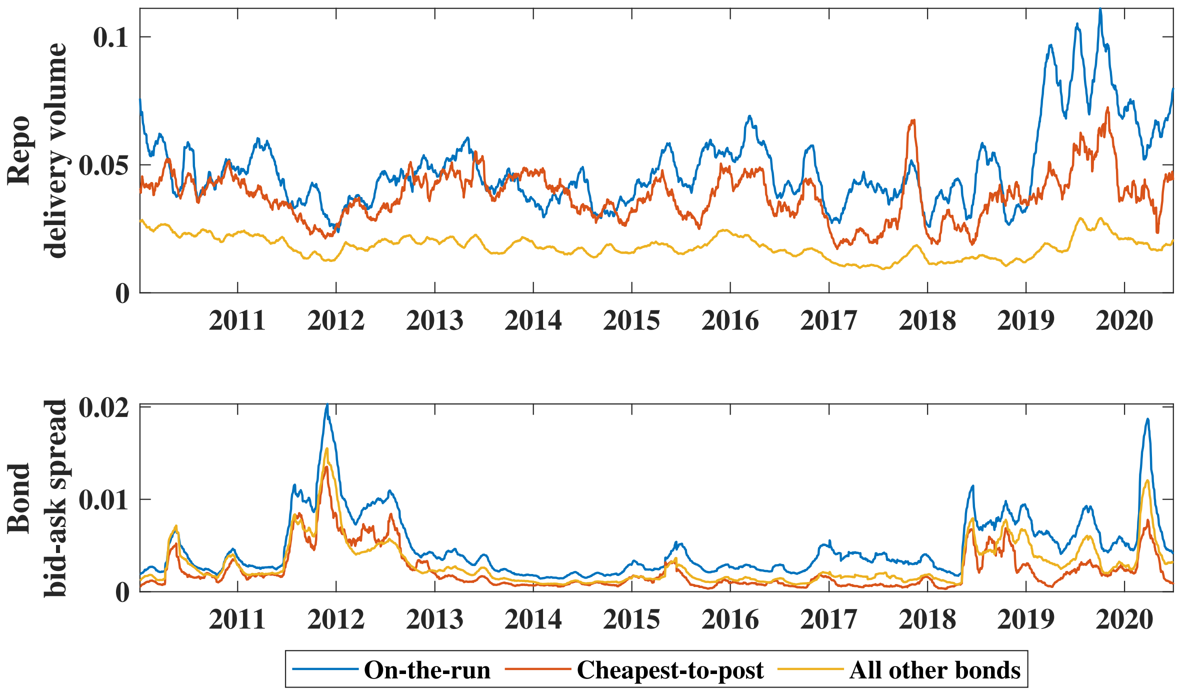


Figure 1 depicts (i) the daily delivery volume of a given bond type into GC repos relative to its outstanding volume and (ii) the relative bid-ask spread. The results are depicted for on-the-run bonds (blue), cheapest-to-post securities (orange), and all other bonds (yellow).

Figure 1: Repo delivery volumes and bond bid-ask spread

To motivate my analysis, Figure 1 depicts repo delivery volumes into GC trades and bond market bid-ask spreads for (i) the most recently issued, on-the-run government bond (blue line), (ii) the CTP security (orange line), and (iii) the average across all other bonds (yellow line).[2] The time series of repo deliveries provides a *first stylized fact* that on-the-run bonds are most likely to be delivered as collateral into GC trades and that CTP securities

[2]I compute the repo delivery volume as the daily volume of a bond delivered into GC trades relative to its outstanding volume. Figure 1 does not contain any overlaps between the different bond types.

are also more likely to be delivered than other bonds. Those results point towards the role of collateral availability (with the newly issued security having the highest availability) and opportunity cost of the collateral (with the CTP having the lowest opportunity cost) in explaining collateral choices. Still, the results are noteworthy, since in GC repos, the borrower always has the option of posting the cheapest security which is unlikely to be scarce since scarce collateral is more expensive. This more broadly raises the question *which bonds borrowers choose as collateral* and why they seem to deliver more expensive on-the-run securities that are in high demand in the special market (e.g., Krishnamurthy, 2002). The time series for the bid-ask spreads indicates a *second stylized fact* that spreads are highest for on-the-run bonds, while CTP securities feature the lowest levels. This more broadly raises the question *whether collateral choices in the repo market are connected to the bond market* and the liquidity of the bond being delivered as collateral.

Collateral availability is the first driver of collateral choice, it relates to variations in the net supply of collateral assets and scarcity created by QE. Conceptually, I relate the daily delivery volume of a bond (in terms of its outstanding volume) to a set of variables capturing the bond's auction and QE characteristics. Four main results emerge: First, the delivery volume increases with the auction size; the effect is about three times larger for initial auctions than for reopenings. Second, the intensity of on-the-run deliveries into GC repos declines with the auction cycle, the effect is again larger for initial auctions than for reopenings. Third, the delivery volume is higher for newly issued, on-the-run bonds and decreases as the on-the-run bond becomes closer to turning off-the-run. Finally, bonds eligible for QE purchases are less likely to be delivered.

Next, I consider different aspects of collateral opportunity cost as the second driver of collateral choice. For this, I calculate the CTP spread which measures the opportunity cost of delivering different bonds as collateral into GC trades. I also consider repo specialness which measures the opportunity cost of engaging in a GC trade instead of a special repo. The results are consistent for both measures. The delivered volume is highest for bonds with CTP spreads close to zero and decreases in the specialness of the delivered security. However, when bonds with high CTP spreads are delivered, those are likely to be on-the-run securities.

I show that CTP spreads for on-the-run securities are economically meaningful as they go up to 50bps, hence borrowers accept significant opportunity cost in delivering these securities. Still, even for on-the-run securities, the delivery intensity declines in the opportunity cost. In line with Keane (1996), on-the-run securities become increasingly special until the next auction. Repo deliveries reverse this pattern, i.e., they decline in the repo specialness of the delivered security as collateral opportunity cost increase.

Inspired by the safe asset literature, I also consider the level of short-term rates. Nagel (2016) theorizes that the convenience benefits of collateral assets are more valuable in a high interest rate environment. Consistent with this idea, I find that delivery volumes for on-the-run securities are lower in a high interest rate environment when the superior liquidity services of on-the-run bonds (which the borrower foregoes) are more valuable.

I perform a number of additional tests to ensure the robustness of my results. I experiment with various control variables, consider different euro area countries, and employ variations in the fixed effect specifications and standard error clustering. All results confirm three main takeaways: First, higher collateral availability increases the delivered volume; second, higher collateral opportunity cost decreases the delivered volume; and third, the newly issued, on-the-run bond (with the highest availability) is delivered about twice as often as the CTP bond (with the lowest opportunity cost).

I then introduce a simple theoretical framework that provides an explanation for the empirically observed collateral choices and relates them to the underlying bond market for the collateral.[3] For this, I link the *borrowers'* collateral choices in the repo market to the market makers' inventory holdings. My framework is based on Stoll (1978) and focuses on a stylized repo market in which the borrower (market maker) holds excess on-the-run bonds in

[3]Related studies in this area include, for example, Krishnamurthy (2002), who connects the collateral (bond) market to the repo market and theorizes a lower repo rate for the newly issued, on-the-run U.S. Treasury bond compared to a repo secured by a similar bond issued previously ("off-the-run"). The specialness of the former repo is explained by a higher demand of lenders for on-the-run bonds. By taking a cross-temporal perspective, Huh and Infante (2021) associate higher levels of specialness with lower bond market liquidity. Bartolini et al. (2011) find that the GC collateral rent is informative for pricing short-term bonds but not for medium- or longer-term ones. I complement their views by providing new insights on collateral choices in the GC segment which has implications on the underlying bond market for the collateral as well.

his portfolio after auctions and chooses to deliver those securities into repo trades to finance and diversify his portfolio holdings; but delivering on-the-run securities involves opportunity cost associated with the on-the-run bond. The dealer, therefore, requires a compensation to engage in his market making activities in the bond market for the collateral. The dealer's resulting cost function predicts that the bid-ask spread charged in the bond market increases in the size of the dealer's trading portfolio and in the collateral opportunity cost.

In line with the theoretical predictions, *tomorrow's* bid-ask spread tends to be higher when *today's* GC delivery volumes are higher (i.e., higher inventory cost) and when *today's* collateral opportunity cost is higher (i.e., higher forgone utility of the collateral). My framework thus provides an explanation for the empirically observed pattern that on-the-run securities are more likely to be chosen as collateral than CTP securities, namely that market makers deliver excess on-the-run holdings to finance and diversify their portfolios. On average, the bid-ask spread is higher for on-the-run bonds than for their off-the-run counterparts; at the same time, bond trading volumes in the on-the-run bond are also higher than in their off-the-run counterparts. Those results shed new light on the rather broad concept of liquidity and suggest that different bond types carry different liquidity attributes.

My analysis mainly contributes to two strands of the literature. First, I contribute to the literature on short-term funding markets and the choice of the collateral asset. Bartolini et al. (2011) provides evidence that GC rates involving basket of U.S. Treasuries include a collateral rent which other asset class baskets do not offer.[4] Still, our understanding of which and why safe assets are pledged as collateral in short-term funding markets if the borrower is presented with a choice is very limited. I complement the existing literature by analyzing borrowers' collateral choices in the repo market and determine what characteristics make bonds more likely to be used as collateral. Song and Zhu (2019) analyze a different notion of collateral choice by focusing on the "to-be-announced" market for mortgage-backed securities

[4]Other literature on the GC repo segment includes e.g., Longstaff (2004), Mancini, Ranaldo, and Wrampelmeyer (2016) and Boissel et al. (2017). Papers more strongly focusing on special repos, for instance, include Duffie (1996), Jordan and Jordan (1997), Buraschi and Menini (2002), Krishnamurthy (2002), D'Amico, Fan, and Kitsul (2018), Arrata, Nguyen, Rahmouni-Rousseau, and Vari (2020), Infante (2020), Corradin and Maddaloni (2020), and Ranaldo, Schaffner, and Vasios (2021).

which allows lenders to return a different collateral than they received.

Second, I contribute to the bond literature with a focus on the linkage between bonds and repos. Seminal work linking the bond and repo market include Duffie (1996), Krishnamurthy (2002), and Vayanos and Weill (2008). More recent studies include, for example, Fontaine and Garcia (2012), Chen et al. (2019), Huh and Infante (2021), and D'Amico and Pancost (2022).[5] I provide an extension of the theoretical framework in Stoll (1978) to incorporate a dealer's funding decision and how this relates to the market liquidity for the collateral. Related to it is the literature on auction cycles. Work focusing on the repo market goes back to Keane (1996) and includes e.g., Lou et al. (2013), D'Amico et al. (2018), and Sigaux (2018).[6]

1. European repo market

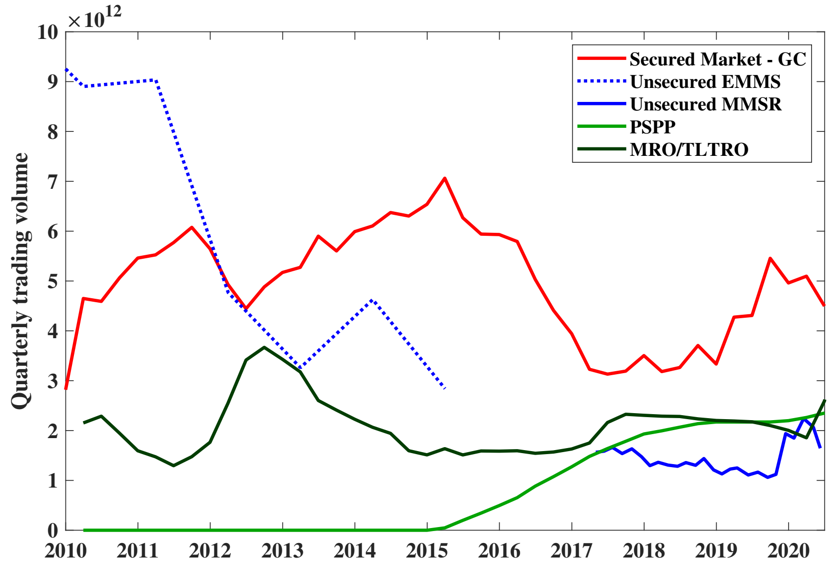
I start by explaining the main characteristics of the European repo market and my data.

1.1 Repo market infrastructure

In a repo contract, two counterparts exchange cash for collateral (first leg) for a predefined period with a fixed repurchase obligation (second leg). Repos are a form of short-term borrowing as collateral is typically sold on an overnight basis. The motive to enter into a repo trade can either be to obtain funding or collateral; the repo market therefore serves a dual role, it represents the main market for banks to rebalance their portfolios or obtain short-term funding. The asset being used as collateral can be a particular bond ("special repo") or any bond from a predefined basket of bonds ("general collateral or GC repo").

[5]Brunnermeier and Pedersen (2009) model the reinforcement of market and funding liquidity. Related literature focuses on the impact of dealers' funding cost on asset prices, e.g., He and Krishnamurthy (2013), Rytchkov (2014), Adrian, Boyarchenko, and Shachar (2017), and He, Kelly, and Manela (2017), and asset liquidity, e.g., Comerton-Forde et al. (2010), Andersen, Duffie, and Song (2019), and Goldstein and Hotchkiss (2020).

