Essays on short-term funding markets

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Cologne, December 2022 Benedikt Ballensiefen

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Summary

The repurchase agreement (repo) market is the primary short-term funding market; it plays a key role in the efficient allocation of liquidity and financial securities and is crucial for the implementation of monetary policy. This dissertation is a collection of three research essays on the structure and functioning of the euro area repo market.

A repo is a secured instrument; it is a short-term collateralized loan. In the first chapter (**Collateral choice**), I study banks' activity in the repo market by focusing on borrowers' collateral choices. In general collateral repos, the borrower can choose which bond he delivers as collateral out of a predefined list. In aggregate, on-the-run bonds are more likely to be delivered as collateral than cheapest-to-post securities, which is surprising given that the former bond is more expensive. I rationalize those findings in a theoretical framework that links the bond to the repo market.

The asset serving as collateral provides safety and liquidity benefits, referred to as *convenience yield*. In the second chapter (**Safe asset carry trade**, *joint with Angelo Ranaldo*), we provide the first systematic asset pricing analysis of repos. We form a carry that, together with a market factor, prices repos in a linear pricing model. The carry depicts heterogeneity in non-pecuniary convenience yields of collateral assets and increases in the safety and liquidity premium. Our carry helps explain the cross-section of short-term rates as well as long-term bond returns after accounting for standard bond pricing factors.

Given its essential role in the financial and economic system, it is important to understand frictions in the repo market. A repo is unique as it is a source of funding and collateral. In the third chapter (**Money market disconnect**, *joint with Angelo Ranaldo and Hannah Winterberg*), we document that the money market is more segmented when the collateral motive in repos prevails. Two crucial aspects of the central bank framework lead to this disconnect: banks' access to the central bank's deposit facility and assets' eligibility for quantitative easing (QE). We show that repo rates lent by banks with access to the deposit facility and secured by QE eligible assets are more collateral-driven and disconnected from funding-based money market rates. Our results are relevant for different monetary policies and have suggestive implications for the monetary policy pass-through.

Zusammenfassung

Eine Rückkaufvereinbarung, wegen des englischen Begriffs *repurchase agreeement* auch Repo genannt, bezeichnet einen mit Staatsanleihen besicherten, kurzfristigen Kredit zwischen Banken. Der Repo-Markt ist der für die Refinanzierung von Banken wichtigste Markt. Repos spielen daher eine zentrale Rolle für die Allokation von Liquidität und Wertpapieren und für die Implementierung der Geldpolitik. Diese Dissertation ist eine Sammlung von drei Beiträgen zur Struktur und Funktionsweise des europäischen Repo-Marktes.

In allgemeinen Repo-Geschäften kann die kreditaufnehmende Bank die als Sicherheit dienende Staatsanleihe aus einer vorgegebenen Liste frei auswählen. Im ersten Kapitel (**Collateral choice**) analysiere ich, welche Anleihen von Banken ausgewählt werden. Die zuletzt ausgegebene Staatsanleihe wird dabei am häufigsten als Sicherheit verwendet, dies ist überraschend, da es eine besonders hohe Nachfrage nach dieser Anleihe gibt. Diese Beobachtungen reflektiere ich in einem theoretischen Modell, welches einen direkten Zusammenhang zum Anleihenmarkt abbildet.

Je nach Staatsanleihe und Marktumfeld ergeben sich verschiedene Zinssätze für Repo-Geschäfte. Im zweiten Kapitel (**Safe asset carry trade**, *gemeinsam verfasst mit Angelo Ranaldo*) präsentieren wir die erste systematische Analyse der Bepreisung von Repos. Hauptverantwortlich für Variationen in den Zinssätzen sind dabei Aspekte von Sicherheit und Liquidität, welche sich zwischen den Staatsanleihen unterschieden. Basierend hierauf bilden wir einen Carry, welcher nicht nur für die Bepreisung der Zinssätze im Repo-Markt relevant ist, sondern auch für die Bepreisung von Staatsanleihen im Anleihenmarkt.

Ein Repo-Geschäft kann sowohl zum Leihen von Geld als auch zum Beziehen einer Staatsanleihe verwendet werden. Im dritten Kapitel (**Money market disconnect**, *gemeinsam verfasst mit Angelo Ranaldo und Hannah Winterberg*) dokumentieren wir, dass sich der besicherte Repo-Markt vom unbesicherten Geldmarkt entkoppelt, wenn in Repo-Geschäften das Motiv des Beziehens einer Staatsanleihe im Vordergrund steht. Zwei Aspekte des geldpolitischen Rahmenwerks haben zu dieser Entkoppelung beigetragen: der Zugang zu Zentralbankeinlagen und die Bedingungen für den Ankauf von Staatsanleihen durch die Zentralbank. Unsere Ergebnisse sind für die Analyse verschiedener geldpolitischer Massnahmen von Bedeutung.

Chapter 1

Collateral choice

Benedikt Ballensiefen[1]

This is the first systematic analysis of *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, On-the-run, Liquidity.
JEL Classification:E40, E41, E43, G00, G01, G10.

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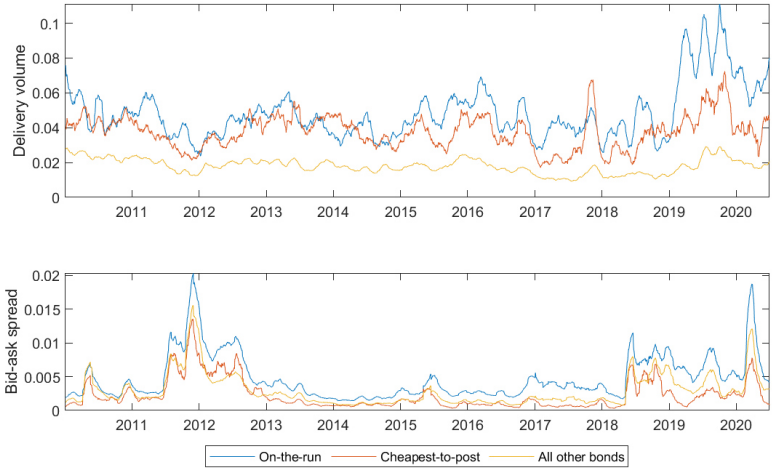
A repurchase agreement (repo) is a secured short-term instrument that serves a dual role in obtaining funding and collateral. Along those lines, the repo market divides into two broad segments, the *general collateral (GC)* market, in which the borrower can choose which bond he pledges as collateral out of a predefined basket of securities, and the *special* market in which a particular bond is specified as collateral.[2] 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). Furthermore, 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, highlighting 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 in GC trades. For this, I employ a novel and highly representative data set of European repo trades for the 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 primary market for banks in the euro area to obtain

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

short-term funding and rebalance portfolio holdings. Second, euro repos are mostly secured by government bonds whose supply and demand vary 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.