[6]Related literature on the impact of asset supply on the bond market includes e.g., Brandt and Kavajecz (2004), Pasquariello and Vega (2009), Krishnamurthy and Vissing-Jorgensen (2012), D'Amico and King (2013), Krishnamurthy and Vissing-Jorgensen (2015), Beetsma et al. (2016), Beetsma et al. (2018), and Eisl et al. (2019). Other papers such as Klingler and Sundaresan (2020) look at auction results from a demand perspective.



The figure depicts the quarterly trading volumes in the secured and unsecured market segments as well as the total cumulative Public Sector Purchase Program (PSPP) purchases and volumes of the European Central Bank's (ECB) main refinancing operations (MRO) and targeted longer-term refinancing operations (TLTRO). The data for the secured market refer to the total general collateral repo trading volume. The data for the unsecured market stem from the Euro Money Market Survey (EMMS) until 2015 and from the Money Market Statistical Reporting (MMSR) thereafter. To be conservative, I sum reported borrowing and lending activity in the unsecured market, which may entail double-counting. The data on PSPP purchases and refinancing operations are from the ECB. All data are in euro.

Figure 2: Different market turnovers

While a large body of the literature has analyzed the special segment with seminal work going back to Duffie (1996), the focus of this paper is on GC repos as I investigate which bond the borrower chooses to deliver as collateral if presented with a choice.

I study the European repo market which is the largest repo market in the world (International Capital Market Association, 2021). To highlight the importance that the repo market plays for euro area banks, Figure 2 depicts trading volumes in the two main euro money market segments: the red line depicts trading volumes in GC repos, the blue line depicts volumes in the unsecured market. The figure shows that trading has moved towards the repo market; in particular, an increase in risk aversion after the European sovereign debt crisis shifted bank activity towards the secured segment (European Central Bank, 2018). To put this into perspective, repo trading volumes exceed, for example, cumulative bond purchases by the European Central Bank (ECB) under the largest euro area QE program, the Public Sector Purchase Program (PSPP), as depicted by the light green line, or the ECB's main refinancing operations (MRO) and targeted longer-term refinancing operations (TLTRO), as depicted by the dark green line. Overall, the GC repo market is now the predominant euro area money market in which banks operate. It is highly representative of banks' funding and portfolio reallocation decisions and thus the ideal laboratory to study collateral choices and delivery patterns.

Four characteristics of the European repo market infrastructure are noteworthy:[7] First, the most common collateral assets are government bonds whose supply and demand varies depending on auctions, reopenings, and QE purchases. Second, repos are euro-denominated and the usual term types are Overnight (ON), Tomorrow-Next (TN), and Spot-Next (SN), indicating purchase dates tonight, tomorrow, and the day after tomorrow, respectively, and the repurchase date one day thereafter. Third, it mostly operates through central counterparties (CCP) that interpose themselves between each lender and borrower.[8] Through novation, a CCP acts as a clearinghouse and applies the same collateral and (credit) risk policies to all market participants. And fourth, the core segment is the interbank market in which banks trade anonymously via centralized electronic order book platforms supporting liquidity and a transparent price discovery process. All those characteristics allow me to eliminate many confounding factors to collateral choices such currency and counterparty risk, thus buttressing the measurement accuracy of my results. It also ensures that borrower-level characteristics and bank reputation do not affect funding cost and collateral choices.

1.2 Data

I observe a unique data set of euro area GC repo transactions executed on the MTS platform for the period from January 2010 to June 2020.[9] For each transaction, I observe the

[7]More detailed information about the European repo market infrastructure can be found in, e.g., Mancini, Ranaldo, and Wrampelmeyer (2016), Nyborg (2016), Bank for International Settlements (2017), and European Central Bank (2018).

[8]CCPs account for more than two-thirds of the total repo market turnover (European Central Bank, 2018).

[9]The MTS market comprises about 70% of all euro area GC transactions and 38% of the traded volume.

trade date, the term, the trade volume, the rate, the GC basket, the bond being delivered as collateral identified by a unique ISIN, and the aggressor type. I also employ data on special repo transactions to connect collateral choices in the GC segment to special repo rates of the bond being pledged as collateral.

Table 1 provides a summary of my data. In total over my sample period, I observe more than 1.5 million GC transactions totalling more than 75 trillion euro in trading volume. All transactions are euro repos and more than 93% of the trades are overnight trades of term types ON, TN, and SN.[10] For each trade, I also observe the aggressor-type; borrower- and lender-initiated trades are roughly equally likely.[11]

The MTS repo market consists of the near-total universe of all electronically traded Italian GC repo transactions.[12] For the main part of my analysis, I focus on those Italian repo trades for which I have almost complete coverage. However, my data also features trade-level information for other euro area countries such as Germany and France. This allows me to show that results are fully consistent for other countries which ensures the general validity of my analysis.

Each government bond type has its own dedicated GC basket on the MTS platform.[13] This ensures that all bonds eligible to be delivered into a basket have the same bond type characteristics and thus guarantees that delivery patterns are not driven by, for example, different regulatory treatment.[14]

The borrower in a repo trade always has the option to post a security in the GC or special segment. For example, 44% of the repo trading volume in on-the-run securities relates to on-the-run deliveries into GC trades compared to 56% special trading volumes for on-the-

[10] My results are fully consistent if I only consider ON, TN, and SN repos in my analysis.

[11] Borrower-initiated trades refer to the counterparty borrowing cash in the repo market as the aggressor (at the "ask" rate), whereas lender-initiated trades refer to the counterparty lending cash in the repo market as the aggressor (at the "bid" rate). About 55% of the trades are borrower-initiated and 39% are lender-initiated.The aggressor type is not specified for about 6% of the trades.

[12] More than 99% of all Italian GC trades are executed on the MTS platform.

[13] A brief description of those baskets traded on the MTS platform as well as a summary of the bond characteristics in terms of coupon rate, maturity, auction size, and number of reopenings is provided in the Online Appendix.

[14] All euro area government bonds in my sample qualify as high-quality liquid assets (HQLA) in terms of the liquidity coverage ratio (LCR) requirement for banks which ensures that my results are not driven by any differential regulatory treatment.

Table 1: Breakdown of the repo data

	Transactions (in million)	Volume (in euro trillion)	Transactions (share in %)	Volume (share in %)
General collateral euro repos	1.57	77.94	100.00%	100.00%
Overnight	0.40	15.29	25.13%	19.62%
Tomorrow-next	0.65	30.39	41.61%	38.99%
Spot-next	0.42	24.70	26.41%	31.69%
Other term types	0.11	7.57	6.85%	9.71%
Borrower-initiated trade	0.86	41.68	54.87%	53.48%
Lender-initiated trade	0.61	30.26	38.83%	38.82%
Repo BTP	0.81	39.72	51.67%	50.96%
Repo BOT	0.28	12.95	17.65%	16.62%
Repo CCT	0.20	10.21	12.90%	13.09%
Repo BTP€i	0.16	7.99	10.36%	10.25%
Repo CTZ	0.11	6.11	6.76%	7.84%
Other baskets	0.01	0.97	0.66%	1.24%
On-the-run in GC and special			100.00%	100.00%
On-the-run deliveries in GC	0.33	17.94	24.14%	44.37%
On-the-run special segment	1.04	22.49	75.86%	55.63%

The table shows the breakdown of the repo data. My data includes GC repos denominated in euros. The universe of GC repos traded on the MTS platform is broken down by repo term, aggressor profile, and GC basket. The last part compares volumes of on-the-run deliveries into GC trades with special trading volumes for on-the-run securities.

run securities.[15] This means that on-the-run volumes in the GC and special segment are comparable which confirms the importance of the GC market compared to the activity in the special segment.

To ensure the robustness of my results, I exclude quarter-end and end of ECB maintenance period trading days in additional tests. On quarter- and year-end days as well as on end of ECB maintenance period days, window dressing impacts repo rates (Ranaldo, Schaffner, and Vasios, 2021). As further robustness checks, I also remove observations in the 99th percentile of CTP spreads for on-the-run and off-the-run bonds. The results are virtually unchanged in all those specifications.

Throughout my sample period, more than 500 different bonds were chosen as collateral in GC trades. On each day and for each bond, I compute the daily number and volume of trades for which that bond served as collateral. I complement this data with results on auctions and reopenings; this information allows me to determine, for example, the on-the-run status and the remaining time for which a bond serves as an on-the-run bond. I also classify bonds into *eligible* and *noneligible* for QE purchases by the ECB depending on whether a bond fulfilled the purchasing provisions that were valid at a specific point in time.[16] This allows me to measure the number of days a bond has been eligible for QE purchase to capture scarcity effects. I also add haircut information for each bond based on the ECB's collateral framework.[17]

To capture collateral opportunity cost, I derive a daily list of bonds that are eligible to be pledged as collateral into a GC basket. Based on this list, I determine, for each GC trade,

---

[15] In line with the balanced shares, the average quarterly delivery volumes of on-the-run securities into GC trades are 450 billion euro compared to special trading volumes for on-the-run securities of, on average, 592 billion euro.

[16] The ECB has constituted implementation provisions to limit market impacts and distortions of bond purchases under the Public Sector Purchase Program, the largest of the QE programs implemented in the Eurosystem. These provisions specify the conditions under which the ECB (via local central banks) is allowed to purchase government bonds: they contain (i) a maturity restriction that specifies the minimum and maximum remaining maturity of a security, (ii) a yield restriction that states that the yield of a security needs to be above the ECB's deposit facility rate (DFR), and (iii) a restriction limiting the purchase of bonds to those denominated in euros. Over time, the ECB has adjusted and modified the initial implementation provisions.

[17] The ECB collateral framework (https://www.ecb.europa.eu/paym/coll/assets/html/list-MID.en.html) provides a reference for individual bonds' haircut levels. The economics of central bank collateral frameworks have been discussed in, for example, Nyborg (2016).

the cheapest-to-post bond which is the bond with the highest special repo rate of all bonds that are eligible to be delivered into a particular basket.[18] Finally, to connect the collateral choices in the repo market to the bond market for the collateral, I obtain the corresponding set of tick-by-tick, intraday bond quotes and trades from the MTS Cash market.[19] The size and liquidity of the MTS market make my bond data highly representative. For my analysis, I focus on the cross-section of sovereign bonds that are posted as collateral into GC trades. For each day between a bond's issuance and maturity, I compute the daily volume-weighted average mid-quote, bid-ask spread, and amounts quoted at the best bid and ask, as well as the volume-weighted average transaction price and transaction cost. I also compute the market quality index.[20] Finally, I complement my bond data with investor holding information from Bloomberg which allows me to calculate the bond-level buy-and-hold investor share.[21]

Overall, my data covers a large segment of the European money and bond markets and is therefore a unique sample with which to examine borrowers' collateral choices.

2. Drivers of collateral choice

Figure 1 in the Introduction highlights that newly issued, on-the-run bonds and CTP securities are most likely to be delivered as collateral into GC trades, pointing towards collateral availability and opportunity cost as the two main drivers of collateral choice. I start by analyzing different aspects of collateral availability and opportunity cost separately before looking at their interplay.

[18]My results are robust if I determine the CTP bond based on yesterday's special repo rate.

[19]The MTS Cash market is the largest interdealer trading network for European government bonds; liquidity is ensured by active market-making and a quote-driven electronic limit order book. Related studies which have used this data include, for example, Pelizzon et al. (2016), who also provide a detailed description of the MTS market, and Corradin and Maddaloni (2020).

[20]The market quality index is defined as half of the quoted depth divided by the mid-quote. Quoted depth refers to the amount of bonds quoted at the best bid plus the best ask.

[21]I derive quarterly bond holding information by institution for ten-year Italian government bonds during the first three years after the initial auction. I classify an institution as a buy-and-hold investor if it reduces its position in less than a third of all observations. My results are robust to alternative classifications. For each bond and for each quarter after the initial auction, I calculate a bond's buy-and-hold investor share as the sum of the positions held by buy-and-hold investors over the total coverage in the database.

2.1 Collateral availability

Collateral availability relates to the net supply of collateral assets. Auction cycles are a first source of variation in the supply impacting money and bond markets (e.g., Keane, 1996; Krishnamurthy and Vissing-Jorgensen, 2012; Lou et al., 2013; D'Amico et al., 2018; Sigaux, 2018; Huh and Infante, 2021). A second form of variation stems from scarcity induced by QE (e.g., Arrata et al., 2020; Corradin and Maddaloni, 2020). Asset scarcity is the counterpart to collateral availability; while auctions increase the availability, central bank asset purchasing programs reduce it. Figure 3 illustrates those aspects of collateral availability.

Figure 3a plots the volume of a bond delivered into GC repos against its issuance volume, separately for initial auctions (orange crosses) and reopenings (blue circles). The delivered volume is measured as the cumulative volume of a bond posted into GC repo trades over the first 90 days after an auction relative to the bond's outstanding volume.[22] It is clearly visible that the delivery volume increases in the auction size. For example, the delivery volume over the first 90 days after an initial auction is about 200% of the outstanding volume for an auction size of euro 2 billion; the delivery volume increases to about 400% for an auction size of euro 10 billion. The results are consistent for reopenings, although the issuance size of reopenings tends to be smaller.

Figure 3b looks more closely at the delivery patterns during the first 90 days after an auction; it graphs the volume delivered against the time since the last auction, again separately for initial auctions (orange crosses) and reopenings (blue circles). Here, the delivery volume is measured on a daily horizon. Three patterns stand out: the delivery volume (i) is higher for initial auctions than for reopenings, (ii) decreases in the days after an initial auction or reopening, and (iii) peaks again around reopenings. For example, daily delivery volumes are about 20% of the outstanding volume for delivery dates close to the initial auction; those volumes drop to around 6% one month after the initial auction. Around reopenings, the delivered volume peaks again at about 8% before it starts decreasing to around 4% one month

[22] The results are consistent if the delivery volume is measured over a different period of, for example, 30 or 60 days.

(a) Auction size

(c) On-the-run status remaining

(b) Time since auction

(d) QE eligibility

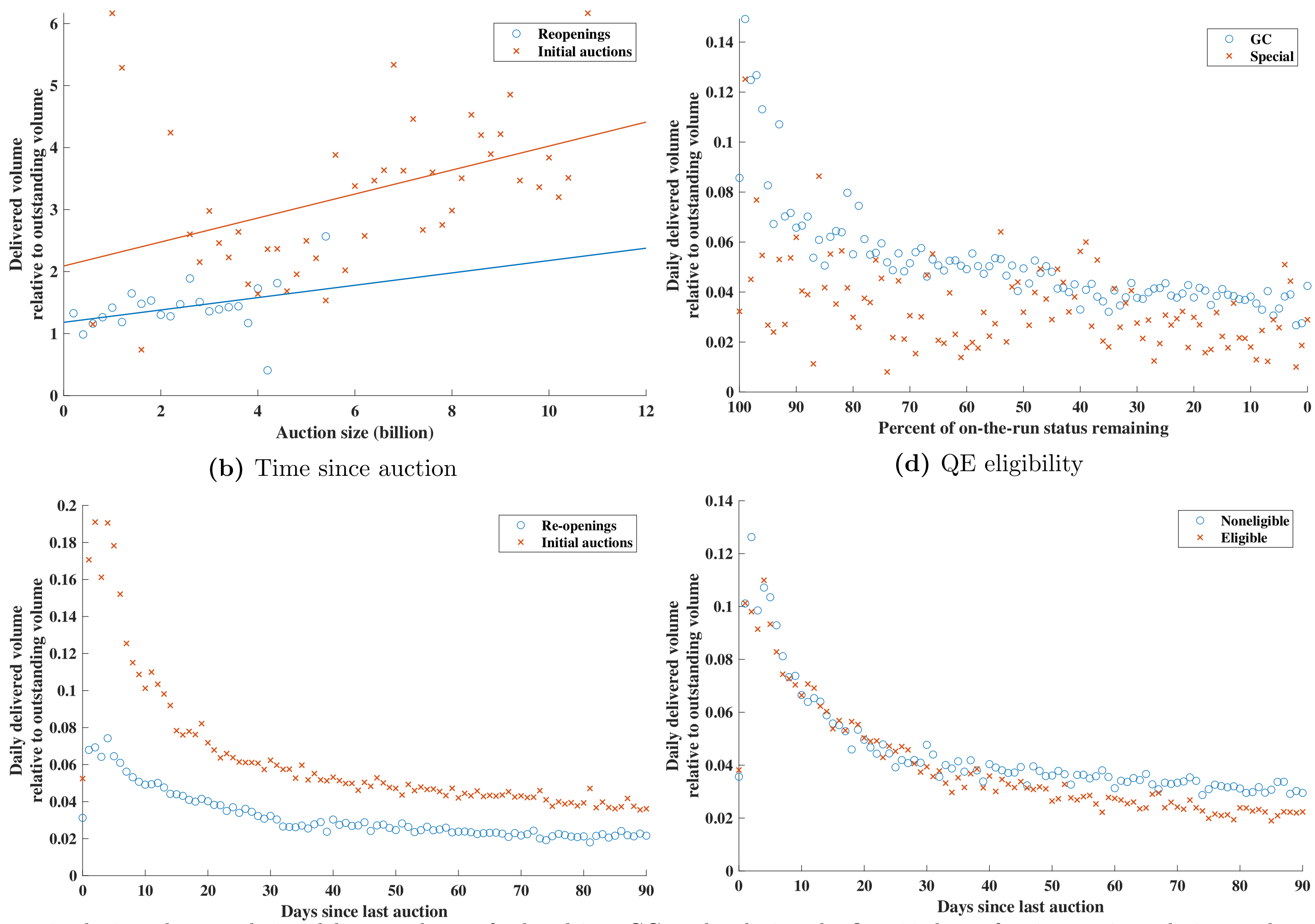


Figure 3a depicts the cumulative delivery volume of a bond into GC trades during the first 90 days after its auction relative to the total outstanding volume. Figure 3b depicts the daily delivered volume of a bond into GC trades relative to its outstanding volume on each of the first 90 days after the auction. Both graphs differentiate between initial auctions (orange crosses) and reopenings (blue circles). Figure 3c depicts the daily delivered volume of a bond relative to its outstanding volume in the GC market (blue circles) as well as the on-the-run trading volume in the special repo market (orange crosses) in relation to the remaining on-the-run status. Figure 3d depicts the daily delivered volume of a bond in GC trades relative to its outstanding volume for each of the first 90 days after the initial auction or reopening by differentiating between bonds eligibile (orange crosses) and noneligible (blue circles) for PSPP purchases.

Figure 3: Aspects of collateral availability

after the reopening.

Figure 3c is developed in a similar spirit, it depicts the daily volume delivered against the remaining time for which a bond serves as the on-the-run (blue circles).[23] The results are consistent: The delivery volume of newly issued, on-the-run government bonds peaks at the auction and decreases as the on-the-run bond gets closer to turning off-the-run. The figure also displays on-the-run trading volumes in the special repo market (orange crosses). Note that on-the-run deliveries into GC baskets and special trading volumes for on-the-run securities are comparable in size which reinforces the importance of the GC market compared to the activity in the special repo segment.

In contrast to government bond auctions which are a source of supply of collateral assets, central bank asset purchase programs have led to asset scarcity and a corresponding reduction in collateral availability. Figure 3d graphs the volume delivered against the time since the last auction, separately for QE eligible bonds (orange crosses) and bonds that are not eligible for QE purchases (blue circles). For the first 30 days after a government bond auction, delivery volumes are similar between eligible and noneligible bonds; however, for periods more than one month after the auction, bonds that are not eligible for QE are delivered about one-and-a-half times as often as QE eligible bonds. Those results are consistent with the idea that central banks target QE eligible bonds which leads to their scarcity. Among other things, this reduces the availability of those bonds to be posted as collateral into GC trades.

For the empirical analysis, I formalize the graphical intuition in a set of panel regressions. The main variable of interest is the volume delivered of a particular bond into GC repos which I measure as a bond's daily delivery volume over its outstanding volume ("Delivery volume"). I relate this delivery volume to the different aspects of collateral availability as depicted in Table 2: column (1) serves as the baseline specification and reports the results of the regressions of the delivery volume on a bond's issuance volume at the preceding auction or reopening ("Auction size") and the time since the preceding auction or reopening ("Time since auction"), both variables interacted with a dummy for initial auctions, as well as the

[23] I display the percentage of the on-the-run status remaining since government bonds with different tenors follow different auction cycles and thus serve as the on-the-run bond for different time periods.

Table 2: Collateral availability

	(1)	(2)	(3)	(4)	(5)	(6)
	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t
Auction size	0.056^{**}	0.069^{***}	0.043^{**}			
	(2.575)	(2.961)	(2.021)			
Auction size $\cdot D^{Initial}$	0.188^{***}	0.104^{***}	0.166^{***}			
	(6.154)	(3.542)	(5.667)			
Auction size relative				0.400^{**}	0.493^{***}	0.299^{*}
				(2.406)	(2.782)	(1.920)
Auction size relative $\cdot D^{Initial}$				1.515^{***}	0.889^{***}	1.333^{***}
				(7.361)	(4.333)	(6.707)
Time since auction	-0.036^{***}	-0.035^{***}	-0.017^{*}	-0.035^{***}	-0.035^{***}	-0.016^{*}
	(-3.033)	(-3.005)	(-1.721)	(-3.001)	(-2.984)	(-1.707)
Time since auction $\cdot D^{Initial}$	-1.710^{***}	-1.658^{***}	-1.786^{***}	-1.715^{***}	-1.669^{***}	-1.788^{***}
	(-13.700)	(-14.045)	(-14.346)	(-13.861)	(-14.237)	(-14.473)
$D^{OnTheRun}$	0.934^{***}		0.820^{***}	0.928^{***}		0.818^{***}
	(11.173)		(10.876)	(11.157)		(10.872)
On-the-run remaining		0.020^{***}			0.020^{***}	
		(12.282)			(12.279)	
Time since QE eligibility			-0.469^{***}			-0.461^{***}
			(-9.535)			(-9.430)
N	613,534	613,534	613,534	613,534	613,534	613,534
R^2	0.233	0.254	0.243	0.234	0.255	0.244
FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of different aspects of collateral availability on the delivery volume into GC repo trades. The dependent variable is a security's daily delivery volume over its outstanding volume in percentage points. Auction size depicts a security's issuance volume at the preceding auction or reopening in euro billion; auction size relative is defined as the ratio of a security's issuance volume at the preceding auction or reopening over the total debt outstanding held by financial institutions; time since auction denotes the time since the preceding auction or reopening in years; $D^{Initial}$ equals one for initial auctions; $D^{OnTheRun}$ equals one if a security is the on-the-run bond and on-the-run remaining measures the remaining time outstanding for which a security is the on-the-run bond; and time since QE eligibility refers to the time since QE eligibility in years (i.e, the cumulative time a bond is eligible for purchase under the PSPP). ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. All regressions include basket-month-term fixed effects and standard errors clustered at the bond-level. Data include GC repo transactions executed on the MTS platform for Italy for the period January 2010–June 2020.

dummy variable $D^{OnTheRun}$ that is equal to one for on-the-run bonds; column (2) introduces the remaining time outstanding for which a bond serves as the on-the-run ("On-the-run remaining") and column (3) the time for which a bond has been eligible for purchase under the PSPP ("Time since QE eligibility, TSE");[24] columns (4)–(6) repeat the same regression set-up by exchanging the auction size variable with the ratio of the issuance volume over the total debt outstanding held by financial institutions ("Auction size relative").[25]

Column (1) confirms that the delivery volume follows the auction cycle. Three patterns stand out: First, the delivery volume increases with the auction size; all else equal, a euro 10 billion increase in the auction size increases a bond's delivery volume (relative to its outstanding volume) by about 1.9%-points for initial auctions (0.6%-points for reopenings). Second, the delivery volume decreases in the time since the last auction. For example, one month after the initial auction, the delivery volume decreases by about 0.14%-points, the effect is again stronger for initial auctions than for reopenings. And third, the delivery volume tends to be 0.9%-points higher for newly issued, on-the-run bonds.

Column (2) replaces the on-the-run dummy with the variable measuring the remaining time for which a bond serves as the on-the-run; it shows that a 10% decrease in the remaining time for which a bond serves as the on-the-run is associated with a 0.2%-points lower delivery volume. The on-the-run dummy captures the, on average, higher delivery volume of on-the-run bonds during the entire on-the-run period, while the continuous variable capturing the remaining on-the-run time highlights that the delivery volume of on-the-run bonds tends to peak around auction days and decrease thereafter.

Column (3) highlights the role of asset scarcity associated with QE and the lower delivery volume of bonds eligible for central bank asset purchasing programs. In economic terms, bonds that have been eligible for QE purchases for a period of one year have a 0.5%-points lower delivery volume.

Lastly, columns (4)–(6) replace the auction size variable with the relative auction size. The

[24] Time since eligibility is a continuous variable that increases by one day if bond i on day t was eligible for purchase under the PSPP. If a bond was eligible in the past but is not at the moment, the TSE variable keeps its value.

[25] All regressions include basket-month-term fixed effects and standard errors clustered at the bond-level.

idea here is that a larger auction size relative to the total outstanding debt held by financial institutions implies a greater need for banks to diversify their portfolio holdings. Overall, the results remain statistically and economically consistent; an increase in the relative auction size is accompanied by an increase in delivery volumes, the effect is up to four times larger for initial auctions than for reopenings.

Overall, the results are consistent with the idea that collateral choices depend on collateral availability: the delivery volume is higher for on-the-run government bonds, declines in the auction cycle, and is lower for bonds that are scarcer due to QE purchases.

2.2 Opportunity cost

Collateral opportunity cost is the second driver of collateral choice, it relates to the utility a borrower forgoes during the time between the purchase and repurchase when he delivers a bond as collateral into a GC trade. Any income arising from the bond pledged as collateral during the term of the repo is transferred back to the borrower, hence, any foregone utility must stem from the collateral's safety and liquidity attributes, also referred to as convenience benefits (Gorton, 2017).[26] Posting a bond in a GC repo which is in high demand in the special segment due to its utility benefits is therefore costly as rates on special repos that earmark the specific collateral are often lower than prevailing GC rates. A bank therefore faces opportunity cost for the delivery of a special collateral bond into a GC repo.