The figure 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 1.1: Repo delivery volumes and bond market spread

To motivate my analysis, Figure 1.1 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).[3] The time series of repo

[3]I compute the repo delivery volume as the daily volume of a bond delivered into GC trades relative to its outstanding volume. Figure 1.1 does not contain any overlaps between the different bond types.

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 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 expensive. This more broadly raises the question *which bonds borrowers choose as collateral* and why they 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 (relative to 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 on-the-run bonds become 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 50 basis points; hence borrowers accept significant opportunity cost in delivering those bonds. Still, the delivery intensity declines in the opportunity cost even for on-the-run securities. In line with Keane (1996), on-the-run securities become increasingly special until the next auction. Repo deliveries reverse this pattern, i.e., deliveries decline in the repo specialness of the delivered security as the collateral opportunity cost increases.

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 forgoes) are more valuable.

I perform several 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.[4] 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). It focuses on a stylized GC segment

[4]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 also has implications on the underlying bond market for the collateral.

in which the borrower (market maker) holds excess on-the-run bonds in his portfolio after auctions. He chooses to deliver those securities in GC trades to finance and diversify his portfolio holdings, but delivering on-the-run securities involves opportunity cost.[5] 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 the collateral opportunity cost.

In line with the theoretical predictions, *tomorrow's* bid-ask spread tends to be higher when *today's* GC delivery volume is 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 a basket of U.S. Treasuries include a collateral rent that other asset class baskets do not offer.[6] 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

[5]Following this notion, collateral availability refers to the availability of a specific bond in the market makers' portfolio, and collateral opportunity cost refers to the forgone utility of delivering certain securities as collateral. My framework complements the dynamics in the special repo segment in which lenders have a specific demand for certain bonds, such as the on-the-run leading the on-the-run repo rate to fall below the off-the-run rate.

[6]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).

by analyzing borrowers' collateral choices in the repo market and determining 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, 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. (2018), Huh and Infante (2021), and D'Amico and Pancost (2022).[7] 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).[8]

1.1 European repo market

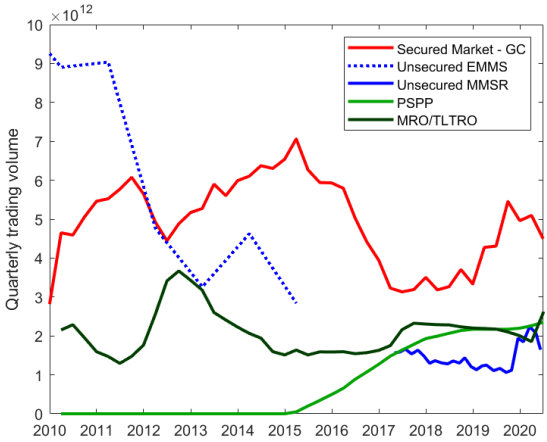
I start by explaining the main characteristics of the European repo market and my data.

1.1.1 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 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 and obtain short-term funding.

[7] 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).

[8] 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), and Beetsma et al. (2018). 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 refers 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 1.2: Different market turnovers

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"). While a large body of the literature has analyzed the special segment with seminal work going back to Duffie (1996), this paper focuses 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, 2022). To highlight the importance of the repo market for euro area banks, Figure 1.2 depicts trading volumes in the two main euro money market segments: the red line depicts trading volumes in GC repos and the blue line depicts volumes in the unsecured market. It 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 the size of the repo market 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, therefore, 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:[9] First, the most common collateral assets are government bonds issued by different euro area countries whose supply and demand vary 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.[10] 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 as 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.

[9] 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).

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

1.1.2 Data

I employ a unique data set of euro area GC repo transactions executed on the MTS platform for the period from January 2010 to June 2020.[11] For each transaction, I observe the 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. In addition, 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 1.1 provides a summary of my data. Over my sample period, I observe more than 1.5 million GC transactions totaling 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.[12] For each trade, I also observe the aggressor-type; borrower- and lender-initiated trades are roughly equally likely.[13]

The MTS repo market consists of the near-total universe of all electronically traded Italian GC repo transactions.[14] For the main part of my analysis, I focus on those Italian repo trades for which I have almost complete coverage. The Italian government issues several types of bonds, each having its dedicated GC basket on MTS.[15] 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.[16] My data also features trade-level information for other euro area countries such as Germany and France. While the overall trading shares for those countries are smaller on the MTS platform, it allows me to show that results are fully

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

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

[13] 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.

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

[15] A brief description of those baskets traded on the MTS platform and a summary of the bond characteristics in terms of coupon rate, maturity, auction size, and the number of reopenings are provided in the online appendix.

[16] In addition, 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, ensuring that my results are not driven by any differential regulatory treatment.

Table 1.1: 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 Italy BTP	0.81	39.72	51.67%	50.96%
Repo Italy BOT	0.28	12.95	17.65%	16.62%
Repo Italy CCT	0.20	10.21	12.90%	13.09%
Repo Italy BTP€i	0.16	7.99	10.36%	10.25%
Repo Italy CTZ	0.11	6.11	6.76%	7.84%
Other basket	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. GC repos traded on the MTS platform are 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.

consistent for other countries, which ensures the general validity of my analysis.

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-run securities.[17] 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. This is because window dressing impacts repo rates on those trading days (Ranaldo, Schaffner, and Vasios, 2021). As further robustness checks, I also remove observations in the 99th percentile of the cheapest-to-post spread for on-the-run and off-the-run bonds to ensure that outliers do not impact my analysis. The results are virtually unchanged in all those specifications.

Over 500 different bonds were chosen as collateral in GC trades throughout my sample period. On each day, I compute the daily number and volume of trades for which a 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.[18] 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.[19]

[17] 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.