For my analysis, I compute two measures of collateral opportunity cost as illustrated in Equations (1) and (2).

$$CTP\ spread_{i,t} = reporate^{special}_{CTP,t} - reporate^{special}_{i,t} \tag{1}$$

$$Repo\ specialness_{i,t} = reporate^{GC}_{basket,t} - reporate^{special}_{i,t}. \tag{2}$$

[26] A repo represents a sale and repurchase of the collateral asset, i.e., the lender becomes the legal owner of the collateral at the purchase date. Still, while the buyer of the collateral is the owner of the bond during the term of the repo, the borrower retains the risk of the bond as he has agreed to buy it back at the repurchase date. Any income arising from the bond during the term of the repo (e.g., coupon payments) is therefore transferred to the borrower.

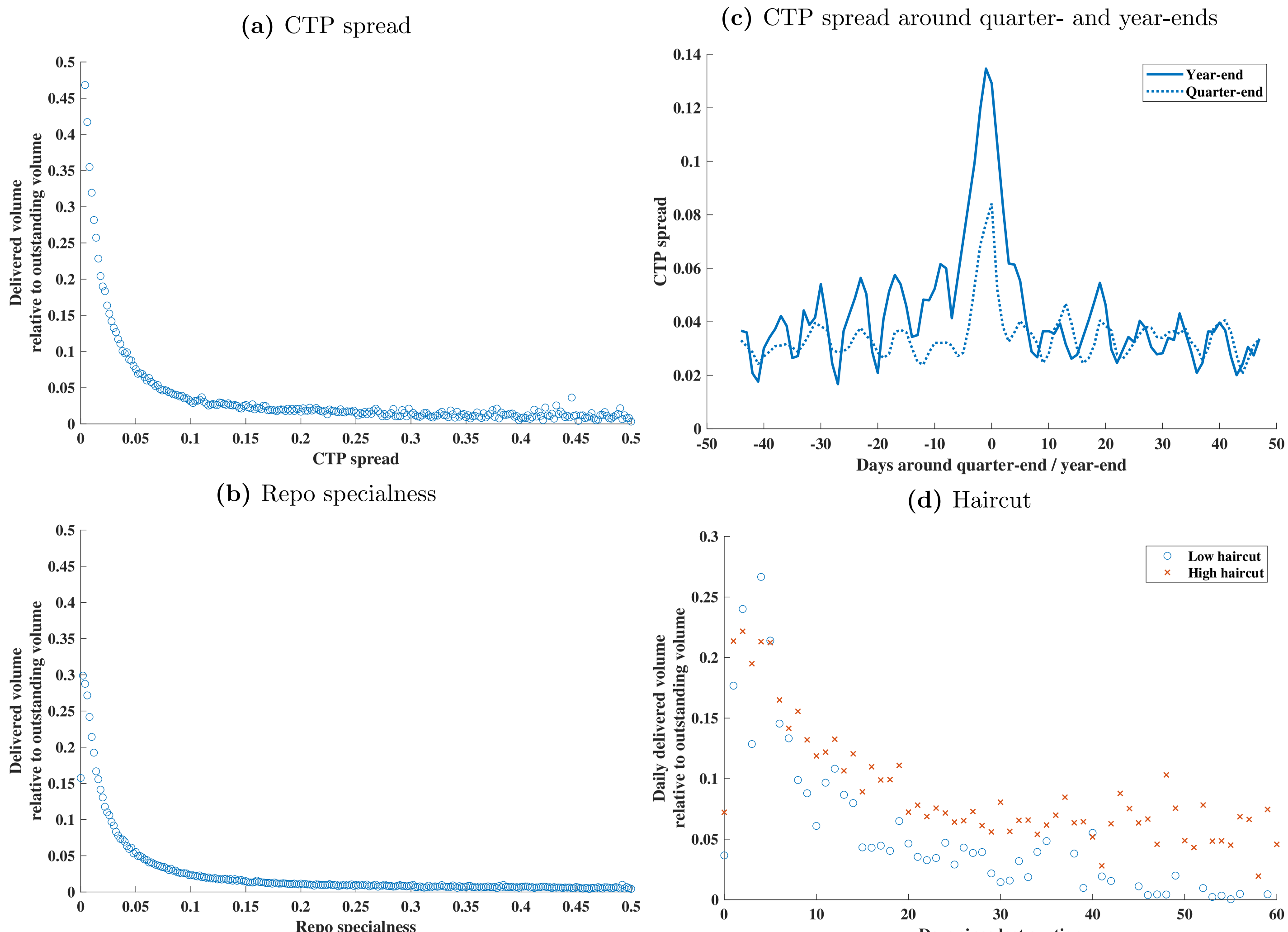
Equation (1) computes the "CTP spread" as the difference in special repo rates between the CTP bond and the bond actually delivered as collateral. This spread measures the opportunity cost of delivering different bonds as collateral into a GC repo and is per definition positive. Equation (2) computes the "repo specialness" measure as the difference between the GC repo rate of the basket in which a security is posted as collateral and the special repo rate of the delivered security. This spread measures the opportunity cost of engaging in a GC trade as opposed to a special repo trade.[27] The economic intuition behind both measures is the same, i.e., the opportunity cost of posting a bond into a GC repo is higher for bonds that carry larger convenience benefits and thus are more special.

Figure 4a plots the relative delivery volume of a bond into GC repos for different levels in the CTP spread. Two patterns stand out: the delivery volume (i) peaks for CTP spreads close to zero and (ii) almost monotonically decreases in the CTP spread. For example, the delivery volume is up to 50% of the outstanding volume for CTP spreads close to zero; the volume drops to below 5% for CTP spreads larger than 10bps. Figure 4b presents consistent results for repo specialness as an alternative measure of collateral opportunity cost. Overall, the declining delivery intensity in a bond's specialness confirms the role of collateral opportunity cost in borrowers' collateral choices.

An interesting perspective is to look at the CTP spread on reporting dates. Ranaldo, Schaffner, and Vasios (2021) show that the introduction of the leverage ratio rules under the Basel III framework disincentivizes the borrowing demand by tightening banks' balance sheet constraints at quarter- and year-end periods when the leverage ratio is calculated.[28] Figure 4c illustrates the CTP spread for the 50 days prior to and after quarter-ends (dotted blue line) and year-ends (straight blue line). The CTP spread spikes on those reporting dates: at quarter-ends, the CTP spread increases to about 8bps; at year-ends, the increase is even stronger to about 14bps. The increase in the CTP spread around quarter- and year-ends can

[27]The decision to use a GC trade instead of a special repo trade involves subtle differences. In a GC trade, the borrower has the choice which bond he delivers as collateral out of a predefined basket of bonds until the first leg is settled. By contrast, a borrower already commits to deliver a specific collateral in a special trade at the trade date of the repo transaction.

[28]The Basel III rules imply that borrowing cash through a repo expands the balance sheet of financial intermediaries and thus reduces the leverage ratio, whereas lending cash via a repo does not.



Figures 4a and 4b depict the delivered volume of a bond into GC trades relative to its outstanding volume for different levels in the CTP spread and in repo specialness. Figure 4c depicts the CTP spread for the 50 days prior to and after the quarter-ends (dotted blue line) and year-ends (straight blue line). Figure 4d depicts the daily delivered volume of a bond relative to its outstanding volume for the first 60 days after the initial auction, separately for bonds with high (i.e., daily haircut above average haircut, orange crosses) and low haircuts (i.e., daily haircut below average haircut, blue circles). For illustrative purposes, Figure 4d only includes medium- and long-term bonds.

Figure 4: Aspects of collateral opportunity cost

be considered a measure of collateral stress since the opportunity cost to post bonds into GC repos are higher on those dates. The results highlight an unintended consequence of the new regulatory framework which leads to window dressing and a resulting spike in collateral opportunity cost around quarter- and year-end periods.

A bond's haircut is another aspect of collateral opportunity cost. The idea here is that bonds with higher haircuts have a lower fungibility and (re-)pledgeability, thus they are less special in the repo market and have lower collateral opportunity cost. Figure 4d graphs the daily volume delivered against the time since the last auction, separately for bonds with high (orange crosses) and low haircuts (blue circles).[29] The results confirm the intuition as the delivery volume tends to be higher for high-haircut bonds.

To empirically capture the different aspects of collateral opportunity cost, I perform a similar panel regression. Table 3 reports the results of the regressions of the delivery volume on a dummy variable that equals one for the CTP bond (D^{CTP}) in column (1); on the two measures of collateral opportunity cost ("CTP spread" and "Repo specialness") in columns (2) and (3); combinations of the dummy variable with the two spreads in columns (4) and (5); and adding a security's haircut ("Haircut") in columns (6) and (7).

Column (1) shows that the CTP bond has, all else equal, a 0.6%-points higher delivery volume. Columns (2) and (3) highlight that the delivery volume decreases in the CTP spread respectively the repo specialness of the delivered security. If the CTP spread (repo specialness) increases by one percentage point, the daily delivery volume decreases by 1.3%-points (0.7%-points). This means that if the special repo rate of a bond decreases (i.e., its specialness increases), its delivery volume into GC repos also decreases. Columns (4) and (5) confirm the statistical significance and economic magnitude of the results by combining the CTP dummy with the two opportunity cost measures.

Finally, columns (6) and (7) introduce a bond's haircut as an additional variable. The regressions show that bonds with a higher haircut tend to have a higher delivery volume. At the same time, the haircut variable is not statistically significant as there is limited within-

[29] At each point in time, I classify a newly issued security into a bond with a high (low) haircut depending on whether its haircut is above (below) the average haircut of newly issued securities.

Table 3: Opportunity cost of collateral

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t
D^{CTP}	0.617***			0.573***	0.594***	0.587***	0.609***
	(12.276)			(11.472)	(11.953)	(11.381)	(11.849)
CTP spread		−1.309***		−1.098***		−1.169***	
		(−7.970)		(−8.032)		(−8.860)	
Repo specialness			−0.702***		−0.577***		−0.604***
			(−11.400)		(−11.129)		(−11.299)
Haircut						0.019	0.018
						(1.173)	(1.085)
N	613,534	613,534	613,534	613,534	613,534	566,873	566,873
R^2	0.148	0.144	0.142	0.151	0.149	0.149	0.147
FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of different aspects of collateral opportunity cost on the delivery volume into GC repo trades. The dependent variable is a security's daily delivery volume over its outstanding volume in percentage points. D^{CTP} equals one if a security is the CTP security for delivery into a GC basket; CTP spread reflects the difference in special repo rates between the CTP security and the delivered security and repo specialness reflects the difference between the GC repo rate of the basket in which a security is delivered and the special repo rate of the delivered security; and haircut denotes the security's haircut in percentage points. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. All regressions include basket-month-term fixed effects and standard errors clustered at the bond-level. Data include GC repo transactions executed on the MTS platform for Italy for the period January 2010–June 2020.

country and within-basket variation in haircuts.

Overall, the results confirm that collateral opportunity cost is the second driver of collateral choice; the delivery intensity is higher for the CTP security and declines when bonds become more expensive.

2.3 Combined effects

I also want to understand the interplay of collateral availability and opportunity cost. Figure 5 provides several illustrations of it.

Figure 5a plots the relative delivery volume of a bond into GC repos for different levels in the CTP spread, as we have seen before, but now separately for the most recently issued, on-the-run government bond (orange crosses) and its off-the-run counterparts (blue circles). We clearly see that if bonds with high CTP spreads are delivered, those are likely to be on-the-run securities. The CTP spreads for on-the-run securities are economically meaningful as they go up to 50bps; this means that borrowers are willing to accept significant opportunity cost to post those on-the-run bonds into GC repos. Still, also for on-the-run securities, the delivery intensity declines in the opportunity cost. This nicely illustrates both aspects of collateral choice: the generally declining delivery volumes in a bond's repo specialness point towards the role of collateral opportunity cost, whereas the relatively higher delivery volumes of on-the-run securities for higher levels in the CTP spread highlight the role of collateral availability.

Figure 5b is developed in a similar spirit, it shows the delivery volume of a bond into GC repos (blue circles) and the repo specialness of the delivered security (orange crosses) relative to the position in the auction cycle. In line with Keane (1996), clear cyclical patterns emerge as on-the-run government bonds become increasingly special until the next auction. Repo deliveries reverse this pattern, i.e., they decline in the repo specialness of the delivered security as collateral opportunity cost increase. This means that borrowers have less incentive to post on-the-run bonds into GC repos as their specialness increases throughout the auction

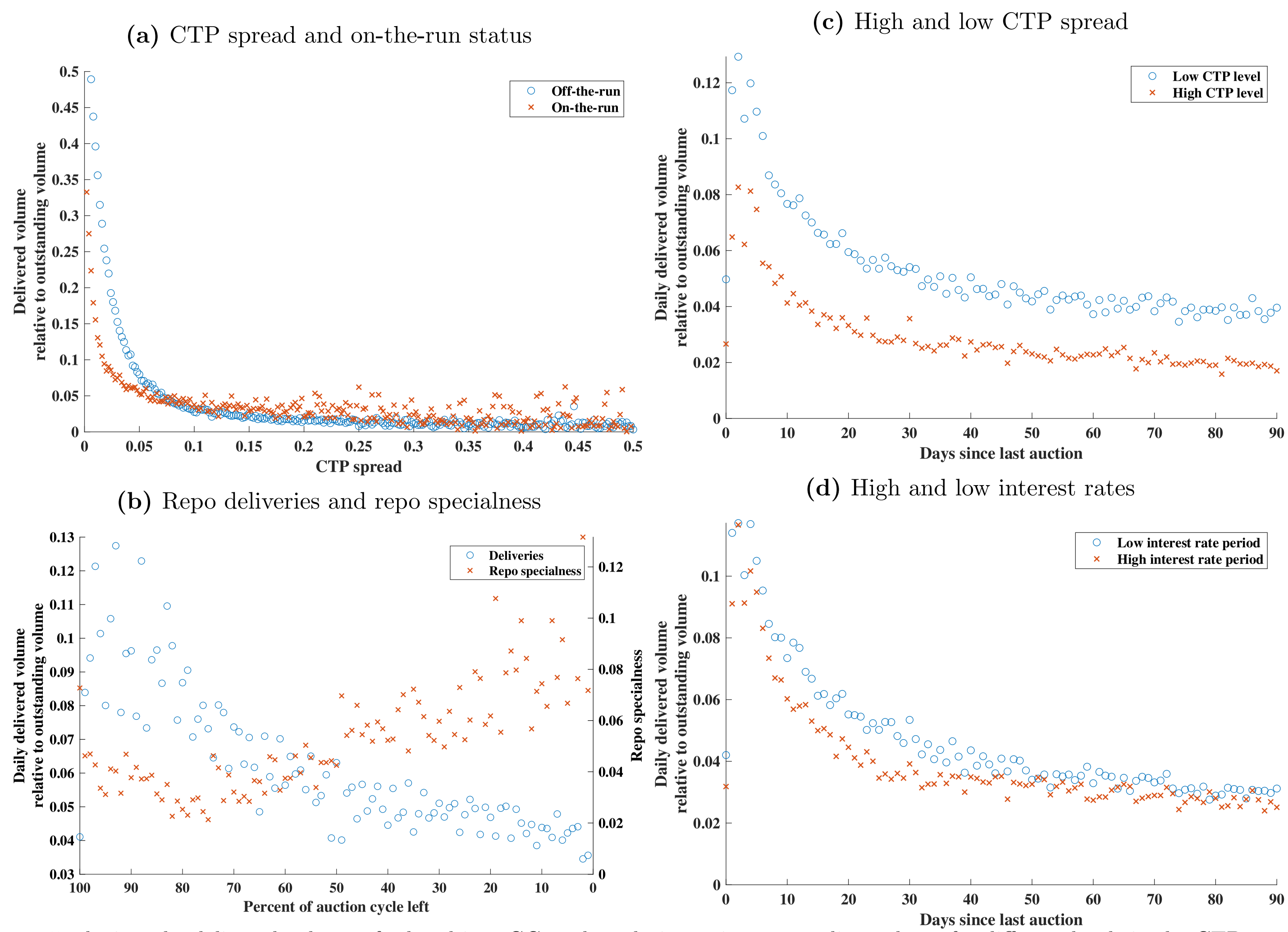


Figure 5a depicts the delivered volume of a bond into GC trades relative to its outstanding volume for different levels in the CTP spread, separately for on-the-run (orange crosses) and off-the-run securities (blue circles). Figure 5b depicts the daily delivered volume of a bond relative to its outstanding volume (blue circles) and the repo specialness of the delivered security (orange crosses) relative to the position in the auction cycle. Figures 5c and 5d depict the daily delivered volume of a bond relative to its outstanding volume for the first 90 days after the initial auction or reopening by differentiating between bonds with high (i.e., CTP spread above the average CTP spread over the sample period, orange crosses) and low levels of CTP spread (i.e., CTP spread below the average CTP spread over the sample period, blue circles), respectively during high (i.e., positive rate on the ECB's main refinancing operations (MRO), orange crosses) and low interest rate periods (i.e., non-positive rate on the ECB's MRO, blue circles) .

Figure 5: Aspects of collateral opportunity cost

cycle.[30] Figure 5c complements this view by showing that on-the-run deliveries are lower during periods when CTP spreads are higher.

Inspired by the safe asset literature, I also consider the level of short-term interest rates. The borrower in a repo forgoes the convenience benefits of the bond which he posts as collateral. Nagel (2016) shows that the value of those convenience benefits depends on the level of short-term rates. His main finding is that the liquidity premium provided by near-money assets is more valuable in a high interest rate environment. The utility loss of delivering on-the-run bonds with the highest liquidity attributes into GC repos therefore also depends on the level of short-term interest rates. Figure 5d shows the relative delivery volume of a bond into GC repos during the first 90 days after the auction, separately for periods with high (orange crosses) and low interest rates (blue circles). Consistent with Nagel (2016), the delivery intensity of on-the-run bonds is lower in a high interest rate environment when the superior liquidity services of on-the-run securities are more valuable.

To empirically assess the combined effect of collateral availability and collateral opportunity cost, I employ the same set of variables in a multivariate panel regression set-up. Table 4 reports the results. Column (1) serves as the baseline and depicts the regression of the delivery volume on different aspects of collateral availability ("Auction size," "Time since auction," $D^{OnTheRun}$, and "Time since QE eligibility") and opportunity cost (D^{CTP} and "CTP spread").

Three main results emerge: First, the delivery volume depends on aspects of collateral availability. On-the-run deliveries tend to be higher for larger auction sizes, this effect is more pronounced for initial auctions than for reopenings. For example, all else equal, a euro 10 billion increase in the allotment at an initial auction increases a bond's delivery volume by about 1.6%-points compared to 0.4%-points for reopenings. The intensity of on-the-run deliveries into GC repos declines with the auction cycle, this effect is up to ten times larger

[30] In a repo squeeze, banks post a substantial portion of their on-the-run bond holdings into GC trades at a higher GC rate instead of using the less expensive special rate. The goal of this trading strategy is to keep the specialness of the bond in the special repo segment high with the idea of profiting from it at a later point. The pattern in my data that repo specialness is low shortly after the auction when on-the-run deliveries into GC repos are more frequent counters this idea and alleviates any concerns around the concept of repo squeeze for my analysis.

Table 4: Collateral availability and opportunity cost

	(1) Delivery volume b/t	(2) Delivery volume b/t	(3) Delivery volume b/t	(4) Delivery volume b/t	(5) Delivery volume b/t	(6) Delivery volume b/t
Auction size	0.038*		0.048**	0.040*	0.031	0.041**
	(1.880)		(2.193)	(1.955)	(1.614)	(2.080)
Auction size $\cdot D^{Initial}$	0.160***		0.079***	0.161***	0.155***	0.149***
	(5.494)		(2.892)	(5.535)	(5.363)	(5.652)
Auction size relative		0.268*				
		(1.788)				
Auction size relative $\cdot D^{Initial}$		1.284***				
		(6.493)				
Time since auction	−0.018*	−0.018*	−0.015*	−0.018*	−0.018**	−0.026**
	(−1.910)	(−1.899)	(−1.661)	(−1.874)	(−2.018)	(−2.575)
Time since auction $\cdot D^{Initial}$	−1.716***	−1.718***	−1.640***	−1.731***	−1.669***	−1.618***
	(−13.905)	(−14.026)	(−14.109)	(−14.029)	(−13.631)	(−12.486)
$D^{OnTheRun}$	0.809***	0.806***		0.807***	0.888***	1.022***
	(10.959)	(10.957)		(10.919)	(11.060)	(7.746)
On-the-run remaining			0.019***			
			(12.448)			
Time since QE eligibility	−0.455***	−0.447***	−0.453***	−0.458***	−0.414***	−0.172***
	(−9.473)	(−9.369)	(−9.710)	(−9.475)	(−8.980)	(−5.382)
D^{CTP}	0.387***	0.386***	0.361***	0.404***	0.331***	0.348***
	(12.704)	(12.660)	(12.436)	(13.252)	(11.709)	(10.551)
CTP spread	−0.876***	−0.872***	−0.953***			−1.105***
	(−8.761)	(−8.737)	(−8.732)			(−8.975)
Repo specialness				−0.462***		
				(−11.156)		
$D^{HighCTP}$					−0.232***	
					(−14.177)	
$D^{OnTheRun} \cdot D^{HighCTP}$					0.315***	
					(4.964)	
$D^{HighInterest}$						−0.275***
						(6.100)
$D^{OnTheRun} \cdot D^{HighInterest}$						0.453***
						(5.692)
N	613,534	613,534	613,534	613,534	613,534	615,480
R^2	0.248	0.249	0.269	0.247	0.253	0.191
FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of different aspects of collateral availability and opportunity cost on the delivery volume into GC repo trades. The dependent variable is a security's daily delivery volume over its outstanding volume in percentage points. Auction size depicts a security's issuance volume at the preceding auction or reopening in euro billion; auction size relative is defined as the ratio of a security's issuance volume at the preceding auction or reopening over the total debt outstanding held by financial institutions; time since auction denotes the time since the preceding auction or reopening in years; $D^{Initial}$ equals one for initial auctions; $D^{OnTheRun}$ equals one if a security is the on-the-run bond and on-the-run remaining measures the remaining time outstanding for which a security is the on-the-run bond; time since QE eligibility refers to the time since QE eligibility in years (i.e., the cumulative time a bond is eligible for purchase under the PSPP); D^{CTP} equals one if a security is the CTP security for delivery into a GC basket; CTP spread reflects the difference in special repo rates between the CTP security and the delivered security and repo specialness reflects the difference between the GC repo rate of the basket in which a security is delivered and the special repo rate of the delivered security; $D^{HighCTP}$ equals one if the CTP spread is above the average CTP spread over the sample period; and $D^{HighInterest}$ equals one for periods when the ECB's MRO rate is positive. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. All regressions include basket-month-term fixed effects except for regression (6) which contains basket-term fixed effects and standard errors clustered at the bond-level. Data include GC repo transactions executed on the MTS platform for Italy for the period January 2010–June 2020.

for initial auctions than for reopenings. Related to asset scarcity, the delivery volume tends to be lower for QE eligible bonds. Bonds that qualify for central bank purchases for one year have a 0.5%-points lower delivery volume. Second, the delivery volume is related to collateral opportunity cost. For a one-percentage-point increase in the CTP spread, the delivery volume decreases by about 0.9%-points. And third, the delivery volume of on-the-run bonds tends to be twice as large than that of CTP securities. More precisely, the delivery volume is 0.8%-points higher for on-the-run bonds compared to 0.4%-points for CTP bonds.

Columns (2)–(4) provide different specifications of the baseline set-up: column (2) exchanges the auction size variable with the relative auction size, column (3) replaces the on-the-run dummy with the continuous variable capturing the remaining time for which a bond is the on-the-run, and column (4) employs the repo specialness measure instead of the CTP spread. All results are fully consistent.

Column (5) exchanges the CTP spread with the dummy variable $D^{HighCTP}$ that is equal to one for deliveries with high CTP spreads and also includes its interaction with the on-the-run dummy. The results confirm that delivery volumes in general and on-the-run deliveries in particular are lower when CTP spreads are higher.

Lastly, column (6) extends the basic framework and additionally includes the dummy variable $D^{HighInterest}$ to capture high interest rate periods; I also include the interaction of the interest rate dummy with the on-the-run dummy. The results are in line with Nagel (2016) and provide evidence for the idea that on-the-run deliveries are lower during high interest rate periods when the superior liquidity services provided by on-the-run bonds are more valuable.

Overall, my results confirm that aspects of collateral availability and opportunity cost jointly play a role in explaining collateral choices. To ensure the robustness of my results, I provide several additional tests as reported in Table 5: column (1) depicts the baseline set-up for reference; column (2) extends this framework and also includes the bid-to-cover ratio at the preceding auction or reopening as a measure of collateral demand; column (3) introduces the bond bid-ask spread and bond tenor as additional controls on the bond-level;

Table 5: Robustness checks

	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline	Auction bid-cover	Bond controls	Futures CTD	Economic controls	Log
	b/t	b/t	b/t	b/t	b/t	b/t
Auction size	0.038*	0.091***	0.019	0.038*	0.038*	0.310***
	(1.880)	(5.098)	(1.129)	(1.894)	(1.884)	(4.913)
Auction size $\cdot D^{Initial}$	0.160***	0.250***	0.212***	0.160***	0.161***	0.494***
	(5.494)	(10.153)	(9.686)	(5.496)	(5.625)	(8.658)
Time since auction	−0.018*	−0.010	−0.012	−0.018*	−0.019**	−0.050**
	(−1.910)	(−0.944)	(−1.131)	(−1.907)	(−2.013)	(−2.499)
Time since auction $\cdot D^{Initial}$	−1.716***	−1.608***	−1.699***	−1.716***	−1.705***	−0.877***
	(−13.905)	(−13.150)	(−13.782)	(−13.908)	(−13.491)	(−11.991)
$D^{OnTheRun}$	0.809***	0.817***	0.834***	0.808***	0.795***	0.533***
	(10.959)	(10.922)	(12.328)	(10.959)	(11.039)	(9.078)
Time since QE eligibility	−0.455***	−0.438***	−0.428***	−0.457***	−0.431***	−0.357***
	(−9.473)	(−8.837)	(−8.873)	(−9.525)	(−9.236)	(−7.041)
D^{CTP}	0.387***	0.400***	0.385***	0.388***	0.377***	0.301***
	(12.704)	(11.964)	(12.592)	(12.707)	(12.234)	(16.179)
CTP spread	−0.876***	−0.835***	−0.809***	−0.876***	−0.886***	−1.570***
	(−8.761)	(−8.190)	(−8.367)	(−8.745)	(−9.243)	(−10.788)
Bid-to-cover ratio	No	Yes	No	No	No	No
Bond bid-ask spread	No	No	Yes	No	No	No
Bond tenor	No	No	Yes	No	No	No
Futures CTD	No	No	No	Yes	No	No
Debt-to-GDP	No	No	No	No	Yes	No
CDS	No	No	No	No	Yes	No
QE purchases	No	No	No	No	Yes	No
N	613,534	524,837	608,272	613,534	615,284	613,534
R^2	0.248	0.257	0.258	0.248	0.226	0.251
FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of different aspects of collateral availability and opportunity cost on the delivery volume into GC repo trades. The dependent variable is a security's daily delivery volume over its outstanding volume in percentage points. Auction size depicts a security's issuance volume at the preceding auction or reopening in euro billion; time since auction denotes the time since the preceding auction or reopening in years; $D^{Initial}$ equals one for initial auctions; $D^{OnTheRun}$ equals one if a security is the on-the-run bond; time since QE eligibility refers to the time since QE eligibility in years (i.e., the cumulative time a bond is eligible for purchase under the PSPP); D^{CTP} equals one if a security is the CTP security for delivery into a GC basket; CTP spread reflects the difference in special repo rates between the CTP security and the delivered security; the bid-to-cover ratio refers to the ratio of specialists at the preceding auction or reopening; bond bid-ask spread refers to the bid-ask spread in the bond market for the delivered security and bond tenor refers to the initial tenor of the delivered bond; futures CTD is a dummy that equals one for the cheapest-to-deliver bond into the nearest futures contract; debt-to-GDP denotes Italy's quarterly debt-to-GDP ratio; CDS denotes Italy's 10-year CDS price; and QE purchases denotes the ECB's net quarterly PSPP purchases of Italian government bonds over GDP. In column (6), delivery volume and auction size are taken in logarithm. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. All regressions include basket-month-term fixed effects except for regression (5) which contains basket-year-term fixed effects and standard errors clustered at the bond-level. Data include GC repo transactions executed on the MTS platform for Italy for the period January 2010–June 2020.