[18] 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 bond, (ii) a yield restriction that states that the yield of a bond 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.

[19] 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 are discussed in, for example, Nyborg (2016).

To capture collateral opportunity cost, I derive a daily list of bonds eligible to be pledged as collateral into a GC basket. Based on this list, I determine the cheapest-to-post bond for each GC trade, which is the bond with the highest special repo rate of all bonds that are eligible to be delivered into a particular basket.[20] 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.[21] 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 in 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.[22] 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.[23]

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

1.2 Drivers of collateral choice

Figure 1.1 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

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

[21] 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).

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

[23] I derive quarterly bond holding information per 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 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.

two main drivers of collateral choice. I start by analyzing different aspects of collateral availability and opportunity cost separately before looking at their interplay.

1.2.1 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 1.3 illustrates those aspects of collateral availability.

Figure 1.3a 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.[24] It is 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 1.3b 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 ini-

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

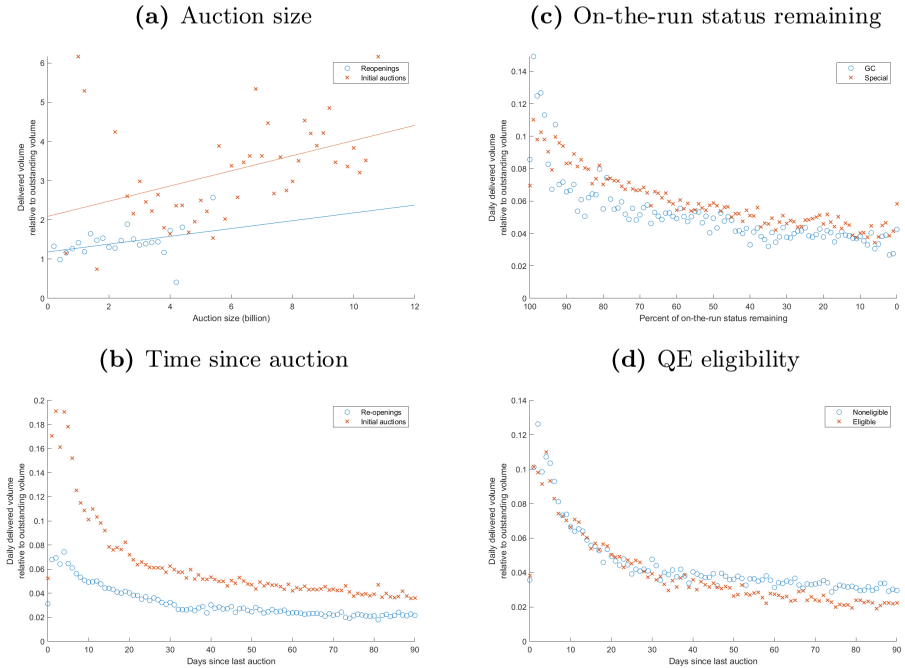


Figure 1.3a depicts the cumulative delivery volume of a bond into GC trades during the first 90 days after its auction relative to the total outstanding volume. Figure 1.3b depicts the daily delivered volume of a bond into GC trades relative to its outstanding volume on each of the first 90 days after the auction. Both graphs differentiate between initial auctions (orange crosses) and reopenings (blue circles). Figure 1.3c depicts the daily delivered volume of a bond relative to its outstanding volume in the GC market (blue circles) and the on-the-run trading volume in the special repo market (orange crosses) in relation to the remaining on-the-run status. Figure 1.3d 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 eligible (orange crosses) and noneligible (blue circles) for PSPP purchases.

Figure 1.3: Aspects of collateral availability

tial auction. Around reopenings, the delivered volume peaks again at about 8% before decreasing to around 4% one month after the reopening.

Figure 1.3c is developed in a similar spirit; it depicts the daily volume delivered against the remaining time a bond serves as the on-the-run (blue circles).[25] The results are consistent: The delivery volume of 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 underlines 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 1.3d 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 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 in 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 1.2. 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

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

Table 1.2: 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. 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 for initial auctions, as well as the 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");[26] 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").[27]

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 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 one year have a 0.5%-points lower delivery volume.

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

[26] 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.

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

auction size. The 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. 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 confirm 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.

1.2.2 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 from the bond pledged as collateral during the repo term is transferred back to the borrower. Hence, any forgone utility must stem from the collateral's safety and liquidity attributes, also referred to as convenience benefits (Gorton, 2017).[28] Posting a bond in a GC repo which is in high demand in the special segment due to its utility benefits is 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 delivering a special collateral bond into a GC repo.

For my analysis, I compute two measures of collateral opportunity cost as illustrated in Equations (1.1) and (1.2).

$$CTP\ spread_{i,t} = reporate^{special}_{CTP,t} - reporate^{special}_{i,t} \tag{1.1}$$

$$Repo\ specialness_{i,t} = reporate^{GC}_{basket,t} - reporate^{special}_{i,t}. \tag{1.2}$$

Equation (1.1) computes the "CTP spread" as the difference in special repo rates between the CTP bond and the bond delivered as collateral. This spread

[28] 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 repo term (e.g., coupon payments) is therefore transferred to the borrower.

measures the opportunity cost of delivering different bonds as collateral into a GC repo and is, per definition, positive. Equation (1.2) 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 instead of a special repo trade.[29] 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.

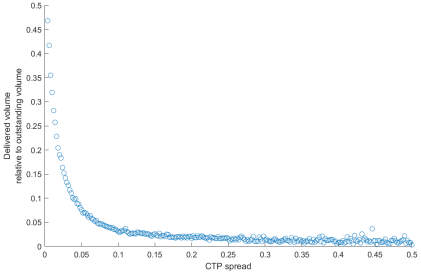
Figure 1.4a plots the relative delivery volume of a bond into GC repos for different levels in the CTP spread. Two patterns stand out: the delivery volume (i) peaks for CTP spreads close to zero and (ii) almost monotonically decreases in the CTP spread. For example, the delivery volume is up to 50% of the outstanding volume for CTP spreads close to zero; the volume drops to below 5% for CTP spreads larger than ten basis points. Figure 1.4b 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.[30] Figure 1.4c illustrates the CTP spread for the 50 days before and after quarter-end (dotted blue line) and year-end (straight blue line) periods. The CTP spread spikes on those reporting dates: at the quarter-end, the CTP spread increases to about eight basis points; at the year-end, the increase is even stronger to about 14 basis points. The increase in the CTP spread around quarter- and year-ends can 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 unin-

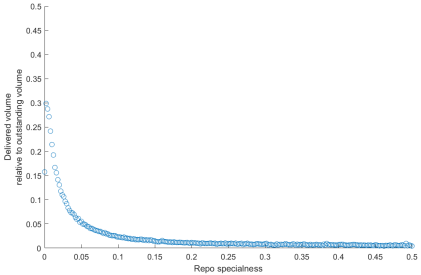
[29] The decision to use a GC trade instead of a special repo trade involves subtle differences. In a GC trade, the borrower chooses which bond he delivers as collateral out of a predefined basket of bonds until the first leg is settled. By contrast, a borrower already commits to deliver a specific collateral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

[30] 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.

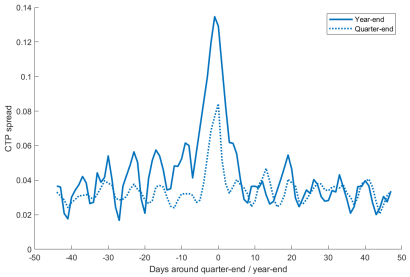
(a) CTP spread



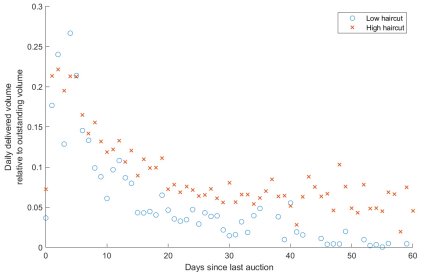
(b) Repo specialness



(c) CTP spread around quarter- and year-ends



(d) Haircut



Figures 1.4a and 1.4b 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 1.4c depicts the CTP spread for the 50 days before and after the quarter-ends (dotted blue line) and year-ends (straight blue line). Figure 1.4d 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 the average haircut, orange crosses) and low haircuts (i.e., daily haircut below the average haircut, blue circles). Figure 1.4d only includes medium- and long-term bonds for illustrative purposes.

Figure 1.4: Aspects of collateral opportunity cost

tended consequence of the new regulatory framework, which leads to window dressing and a resulting spike in collateral opportunity cost around quarter-end 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 costs. Figure 1.4d graphs the daily volume delivered against the time since the last auction, separately for bonds with high (orange crosses) and low haircuts (blue circles).[31] 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 set of panel regressions. Table 1.3 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 and the repo specialness of the delivered security, respectively. 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-country and within-basket variation in haircuts.

Overall, the results confirm that collateral opportunity cost is the second

[31] 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 1.3: Opportunity cost of collateral

	(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	(7) 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. 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.

driver of collateral choice; the delivery intensity is higher for the CTP security and declines when bonds become more expensive.

1.2.3 Combined effects

I also want to understand the interplay of collateral availability and opportunity cost. Figure 1.5 provides several illustrations of it.

Figure 1.5a 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).If bonds with high CTP spreads are delivered, those are likely to be on-the-run securities. CTP spreads for on-the-run securities are economically meaningful as they go up to 50 basis points; this means that borrowers are willing to accept significant opportunity costs 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. The figure nicely illustrates both aspects of collateral choice. The generally declining delivery volumes

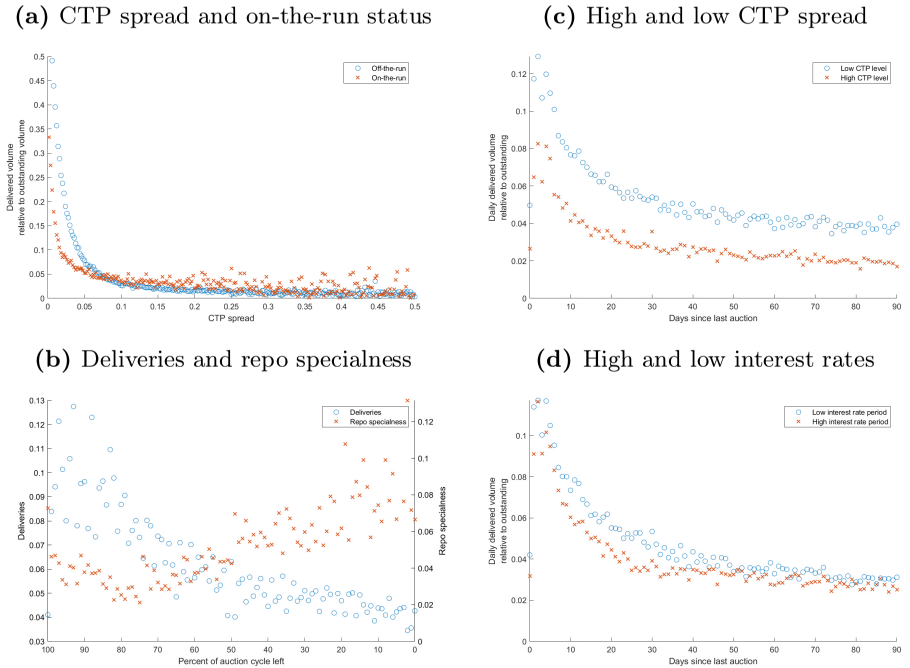


Figure 1.5a depicts the delivered volume of a bond in GC trades relative to its outstanding volume for different levels in the CTP spread, separately for on-the-run (orange crosses) and off-the-run bonds (blue circles). Figure 1.5b depicts the daily delivered volume of a bond relative to its outstanding volume (blue circles) and the repo specialness of the delivered bond (orange crosses) relative to the position in the auction cycle. Figures 1.5c and 1.5d depict the daily delivered volume of a bond relative to its outstanding volume for the first 90 days after the initial auction or reopening. Figure 1.5c differentiates 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, blue circles). Figure 1.5d differentiates between high (i.e., positive rate on the ECB's main refinancing operations (MRO), orange crosses) and low interest rate periods (i.e., a non-positive rate on the ECB's MRO, blue circles).