Table 6: Germany and France

	(1)	(2)	(3)	(4)	(5)	(6)
	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t	Delivery volume b/t
Auction size	0.002	−0.004	0.014	0.002	0.003	0.003
	(0.299)	(−0.478)	(1.369)	(0.302)	(0.319)	(0.350)
Auction size $\cdot D^{Initial}$	0.238***	0.170***	0.285***	0.238***	0.239***	0.239***
	(4.296)	(3.226)	(5.035)	(4.296)	(4.299)	(4.309)
Time since auction	−0.005	−0.008*	−0.015**	−0.005	−0.005	−0.005
	(−1.259)	(−1.792)	(−2.180)	(−1.257)	(−1.247)	(−1.181)
Time since auction $\cdot D^{Initial}$	−0.062***	−0.043**	−0.078***	−0.062***	−0.062***	−0.062***
	(−3.285)	(−2.511)	(−3.879)	(−3.285)	(−3.280)	(−3.264)
$D^{OnTheRun}$	0.287***			0.287***	0.288***	0.291***
	(5.908)			(5.836)	(5.846)	(5.894)
On-the-run remaining		0.008***				
		(5.547)				
D^{CTP}			0.045	0.002	−0.008	−0.012
			(0.717)	(0.047)	(−0.153)	(−0.238)
CTP spread					−0.266*	
					(−1.685)	
Repo specialness						−0.386***
						(−2.798)
N	2,978	2,978	2,978	2,978	2,978	2,978
R^2	0.268	0.289	0.238	0.268	0.268	0.270
FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of different aspects of collateral availability and opportunity cost on the delivery volume into GC repo trades. The dependent variable is a security's daily delivery volume over its outstanding volume in percentage points. Auction size depicts a security's issuance volume at the preceding auction or reopening in euro billion; time since auction denotes the time since the preceding auction or reopening in years; $D^{Initial}$ equals one for initial auctions; $D^{OnTheRun}$ equals one if a security is the on-the-run bond and on-the-run remaining measures the remaining time outstanding for which a security is the on-the-run bond; D^{CTP} equals one if a security is the CTP security for delivery into a GC basket; CTP spread reflects the difference in special repo rates between the CTP security and the delivered security and repo specialness reflects the difference between the GC repo rate of the basket in which a security is delivered and the special repo rate of the delivered security. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; *t*-statistics are in parentheses. All regressions include basket-month-term fixed effects and standard errors clustered at the bond-level. Data include GC repo transactions executed on the MTS platform for Germany and France for the period January 2010–June 2020.

column (4) accounts for the cheapest-to-deliver bond in the futures market; column (5) considers additional economic variables as controls;[31] and column (6) reports the results of the regression estimated in logs rather then levels. Overall, the effect of collateral availability and opportunity cost on delivery volumes remains statistically and economically consistent across all specifications.

I also consider different fixed effect combinations and standard error clustering and repeat my analysis in a sample without quarter end and end of ECB maintenance period trading days, those results are fully consistent and reported in the Online Appendix.

Finally, to ensure the general validity of my results, I replicate my analysis for Germany and France, which are the two largest euro area countries, as reported in Table 6. The results are fully consistent which ensures that my analysis also speaks to other markets such as the German "safe haven" market which is the quintessential safe asset in the euro area.

Overall, my analysis provides clear and consistent evidence for three main takeaways: First, higher collateral availability increases the delivery intensity; second, higher collateral opportunity cost decreases the delivery intensity; and third, the newly issued, on-the-run government bond with the highest availability is delivered about twice as often as the CTP bond with the lowest opportunity cost.

3. Theoretical implications

My empirical results show that collateral availability and opportunity cost are the two main drivers of *borrowers'* collateral choices; the results also show that on-the-run bonds are more likely to be posted as collateral in GC repos than CTP securities, which is surprising given that on-the-run bonds carry a higher repo specialness. The focus in the second part

[31]First, I employ the debt-to-GDP ratio to account for overall asset supply in line with Krishnamurthy and Vissing-Jorgensen (2012). Second, I include the price on 10-year CDS spreads as a measure of the overall sovereign risk level. More public debt creates uncertainty, which raises default risk premia (Liu, Schmid, and Yaron, 2019) so that collateral quality deteriorates with weak sovereign resources (He, Krishnamurthy, and Milbradt, 2019) and the government's inability to back its borrowing with taxation (Krishnamurthy and Vissing-Jorgensen, 2015). When a sovereign bond bears a convenience premium that is uncertain and adversely affected by risk, it becomes a quasi-safe asset (Ballensiefen and Ranaldo, 2022). Finally, I consider the ECB's purchases under the PSPP as those purchases reduced the overall supply of government debt in line with Arrata et al. (2020) and Corradin and Maddaloni (2020).

is, therefore, to provide a simple theoretical framework related to market makers and their inventory holdings that rationalizes borrowers' collateral choices and links them to the bond market for the collateral.[32]

3.1 Intuition

I consider a dealer for government bonds. This dealer participates in government bond auctions, i.e., in the primary market for government debt, to establish a portfolio of newly issued, on-the-run securities. By participating in these auctions, the dealer builds up an inventory of bonds which allows him (i) to meet the demand of investors who are not able to participate in primary auctions for newly issued bonds ("distribution phase") and (ii) to perform future market-making obligations ("market-making phase").[33] The (i) distribution phase is associated with an increased number of buy orders from investors, while the (ii) market-making phase is associated with a balanced buy and sell order flow from liquidity traders.

Figure 6 illustrates the evolution of the market maker's portfolio weight in newly issued government bonds over time relative to his optimal portfolio weight. The dealer has a time-independent, optimal portfolio share in newly issued securities, denoted as $\tilde{w}$, which allows

[32] A large body of the theoretical literature has focused on the special repo segment. One important reference is Krishnamurthy (2002) who provides a framework that connects the repo market to the bond market for the collateral. In his set-up, the *lender* in special repos has a demand for a specific bond which explains the higher repo specialness of newly issued, on-the-run U.S. Treasuries. Other related studies on special repos include, for example, Jordan and Jordan (1997), Buraschi and Menini (2002), D'Amico et al. (2018), and Corradin and Maddaloni (2020). Huh and Infante (2021) consider a cross-temporal perspective and arrive at the conclusion that bond market liquidity is lower when specialness is high due to the associated cost of intermediation. An important reference in the GC segment is Bartolini et al. (2011); their main finding is that U.S. Treasury baskets include a collateral rent which other asset class baskets do not offer. In the spirit of Bartolini et al. (2011), the CTP bond is the one maximizing the collateral rent.

[33] Dealers that are market makers have obligations for subscriptions in government bond auctions and trading volumes in the secondary market; thus, they are required to offer sufficient amounts to meet the demand of secondary market investors who are not able to participate in primary auctions. The market makers' obligations are more closely defined by evaluation criteria set by the Italian Treasury which monitors that specialists participate in primary auctions, in secondary market trading, and in the repo market. An essential requirement for maintaining specialist status in government bonds is the allocation in primary auctions, which is evaluated via a "primary quantitative indicator." In the calculation of this indicator, allotments of on-the-run bonds are weighted twice as much as those of off-the-run bonds (the full set of evaluation criteria for year 2020 can be found in Decree no. 111944 as of December 20, 2019, available at `http://www.dt.mef.gov.it/export/sites/sitodt/modules/documenti_en/debito_pubblico/specialisti_titoli_di_stato/Specialists_evaluation_criteria_-_year_2020.pdf`).

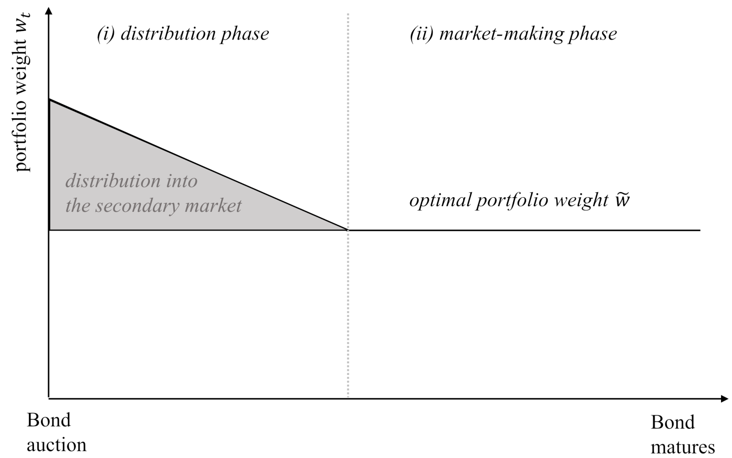


Figure 6: Illustration of optimal time-dependent portfolio weights

him to balance the investors' regular order flow. However, during the distribution phase, the dealer's actual portfolio share in newly issued securities w_t is above the optimal level as he holds additional bonds to be distributed into the secondary market. The share declines as the dealer distributes part of his inventory to buy-and-hold investors. During the market-making phase, the optimal portfolio weight is reached. One can think of the dealer's inventory as holding two portfolios: an optimal portfolio represented by the optimal portfolio weight $\tilde{w}$ and an additional trading portfolio during the distribution phase when the portfolio share in newly issued securities is above the optimal portfolio weight.

As the dealer's portfolio initially deviates from the desired level, he is exposed to inventory risk. This intuition is in line with, for example, Fleming and Rosenberg (2008) who estimate that primary dealers in U.S. Treasuries disseminate part of their auction purchases shortly after the auction but also retain a substantial position until redemption. They argue that this mainly creates inventory risk since adverse selection risk is small. Building on this, Figure 7 depicts the volume of a bond delivered into GC repos relative to the buy-and-hold investor share for the 12 quarters following the initial auction, illustratively for ten-year government bonds. The results confirm that the share of buy-and-hold investors increases in the time since the auction. For example, the share of buy-and-hold investors increases from about

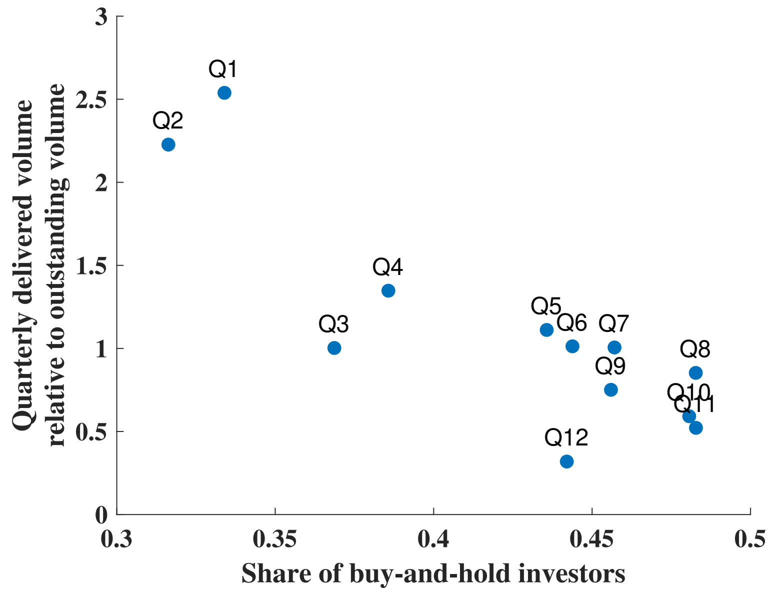


Figure 7 depicts the quarterly delivered volume of a bond into GC trades relative to the share of buy-and-hold investors; the figure illustratively includes data for ten-year government bonds.