Figure 1.5: Aspects of collateral opportunity cost

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 1.5b 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., deliveries decline in the repo specialness of the delivered security as the collateral opportunity cost increases. This means borrowers have less incentive to post on-the-run bonds into GC repos as their specialness increases throughout the auction cycle.[32] Figure 1.5c 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, depends on the level of short-term interest rates. Figure 1.5d 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 variables in a multivariate panel regression set-up. Table 1.4 reports the results. Column (1) serves as the base-

[32] 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 later. 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 1.4: Collateral availability and opportunity cost

	(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	0.038*		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. $D^{HighInterest}$ 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.

line. It 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 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 for initial auctions than 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 as 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 equals 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 particularly on-the-run deliveries 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 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 1.5. 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; column (4) accounts for the cheapest-to-deliver bond in the futures market; column (5) considers additional economic variables as controls;[33] and column (6) reports the results of the regression estimated in logs rather than 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, the two largest euro area countries, as reported in Table 1.6. 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

[33]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 to measure the overall sovereign risk level. More public debt creates uncertainty, which raises default risk premia (Liu, Schmid, and Yaron, 2021) 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).

Table 1.5: Robustness checks

	(1) Baseline b/t	(2) Auction bid-cover b/t	(3) Bond controls b/t	(4) Futures CTD b/t	(5) Economic controls b/t	(6) Log 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. 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. 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 1.6: 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.

opportunity cost.

1.3 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 more expensive on-the-run bonds are more likely to be posted as collateral than CTP securities. These results are noteworthy since, in GC repos, the borrower always has the option of delivering the cheapest-to-post bond. The focus of the second part of the paper 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.[34]

1.3.1 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. This inventory 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").[35] The (i)

[34] 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 that 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.

[35] Dealers that are market makers have obligations for subscriptions in government bond auctions and trading volumes on the secondary market. Thus, they are required to offer sufficient amounts to meet the demand of secondary market investors who do not 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, secondary market trading, and the repo market. An essential requirement for maintaining specialist status in government bonds is the allo-

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.

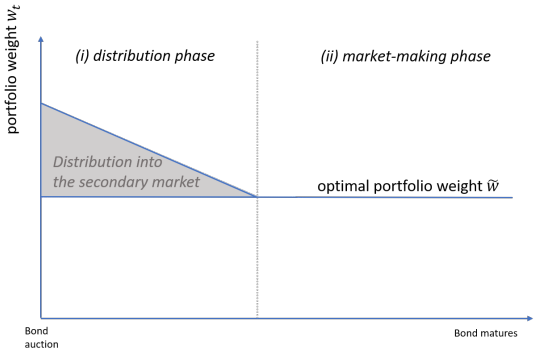
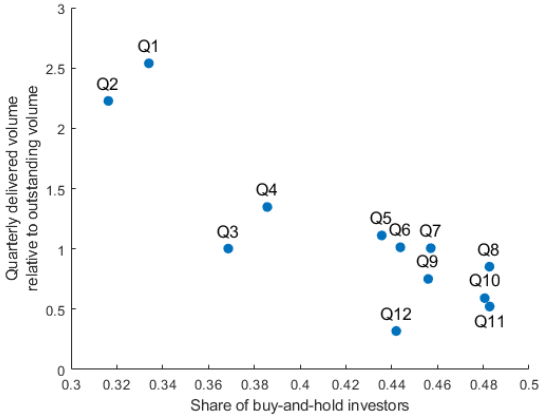


Figure 1.6: Illustration of optimal time-dependent portfolio weights

Figure 1.6 illustrates the evolution of the market maker's portfolio weight in newly issued government bonds relative to his optimal portfolio weight over time. The dealer has a time-independent, optimal portfolio share in newly issued securities, denoted as $\tilde{w}$, which allows 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 he distributes part of his inventory to buy-and-hold investors. During the market-making phase, the optimal portfolio weight is achieved. 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

cation 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 the 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`).



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

Figure 1.7: Delivery volume and buy-and-hold investor share

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 1.7 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 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.[36]

[36] 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.

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 securities 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 (e.g., Bartolini et al., 2011; Macchiavelli and Zhou, 2021).[37] However, the dealer's decision to post a newly issued security as collateral into a GC trade is costly as on-the-run securities tend to be more "special" in the repo market (Krishnamurthy, 2002). The dealer, therefore, requires a compensation to engage in his market-making activities in the bond market for the collateral.

1.3.2 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 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 the bid and ask quotes compensates the dealer for each trade's cost C_i.

I consider repos as the dealer's main funding vehicle for bond inventories;

[37] GC repo trades are the more suitable repo type to finance and rebalance portfolios compared to special trades for at least three reasons: (i) due to their superior liquidity and high trading volumes; (ii) because of the low price impact of trades; and (iii) since ON repos predominantly trade in the GC segment. The GC repo market is the more liquid segment for ON trades, while the special repo market is more liquid for TN and SN repos. 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 alternative to rebalance portfolios.

this is different from Stoll (1978), in which the dealer can refinance himself at the risk-free rate. The repo market is the closest equivalent to a "true" risk-free rate and the primary market for portfolio reallocations. The funding cost in the repo market is equivalent to the GC repo rate. It, therefore, reads as:

$$R_F = R_{GC}. \tag{1.3}$$

When a dealer has excess bond holdings, he can post them as collateral into GC trades to borrow against them at the GC rate, which effectively reflects the dealer's cost of funding.[38] If the dealer has excess cash holdings, he can lend those in the repo market, earning the GC rate.

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).

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.[39] 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}, and the return of the on-the-run holdings is denoted with $\tilde{R}_{OTR}$. Since the dealer posts the excessive on-the-run bonds into GC trades to finance and rebalance his portfolio, the return is reduced by the collateral opportunity cost OC_i.

The returns on the optimal portfolio and 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 of the period.[40]

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

[38] I consider the convenience yield of the bond pledged as collateral separately in the dealer's wealth function.

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

[40] My setting abstracts from asymmetric information between the dealer and other market participants as government bonds are less prone to asymmetric information than, for example, equities.

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.[41] More formally:

$$EU(\tilde{W}^*) = EU(\tilde{W}). \tag{1.4}$$

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

$$\tilde{W}^* = W_0[1 + \underbrace{k\tilde{R}_e}_{\substack{return\\optimal\\portfolio}} + \underbrace{\frac{Q_{OTR}}{W_0}(\tilde{R}_{OTR} - OC_i)}_{\substack{return\\trading\\portfolio}} + \underbrace{(1 - k - \frac{Q_{OTR}}{W_0})R_F}_{\substack{return\\risk\text{-}free\\investment}}]. \tag{1.5}$$

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:

$$\tilde{W} = W_0(1 + \underbrace{\tilde{R}^*}_{\substack{return\\initial\\portfolio}}) + \underbrace{Q_i(1 + \tilde{R}_{OTR} - OC_i)}_{\substack{change\\trading\\portfolio}} - \underbrace{(Q_i - C_i)(1 + R_F)}_{\substack{financing\\cost}}. \tag{1.6}$$

Q_i indicates the value of the additional on-the-run bond in the trading portfolio. The dealer earns the on-the-run return $\tilde{R}_{OTR}$ on this position but forgoes the opportunity cost 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

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

charges to the investor.[42] 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 1.4 is fulfilled.

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

$$U(W) = -e^{-aW}, \tag{1.7}$$

in which a denotes the coefficient of absolute risk aversion.[43] Under the assumption that W is normally distributed with $\sim \mathcal{N}(\mu, \sigma^2)$, we know that:

$$EU(W) = E(W) - \frac{1}{2}a\text{Var}(W). \tag{1.8}$$

Thus, from Equation (1.4) follows:

$$E(\tilde{W}^*) - \frac{1}{2}a\text{Var}(\tilde{W}^*) = E(\tilde{W}) - \frac{1}{2}a\text{Var}(\tilde{W}) \tag{1.9}$$

The dealer's cost function can be derived by inserting the specifications for the dealer's terminal wealth from the initial and the new portfolio after the trade into Equation (1.9).[44] Solving for C_i leads to:

$$C_i = \frac{\frac{1}{2}aQ_i^2\text{Var}(\tilde{R}_{OTR}) + aQ_iQ_{OTR}\text{Var}(\tilde{R}_{OTR}) + Q_iOC_i}{(1 + R_{GC})}. \tag{1.10}$$

Equation (1.10) 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

[42] Since I compare the terminal wealth differences between the initial and the new portfolio after a trade, I only consider the incremental cost for the new portfolio in the optimization problem. Positive values of Q_i indicate purchases by the dealer from the investor, while negative values indicate sales to the investor. C_i can be positive or negative depending on the trade direction. 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.

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

[44] The model derivation is presented in the online appendix.

cost of intermediation increases in the size of the trading portfolio Q_{OTR} (as his holdings deviate from his efficient portfolio) and the collateral opportunity cost of each bond i (due to the higher forgone utility of posting the bond into a GC trade).[45]

1.3.3 Bond market estimation

I use my repo and bond data to provide empirical support for the theoretical predictions. Table 1.7 summarizes the impact of the different model variables on the bid-ask spread and the measures 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* to relate today's collateral choices by the dealer to tomorrow's bid-ask spread quoted in the bond market.[46] 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 costs imply higher costs 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 1.7: 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

Table 1.8 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 the combined

[45] The conclusions also hold for the relative bid-ask spread, the derivation is presented in the online appendix.

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

Table 1.8: Bond market spread

	(1)	(2)	(3)	(4)	(5)
	Relative spread *t+1* b/t	Relative spread *t+1* b/t	Relative spread *t+1* b/t	Relative spread *t+1* b/t	Relative spread *t+1* 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
FE	Yes	Yes	Yes	Yes	Yes

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 return. 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-term 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.

effect in column (5).[47]

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 with 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 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 show 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 costs (which reflect the forgone utility of the bond posted as collateral) are associated with higher bond market spreads.

The concept of liquidity is usually broadly defined and encompasses different aspects. For example, bond market liquidity is often measured via the bid-ask spread; other measures include the depth of the order book and trading volumes. Table 1.9 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, reinforcing the theoretical intuition. The difference in bid-ask spreads is statistically significant for medium- and longer-term bonds. In contrast, 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, 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), an increase in the repo market specialness can lead to lower bond market liquidity as intermediaries face higher costs. My focus is on the cross-section of assets. I show that higher repo delivery volumes and collateral opportunity cost negatively impact a bond's bid-ask spread in the cross-section,

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

Table 1.9: 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 (mn)					
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.

which translates into a lower market quality index measure.

Still, while on-the-run bonds feature higher bid-ask spreads than their off-the-run counterparts, they also have higher daily trading volumes, reflecting another liquidity aspect. 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 costs for which they want to be compensated in the form of higher bid-ask spreads.

1.4 Conclusion

The novelty of my study is to systematically 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 patterns, for example, that on-the-run bonds are likely to be delivered as collateral into GC trades even though 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.

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Online appendix

OA1.1 Data description

The Italian government issues several types of bonds, each having its dedicated GC basket on MTS.

- Treasury bills (BOTs) are short-term zero-coupon discount bonds with maturities of up to one year. BOTs have no reopenings.
- Treasury bonds (BTPs) are medium- to long-term bonds with a fixed coupon paid semiannually. BTP bonds are regularly reopened.
- Treasury bonds linked to inflation (BTPs€i) are medium- to long-term, inflation-indexed bonds (i.e., indexed to euro zone inflation). BTPs€i bonds are regularly reopened.
- Treasury certificates indexed to six-month Euribor (CCTs) are medium-term bonds with a floating coupon paid semiannually. CCT bonds are regularly reopened.
- Zero-coupon bonds (CTZs) are zero-coupon discount bonds with maturities of two years. CTZ bonds are regularly reopened.

The GC baskets corresponding to the five different bond types are the most frequently traded baskets on the MTS platform. Given the differences in, for example, the tenor of the bonds, it allows me to analyze different aspects of collateral availability. Table OA1.1.1 presents the distribution of the bonds in my sample in terms of coupon rate, maturity, auction size, and the number of reopenings, classified by bond types and maturity groups.