Figure 7: Delivery volume and buy-and-hold investor share

30% in the first quarter after the auction to about 50% two years after the auction. A higher buy-and-hold investor share suggests lower holdings in the market maker's portfolio; this is reflected in lower delivery volumes into GC repos.[34]

Returning to the dealer's decision problem, he bases his decision about each bond's optimal portfolio weight on his portfolio preferences by taking his expectation about the liquidity traders' future order flow into account. During the distribution phase, the dealer holds a portfolio weight w_t in newly issued bonds which is above his optimal level $\tilde{w}$, i.e., the dealer holds an unbalanced portfolio that he can finance and rebalance via the repo market. Repos are the most common vehicle for financing and rebalancing portfolios due to their short-term nature; dealers can stop rolling over overnight repos once they find a buyer for the bonds in the inventory (e.g., Bartolini et al., 2011; Eisl et al., 2019; Macchiavelli and Zhou, 2021).

[34] A different illustration of this is to look at trading volumes in the bond market. In the Online Appendix, I depict the trading volume in government bonds relative to the time since the last auction, separately for initial auctions and reopenings. The results confirm that trading volumes in the bond market are highest around auctions and decrease thereafter. For example, for initial auctions, the daily bond trading volume peaks at around 12% of the outstanding volume on the auction day and decreases to about 2% one month after the auction. This is in line with the idea of market makers distributing auction purchases and an increasing share of buy-and-hold investors.

The dealer's decision to post a newly issued on-the-run bond as collateral into a repo trade is, however, costly as the dealer needs to pay the repo financing cost and forgoes the utility flows of the repo collateral (Krishnamurthy, 2002). The dealer therefore requires a compensation to engage in his market making activities in the bond market for the collateral.

3.2 Model framework

My framework builds on Stoll (1978) who introduces an inventory model in which the representative agent is a dealer (market maker). The model introduced in Stoll (1978) is not specific to a certain asset class, while my considerations focus on the bond market set-up, i.e., the dealer is a market maker for government bonds. The dealer's trade-off between the optimal portfolio holdings and the opportunity cost of posting bonds as collateral can be incorporated into this framework. As a market maker, the dealer provides bond quotes, i.e., bid and ask offers for investors who are looking to either sell the respective bond (at the market maker's bid price) or buy the bond (at the market maker's ask price). Following Stoll (1978), the dealer adjusts his quotes in response to an unexpected and uneven order flow. The spread between bid and ask quotes compensates the dealer for each trade's cost C_i.

The dealer enters the period with wealth W_0. His optimal portfolio choice involves investing a share k into the optimal portfolio (yielding a return $\tilde{R}_e$) and the remaining share $(1-k)$ into cash holdings (earning the risk-free rate r_f).

Over time, the dealer participates in government bond auctions; based on the auction allotments, the dealer holds an additional trading portfolio in newly issued, on-the-run government bonds.[35] As the market maker needs to participate in government bond auctions to retain his market making status, he receives a certain allocation which I consider to be exogenous. The true value of these "excessive" on-the-run holdings in the trading portfolio is denoted with Q_{OTR}, the return of the on-the-run holdings is denoted with $\tilde{R}_{OTR}$.

In my set-up, the dealer refinances his trading portfolio via repos; this is different from Stoll (1978), in which the dealer refinances himself at the risk-free rate. The repo market is the

[35] For expositional simplicity, I assume that the dealer only holds on-the-run securities in his trading portfolio.

closest equivalent to a "true" risk-free rate and the primary market for portfolio reallocations.

The dealer has the option to place on-the-run bonds into both GC and special collateral repos. GC repo rates provide the upper bound for special repo rates; the financing cost for the borrower are, therefore, lower when he posts on-the-run bonds into special repos, where he can earn the repo specialness. However, the market maker faces cost for relying on special repo trades. The underlying market friction relates to different settlement cycles and term types between GC and special repo trades. ON repos predominantly trade in the GC segment, while the special repo market is more liquid for SN repos. If the market maker uses special repo trades, he faces the risk of being locked into repo trades when unexpected liquidity needs or investor trading in the bond market arise.[36] The associated marginal cost increase in the share funded via special repos $\theta_{Special}$.[37] The market maker chooses the optimal repo funding shares in GC and special repos so that the repo specialness earned from using special repo trades equals the cost of being "inflexible" and locked in.[38] The funding cost in the repo market, therefore, reads as:

$$R_F = \theta_{Special} R_{Special} + (1 - \theta_{Special}) R_{GC}. \tag{3}$$

By defining the opportunity cost OC_i as repo specialness (see Equation 2), it follows:

$$R_F = R_{GC} - \theta_{Special} OC_i. \tag{4}$$

Since the dealer posts his excessive on-the-run bonds into repo trades to finance and rebalance his portfolio, the return on the trading portfolio $\tilde{R}_{OTR}$ is reduced by the foregone convenience yield valued OC_i.[39]

[36]GC repo trades also have the advantages of superior liquidity, high trading volumes, and low price impact compared to special repo trades. For reference, I depict the ratio in trading volumes between the GC segment and the special segment for on-the-run securities relative to the time since the initial auction in the Online Appendix. Overall, the GC trading volume surpasses that of special trades for on-the-run securities by about five times around auctions and by about ten times one month after the auction, thus highlighting that GC repos are the more liquid option.

[37]The repo funding share in the GC segment is defined as 1 - $\theta_{Special}$.

[38]The derivation of the optimal repo funding shares is depicted in the Online Appendix.

[39]The returns on the optimal portfolio and on the on-the-run holdings in the trading portfolio are stochastic, while the funding cost is deterministic as the GC rate and the opportunity cost are known at the beginning

The model is based on a one-period setting during which one trade occurs. The dealer's terminal wealth based on the initial portfolio is denoted with $\tilde{W}^*$, the terminal wealth after the trade with $\tilde{W}$. The dealer maximizes his expected utility. This implies that for the dealer to provide quotes and engage in a transaction, the compensation from the trade must offset the utility loss associated with the dealer deviating from his optimal portfolio. The expected utility of the terminal wealth based on the initial portfolio must, therefore, be the same as the expected utility of the terminal wealth of the new portfolio after the transaction, which is the initial portfolio altered by the trade.[40] More formally:

$$EU(\tilde{W}^*) = EU(\tilde{W}). \tag{5}$$

The dealer's end-of-period, terminal wealth from the initial portfolio (comprised of the optimal portfolio, the risk-free investment, and the on-the-run bonds in the trading portfolio) without any trade occurring reads as follows:

$$\tilde{W}^* = W_0[1 + \underbrace{k\tilde{R}_e}_{\substack{return\\optimal\\portfolio}} + \underbrace{(1-k)r_f}_{\substack{return\\risk\text{-}free\\investment}} + \underbrace{\frac{Q_{OTR}}{W_0}(\tilde{R}_{OTR} - OC_i)}_{\substack{return\\trading\\portfolio}} - \underbrace{\frac{Q_{OTR}}{W_0}R_F}_{\substack{financing\\cost}}]. \tag{6}$$

I define $\tilde{W}^* = W_0[1 + \tilde{R}^*]$ in which $\tilde{R}^*$ depicts the overall return on the dealer's initial portfolio.

The dealer's end-of-period, terminal wealth of the new portfolio after a trade (comprised of the initial portfolio, the change in the trading portfolio, and the financing cost of the new trade) reads as follows:

$$\tilde{W} = W_0(1 + \underbrace{\tilde{R}^*}_{\substack{return\\initial\\portfolio}}) + \underbrace{Q_i(1 + \tilde{R}_{OTR} - OC_i)}_{\substack{change\\return}} - \underbrace{(Q_i - C_i)(1 + R_F)}_{\substack{change\\financing\\cost}}. \tag{7}$$

Q_i indicates the value of the additional on-the-run bond in the trading portfolio. The dealer

of the period.

[40]Terminal in this case refers to the end of the one period during which a trade occurs.

earns the on-the-run return $\tilde{R}_{OTR}$ on this position but foregoes the convenience of the bond valued at OC_i as he posts the bond into a repo trade. In addition, the dealer needs to finance the value of the new bond less any cost C_i which he charges to the investor.[41] For example, if the dealer holds a trading portfolio in on-the-run bonds and an investor wants to sell an additional on-the-run security to the dealer, then the dealer is only willing to pay less than the "true" value $Q_i - C_i$ to the investor. This happens since the trade increases the dealer's holdings of on-the-run bonds in the trading portfolio, thus, the dealer deviates more from his optimal portfolio. C_i is endogenously determined in the model, the dealer sets C_i such that Equation 5 is fulfilled.

I assume that the dealer is subject to an exponential utility function with constant absolute risk aversion (CARA) of the following form:

$$U(W) = -e^{-aW}, \tag{8}$$

in which a denotes the coefficient of absolute risk aversion.[42] Under the assumption that W is normally distributed with $\sim \mathcal{N}(\mu, \sigma^2)$, we know that:

$$EU(W) = E(W) - \frac{1}{2}a\text{Var}(W). \tag{9}$$

Thus, from Equation (5) follows:

$$E(\tilde{W}^*) - \frac{1}{2}a\text{Var}(\tilde{W}^*) = E(\tilde{W}) - \frac{1}{2}a\text{Var}(\tilde{W}) \tag{10}$$

The dealer's cost function can be derived by inserting the specifications for the dealer's terminal wealth from the initial portfolio and the new portfolio after the trade into Equation (10).[43] Solving for C_i leads to:

[41] Positive values of Q_i indicate purchases by the dealer (from the investor), while negative values indicate sales to the investor. One can think of the cost as charging the investor the bid-ask spread to cover the cost of holding a portfolio and constantly providing quotes.

[42] The Arrow–Pratt measure of relative risk aversion z is defined as $z = a \cdot W_0$.

[43] The model derivation is presented in the Online Appendix.

$$C_i = \frac{\frac{1}{2}aQ_i^2\text{Var}(\tilde{R}_{OTR}) + aQ_iQ_{OTR}\text{Var}(\tilde{R}_{OTR}) + Q_iOC_i(1-\theta_{Special})}{(1 + R_{GC} - \theta_{Special}OC_i)}. \tag{11}$$

Equation (11) reflects the cost that the dealer charges to the investor for a trade, it incorporates the aspects of collateral availability and opportunity cost into the dealer's decision problem. The model implies that the dealer's cost of intermediation increases in the size of the trading portfolio Q_{OTR} (as his holdings deviate from his efficient portfolio) and in the collateral opportunity cost of each bond i (due to the higher forgone utility of posting the bond into a repo trade).[44]

3.3 Bond market estimation

I use my repo and bond data to provide empirical support for the theoretical predictions. Table 7 summarizes the impact of the different model variables on the bid-ask spread and the measures which I employ to capture them. The main variable of interest is a bond's relative bid-ask spread charged by the dealer. I employ the bid-ask spread at *t+1* so that I can relate today's collateral choices by the dealer to tomorrow's bid-ask spread quoted in the bond market.[45] I relate this bid-ask spread to the main variables in the model. The dealer's cost function suggests that higher holdings of on-the-run bonds in the trading portfolio and higher bond opportunity cost imply higher cost for the dealer. For the estimation, I employ delivery volumes into GC trades and my repo specialness measure to mimic the size of the trading portfolio and collateral opportunity cost. As implied by the model, I also consider the variance of the bond return and the quoted depth difference as controls.

Table 8 reports the results of the panel regressions of the relative bid-ask spread ("Relative spread") on the delivery volume ("Delivery volume") in column (1), on the repo specialness measure ("Repo specialness") in column (2), on the variance of the bond return ($Var(\tilde{R}_i)$) in column (3), on the quoted depth difference ("Quoted depth difference") in column (4), and

[44] The conclusions also hold for the relative bid-ask spread, the derivation is presented in the Online Appendix.

[45] I match the repo delivery volumes to the corresponding bond quotes depending on the settlement conventions.

Table 7: Empirical predictions

	$Spread_i$	Empirical measure
$Q_{OTR} \uparrow$	$\uparrow$	delivery volume in GC basket
$OC_i \uparrow$	$\uparrow$	repo specialness
$Var(\tilde{R}_i) \uparrow$	$\uparrow$	variance of bond return
$Q_{ask} - Q_{bid} \uparrow$	$\uparrow$	quotes ask − quotes bid

the combined effect in column (5).[46]

Column (1) confirms that a bond's bid-ask spread increases in the repo delivery volumes of that bond, the effect is almost one-to-one. Column (2) highlights that a bond's bid-ask spread also increases in its opportunity cost. If the repo specialness of a bond increases by one percentage point, the relative spread increases by 0.4%-points. Columns (3) and (4) show that the bid-ask spreads are higher for more volatile bonds (inventory risk) and for bonds with larger differences in the quoted depth (unbalanced portfolio). Finally, column (5) confirms the statistical significance and economic magnitude in a multivariate setting.

The results are in line with the idea that higher holdings of on-the-run bonds in the trading portfolio (which are posted into GC trades to finance and diversify the portfolio) and higher bond opportunity cost (which reflect the foregone utility services due to the delivery of the bond into a GC trade) are associated with higher bond market spreads.

The concept of liquidity is usually broadly defined and encompasses different aspects. Bond market liquidity is often measured via the bid-ask spread, other measures include, for example, the depth of the order book and trading volumes. Table 9 reports those measures, i.e., the relative bid-ask spread, the market quality index, and the daily bond trading volume, for the on-the-run bond and its off-the-run counterparts, separately for different bond types.