Table OA1.1.1: Bond breakdown by bond types and maturity groups

	# Bonds	Coupon	Maturity	Auction size	# Reopenings
Bond types					
BOT	290	zero	0.73	7.18	–
BTP	148	2.81%	10.93	18.52	3.60
BTP€i	19	inflation	13.41	12.51	7.20
CCT	29	floating	6.58	14.21	3.90
CTZ	30	zero	2.03	13.46	3.10
Maturity groups					
0.25	14	zero	0.26	3.71	–
0.5	132	zero	0.51	7.72	–
1	138	zero	1.01	7.18	–
2	30	zero	2.03	13.46	3.10
3	32	1.72%	3.06	15.52	2.75
4-7	81	2.12%	6.05	15.51	3.91
10	44	3.28%	10.52	20.87	4.23
15	16	3.73%	15.90	20.48	6.69
20+	23	4.11%	30.13	17.02	3.83
Flexible	6	zero	0.56	3.58	–

The table presents the distribution of the bonds in my sample in terms of the coupon rate (in %), maturity (in years), auction size (in euro billion), and the number of reopenings, classified by bond types (upper part) and maturity groups (lower part).

OA1.2 Robustness results

Table OA1.2.1: Variations in the fixed effect specifications and standard error clustering

	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline					
	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	0.038*	0.036***	0.033***	-0.014	0.011	0.016
	(1.880)	(5.895)	(6.966)	(-0.263)	(0.477)	(0.841)
Auction size $\cdot D^{Initial}$	0.160***	0.138***	0.134***	0.336***	0.348***	0.356***
	(5.494)	(9.037)	(11.157)	(5.863)	(15.054)	(16.325)
Time since auction	−0.018*	−0.030***	−0.029***	0.001	−0.016***	−0.019***
	(−1.910)	(−12.577)	(−16.446)	(0.094)	(−3.980)	(−4.677)
Time since auction $\cdot D^{Initial}$	−1.716***	−1.555***	−1.433***	−1.620***	−1.631***	−1.572***
	(−13.905)	(−19.168)	(−22.659)	(−9.692)	(−18.510)	(−19.780)
$D^{OnTheRun}$	0.809***	0.911***	0.905***	0.844**	0.838***	0.839***
	(10.959)	(34.683)	(43.478)	(3.392)	(25.677)	(30.229)
Time since QE eligibility	−0.455***	−0.038***	−0.033***	−0.118	−0.037***	−0.018
	(−9.473)	(−5.411)	(−6.355)	(−1.070)	(−3.232)	(−1.350)
D^{CTP}	0.387***	0.369***	0.365***	0.291**	0.279***	0.277***
	(12.704)	(17.278)	(20.757)	(4.472)	(16.869)	(18.879)
CTP spread	−0.876***	−1.307***	−1.370***	−0.689***	−0.738***	−0.827***
	(−8.761)	(−14.187)	(−20.774)	(−5.208)	(−10.203)	(−14.640)
FE	Basket× Month× Term	Basket× Term	Basket	Bond Month× Term	Bond Term	Bond
SE-clustering	Bond	Bond× Month	Bond× Month× Term	Basket	Basket× Month	Basket× Month× Term
N	613,534	615,480	615,508	615,183	615,504	615,508
R^2	0.248	0.183	0.145	0.279	0.257	0.226
Constant	Yes	Yes	Yes	Yes	Yes	Yes

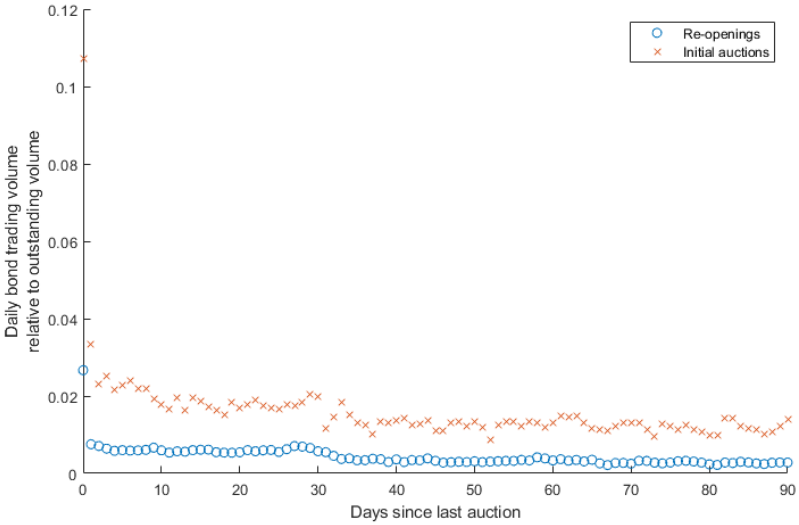
The table reports the regression results examining the impact of different aspects of collateral availability and opportunity cost on the delivery volume into GC repo trades. The dependent variable is a security's daily delivery volume over its outstanding volume in percentage points. Auction size depicts 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. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. The regressions include different fixed effect combinations and standard error clustering. Data include GC repo transactions executed on the MTS platform for Italy for the period January 2010–June 2020.

Table OA1.2.2: Results without quarter ends, without end of ECB maintenance periods, and without outliers

	(1) Baseline	(2) w/o end of quarter	(3) w/o end of ECB maintenance	(4) w/o end of quarter and ECB maintenance	(5) w/o outliers
	b/t	b/t	b/t	b/t	b/t
Auction size	0.038*	0.033*	0.037*	0.038*	0.038*
	(1.880)	(1.706)	(1.859)	(1.898)	(1.876)
Auction size $\cdot D^{Initial}$	0.160***	0.160***	0.159***	0.161***	0.160***
	(5.494)	(5.446)	(5.425)	(5.547)	(5.476)
Time since auction	−0.018*	−0.018*	−0.018*	−0.018*	−0.018*
	(−1.910)	(−1.955)	(−1.918)	(−1.910)	(−1.918)
Time since auction $\cdot D^{Initial}$	−1.716***	−1.699***	−1.704***	−1.723***	−1.711***
	(−13.905)	(−13.687)	(−13.818)	(−13.970)	(−13.881)
$D^{OnTheRun}$	0.809***	0.810***	0.806***	0.812***	0.809***
	(10.959)	(10.952)	(10.952)	(10.951)	(10.943)
Time since QE eligibility	−0.455***	−0.448***	−0.454***	−0.454***	−0.452***
	(−9.473)	(−9.415)	(−9.472)	(−9.451)	(−9.450)
D^{CTP}	0.387***	0.342***	0.385***	0.387***	0.384***
	(12.704)	(11.556)	(12.649)	(12.617)	(12.564)
CTP spread	−0.876***	−2.196***	−0.895***	−0.873***	−0.891***
	(−8.761)	(−14.018)	(−8.644)	(−8.758)	(−8.629)
N	613,534	607,388	604,739	592,377	583,578
R^2	0.248	0.250	0.248	0.249	0.249
FE	Yes	Yes	Yes	Yes	Yes
Constant	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 when dropping additional observations. 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. ***, **, 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. The results for w/o quarter-end remove quarter-end trading days, the results for w/o end of ECB maintenance period remove the last trading days of the end of the ECB maintenance period, and the results for w/o outliers remove the observations in the 99th percentile of the CTP spread for on-the-run and off-the-run bonds.