On average, the bid-ask spread is higher for newly issued, on-the-run securities which reinforces the theoretical intuition. The difference in bid-ask spreads is statistically significant for medium- and longer-term bonds, while spreads are not statistically different for short-term bonds which are less suitable for buy-and-hold investors and for which market makers are willing to hold larger inventories (e.g., Naik and Yadav, 2003 and Fleming and Rosenberg,

[46]All regressions include basket-month fixed effects and standard errors clustered at the bond-level.

Table 8: Bond market spread

	(1)	(2)	(3)	(4)	(5)
	Relative spread *t+1*	Relative spread *t+1*	Relative spread *t+1*	Relative spread *t+1*	Relative spread *t+1*
	b/t	b/t	b/t	b/t	b/t
Delivery volume	1.010**				0.879**
	(1.976)				(2.356)
Repo specialness		0.406***			0.252***
		(4.912)			(5.003)
$Var(\tilde{R}_i)$			0.240***		0.224***
			(13.977)		(13.604)
Quoted depth difference				2.877***	2.963***
				(3.426)	(4.329)
N	253,521	256,944	289,034	289,073	253,521
R^2	0.633	0.633	0.715	0.594	0.736

The table reports the regression results examining the impact of different cost measures on the quoted relative spread in bond markets. The dependent variable is a security's log of tomorrow's relative bid-ask spread at *t+1*. Delivery Volume denotes a security's daily delivery volume into GC repo trades over its outstanding volume in percentage points; repo specialness reflects the difference between the GC repo rate of the basket in which a security is delivered and the special repo rate of the delivered security; $Var(\tilde{R}_i)$ denotes the variance of the bond's return; and quoted depth difference denotes the difference in the volume offered at the best ask minus the volume offered at the best bid. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. All regressions include basket-month fixed effects and standard errors clustered at the bond-level. Data include repo transactions and bond quotes executed on the MTS platform for Italy for the period January 2010–June 2020.

Table 9: Liquidity measures for on-the-run and off-the-run bonds

	(1) Short-term	(2) Medium-term	(3) Medium-term floating	(4) Long-term	(5) Long-term inflation-linked
Bid-ask spread					
On-the-run	0.45	0.33	0.14	0.54	0.78
Off-the-run	0.45	0.28	0.12	0.35	0.54
Difference	−0.00	−0.05***	−0.02***	−0.19***	−0.24***
	(−0.16)	(−24.11)	(−3.74)	(−36.07)	(−6.95)
Market quality index (MQI)					
On-the-run	184,843	37,135	167,691	119,938	152,404
Off-the-run	233,457	47,884	207,403	169,061	156,303
Difference	48,615***	10,749***	39,712***	49,128**	3,899***
	(22.08)	(37.72)	(13.18)	(52.82)	(2.18)
Daily bond trading quantity (mm)					
On-the-run	142.0	15.2	110.0	62.7	42.6
Off-the-run	61.9	14.2	51.7	28.9	28.3
Difference	−80.2***	−1.0***	−58.7***	−33.8***	−14.3***
	(−55.50)	(−3.48)	(−32.27)	(−73.97)	(−19.98)

The table reports the relative bid-ask spread in percentage points, the market quality index and the daily bond trading quantity in millions for on-the-run and off-the-run securities for the five types of government bonds: short-term bonds are Treasury bills (BOTs), medium-term bonds are zero-coupon bonds (CTZs), medium-term floating-rate bonds are Treasury certificates indexed to six-month Euribor (CCTs), long-term bonds are Treasury bonds (BTPs), and long-term inflation-indexed bonds are Treasury bonds linked to inflation (BTPs€i). The difference is defined as the off-the-run value less the on-the-run value. t-statistics are in parentheses. Data include bond quotes and trades executed on the MTS platform for Italy for the period January 2010–June 2020.

2008). Huh and Infante (2021) analyze the relationship between repo market specialness and the bond market liquidity of the underlying collateral. They develop a theoretical model which suggests that over time (and for the same asset), a higher repo market specialness can lead to lower bond market liquidity as intermediaries face higher cost. Broadening their view, my focus is on the cross-section of assets; I show that higher repo delivery volumes and collateral opportunity cost have a negative impact on a bond's bid-ask spread in the cross-section which translates into a lower market quality index measure.

Still, while on-the-run bonds feature higher bid-ask spreads, they also have higher daily trading volumes which reflects another aspect of liquidity. My results provide a *suggestive* explanation for it. For market participants, global safe asset scarcity has led to a net demand for safe assets; thus, they are willing to pay a convenience premium (e.g., in the form of higher repo specialness or bid-ask spreads) to obtain those assets, for example, the on-the-run bond which features superior liquidity benefits in the form of larger trading volumes. Market makers, by contrast, need to hold larger inventories for those on-the-run securities which creates inventory cost for which they want to be compensated in the form of higher bid-ask spreads.

4. Conclusion

The novelty of my study is to analyze borrowers' refinancing behavior and collateral choices in one of the main short-term funding markets. In GC repos, the borrower chooses which bond he posts as collateral. I find that collateral availability and opportunity cost are the two main drivers of this collateral choice. In aggregate, on-the-run bonds are more likely to be delivered as collateral than CTP securities which is surprising given that the former is more expensive. I incorporate the results into a simple theoretical framework that links the funding decision to the bond market for the collateral.

My analysis sheds light on new empirical patters, for example, that on-the-run bonds are likely to be delivered as collateral into GC trades although they carry a high repo market specialness. Future research could analyze collateral choices in other short-term funding markets such as the U.S. The differences between the lenders' repo demand for collateral and the borrowers' collateral choices also suggest a form of segmentation between the GC and special repo market segment as collateral rents in the spirit of Bartolini et al. (2011) are not maximized. Lastly, collateral choices provide a novel link between the funding market and the underlying bond market for the collateral.

References

Adrian, T., N. Boyarchenko, and O. Shachar. 2017. Dealer balance sheets and bond liquidity provision. *Journal of Monetary Economics* 89:92–109.

Andersen, L., D. Duffie, and Y. Song. 2019. Funding value adjustments. *Journal of Finance* 74:145–192.

Arrata, W., B. Nguyen, I. Rahmouni-Rousseau, and M. Vari. 2020. The scarcity effect of quantitative easing on repo rates: Evidence from the Euro area. *Journal of Financial Economics* 137:837–856.

Ballensiefen, B., and A. Ranaldo. 2022. Safe asset carry trade. *Review of Asset Pricing Studies (forthcoming)* .

Bank for International Settlements. 2017. Repo market functioning. *Committee on the Global Financial System (CGFS) Papers* No. 59. Available at `https://www.bis.org/publ/cgfs59.htm`.

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

Beetsma, R., M. Giuliodori, F. De Jong, and D. Widijanto. 2016. Price effects of sovereign debt auctions in the euro-zone: The role of the crisis. *Journal of Financial Intermediation* 25:30–53.

Beetsma, R., M. Giuliodori, J. Hanson, and F. de Jong. 2018. Bid-to-cover and yield changes around public debt auctions in the euro area. *Journal of Banking and Finance* 87:118–134.

Boissel, C., F. Derrien, E. Ors, and D. Thesmar. 2017. Systemic risk in clearing houses: Evidence from the European repo market. *Journal of Financial Economics* 125:511–536.

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

Brunnermeier, M. K., and L. H. Pedersen. 2009. Market liquidity and funding liquidity. *Review of Financial Studies* 22:2201–2238.

Buraschi, A., and D. Menini. 2002. Liquidity risk and specialness. *Journal of Financial Economics* 64:243–284.

Chen, H., Z. Chen, Z. He, J. Liu, and R. Xie. 2019. Pledgeability and asset prices: Evidence from the Chinese corporate bond markets. *University of Chicago Working Paper No. 2018-82* .

Comerton-Forde, C., T. Hendershott, C. M. Jones, P. C. Moulton, and M. S. Seasholes. 2010. Time variation in liquidity: The role of market-maker inventories and revenues. *Journal of Finance* 65:295–331.

Corradin, S., and A. Maddaloni. 2020. The importance of being special: Repo markets during the crisis. *Journal of Financial Economics* 137:392–429.

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

D'Amico, S., R. Fan, and Y. Kitsul. 2018. The scarcity value of Treasury collateral: Repo-market effects of security-specific supply and demand factors. *Journal of Financial and Quantitative Analysis* 53:2103–2129.

D'Amico, S., and T. B. King. 2013. Flow and stock effects of large-scale treasury purchases: Evidence on the importance of local supply. *Journal of Financial Economics* 108:425–448.

D'Amico, S., and N. A. Pancost. 2022. Special repo rates and the cross-section of bond prices: The role of the special collateral risk premium. *Review of Finance* 26:117–162.

Eisl, A., C. Ochs, N. Osadchiy, and M. G. Subrahmanyam. 2019. The Linkage between Primary and Secondary Markets for Eurozone Sovereign Debt: Free Flow or Bottleneck? *Working Paper* .

European Central Bank. 2018. Euro money market survey, 2018. Available at `https://www.ecb.europa.eu/pub/euromoneymarket/html/ecb.euromoneymarket201909_study.en.html`.

Fleming, M. J., and J. V. Rosenberg. 2008. How do Treasury dealers manage their positions? *FRB of New York Staff Report* .

Fontaine, J.-S., and R. Garcia. 2012. Bond liquidity premia. *Review of Financial Studies* 25:1207–1254.

Goldstein, M. A., and E. S. Hotchkiss. 2020. Providing liquidity in an illiquid market: Dealer behavior in US corporate bonds. *Journal of Financial Economics* 135:16–40.

Gorton, G. 2017. The history and economics of safe assets. *Annual Review of Economics* 9:547–586.

He, Z., B. Kelly, and A. Manela. 2017. Intermediary asset pricing: New evidence from many asset classes. *Journal of Financial Economics* 126:1–35.

He, Z., and A. Krishnamurthy. 2013. Intermediary asset pricing. *American Economic Review* 103:732–70.

He, Z., A. Krishnamurthy, and K. Milbradt. 2019. A model of safe asset determination. *American Economic Review* 109:1230–1262.

Huh, Y., and S. Infante. 2021. Bond market intermediation and the role of repo. *Journal of Banking and Finance* 122:105999.

Infante, S. 2020. Private money creation with safe assets and term premia. *Journal of Financial Economics* 136:828–856.

International Capital Market Association. 2021. European repo market survey. Available at https://www.icmagroup.org/Regulatory-Policy-and-Market-Practice/repo-and-collateral-markets/icma-ercc-publications/repo-market-surveys/.

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

Keane, F. M. 1996. Repo patterns for new treasury notes. *Federal Reserve Bank of New York Current Issues in Economics and Finance* 2:1–6.

Klingler, S., and S. M. Sundaresan. 2020. Diminishing Treasury Convenience Premiums: Effects of Dealers' Excess Demand in Auctions. *Working Paper* .

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

Krishnamurthy, A., and A. Vissing-Jorgensen. 2012. The aggregate demand for Treasury debt. *Journal of Political Economy* 120:233–267.

Krishnamurthy, A., and A. Vissing-Jorgensen. 2015. The impact of Treasury supply on financial sector lending and stability. *Journal of Financial Economics* 118:571–600.

Liu, Y., L. Schmid, and A. Yaron. 2019. The risks of safe assets. Working paper, Duke University.

Longstaff, F. A. 2004. The flight-to-liquidity premium in U.S. Treasury bond prices. *Journal of Business* 77:511–526.

Lou, D., H. Yan, and J. Zhang. 2013. Anticipated and repeated shocks in liquid markets. *Review of Financial Studies* 26:1891–1912.

Macchiavelli, M., and X. Zhou. 2021. Funding liquidity and market liquidity: the broker-dealer perspective. *Management Science* 68:3378–3398.

Mancini, L., A. Ranaldo, and J. Wrampelmeyer. 2016. The Euro interbank repo market. *Review of Financial Studies* 29:1747–1779.

Nagel, S. 2016. The liquidity premium of near-money assets. *Quarterly Journal of Economics* 131:1927–1971.

Naik, N. Y., and P. K. Yadav. 2003. Risk management with derivatives by dealers and market quality in government bond markets. *Journal of Finance* 58:1873–1904.

Nyborg, K. G. 2016. *Collateral frameworks: The open secret of central banks.* Cambridge University Press, Cambridge, England.

Pasquariello, P., and C. Vega. 2009. The on-the-run liquidity phenomenon. *Journal of Financial Economics* 92:1–24.

Pelizzon, L., M. G. Subrahmanyam, D. Tomio, and J. Uno. 2016. Sovereign credit risk, liquidity, and European Central Bank intervention: Deus ex machina? *Journal of Financial Economics* 122:86–115.

Ranaldo, A., P. Schaffner, and M. Vasios. 2021. Regulatory effects on short-term interest rates. *Journal of Financial Economics* 141:750–770.

Rytchkov, O. 2014. Asset pricing with dynamic margin constraints. *Journal of Finance* 69:405–452.

Sigaux, J.-D. 2018. Trading ahead of Treasury auctions. *ECB Working Paper No. 2208* .

Song, Z., and H. Zhu. 2019. Mortgage dollar roll. *Review of Financial Studies* 32:2955–2996.

Stoll, H. R. 1978. The supply of dealer services in securities markets. *Journal of Finance* 33:1133–1151.

Vayanos, D., and P.-O. Weill. 2008. A search-based theory of the on-the-run phenomenon. *Journal of Finance* 63:1361–1398.