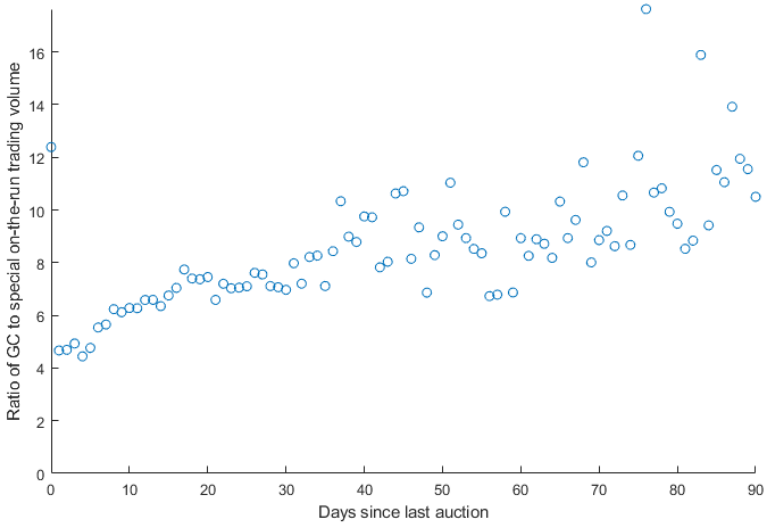
OA1.3 Bond trading volumes



The figure illustrates the average daily bond trading volume for the first 90 days after initial auctions (orange crosses) and reopenings (blue circles).

Figure OA1.3.1: Bond trading volume relative to the days since the last auction

OA1.4 On-the-run repo volumes



The figure illustrates the average daily total trading volume in a basket divided by the average daily trading volume of on-the-run bonds in the special segment. The graph is capped 90 days after the auction and includes data from all baskets.

Figure OA1.4.1: The ratio of GC trading volumes to special trading volumes in on-the-run securities relative to the time since the last auction

OA1.5 Theoretical implications

Model derivation

The idea is to solve for the cost C_i, which the dealer charges in the bond market. The derivation of the cost function reads as follows:

$$E(\tilde{W}^*) - \frac{1}{2}a\text{Var}(\tilde{W}^*) = E(\tilde{W}) - \frac{1}{2}a\text{Var}(\tilde{W}) \tag{1.11}$$

$$\underbrace{E(\tilde{W})}_{(i)} - \underbrace{E(\tilde{W}^*)}_{(ii)} = \frac{1}{2}a[\underbrace{\text{Var}(\tilde{W})}_{(iii)} - \underbrace{\text{Var}(\tilde{W}^*)}_{(iv)}]. \tag{1.12}$$

Part (i):

$$E(\tilde{W}) = E(W_0(1+\tilde{R}^*)) + E(Q_i(1+\tilde{R}_{OTR} - OC_i)) - (Q_i - C_i)(1+R_F). \tag{1.13}$$

Part (ii):

$$E(\tilde{W}^*) = E(W_0(1+\tilde{R}^*)). \tag{1.14}$$

The left-hand side of (i) and (ii) simplifies to:

$$E(\tilde{W}) - E(\tilde{W}^*) = Q_i(E(\tilde{R}_{OTR}) - OC_i - R_F) + C_i(1+R_F). \tag{1.15}$$

Part (iii):

$$\text{Var}(\tilde{W}) = \text{Var}(W_0(1+\tilde{R}^*) + Q_i(1+\tilde{R}_{OTR} - OC_i))^{48} \tag{1.16}$$

$$\text{Var}(\tilde{W}) = W_0^2\text{Var}(\tilde{R}^*) + Q_i^2\text{Var}(\tilde{R}_{OTR}) + 2W_0Q_i\text{Cov}(\tilde{R}^*, \tilde{R}_{OTR}); \tag{1.17}$$

Part (iv):

$$\text{Var}(\tilde{W}^*) = W_0^2\text{Var}(\tilde{R}^*). \tag{1.18}$$

The right-hand side of (iii) and (iv) simplifies to:

$$\text{Var}(\tilde{W}) - \text{Var}(\tilde{W}^*) = Q_i^2\text{Var}(\tilde{R}_{OTR}) + 2W_0Q_i\underbrace{\text{Cov}(\tilde{R}^*, \tilde{R}_{OTR})}_{(v)}. \tag{1.19}$$

[48] Since R_F is nonstochastic, the term $(Q_i - C_i)(1+R_F)$ drops from the variance equation.

Part (v):

$$\text{Cov}(\tilde{R}^*, \tilde{R}_{OTR}) = \text{Cov}(k\tilde{R}_e + \frac{Q_{OTR}}{W_0}(\tilde{R}_{OTR} - OC_i) + (1 - k - \frac{Q_{OTR}}{W_0})R_F, \tilde{R}_{OTR}) \tag{1.20}$$

$$\text{Cov}(\tilde{R}^*, \tilde{R}_{OTR}) = k\text{Cov}(\tilde{R}_e, \tilde{R}_{OTR}) + \frac{Q_{OTR}}{W_0}\text{Var}(\tilde{R}_{OTR}). \tag{1.21}$$

Inserting Equations (1.15), (1.19), and (1.21) into (1.12):

$$\begin{aligned} &Q_i(E(\tilde{R}_{OTR}) - OC_i - R_F) + C_i(1 + R_F) = \\ &\frac{1}{2}a[Q_i^2\text{Var}(\tilde{R}_{OTR}) + 2W_0Q_i(k\text{Cov}(\tilde{R}_e, \tilde{R}_{OTR}) + \frac{Q_{OTR}}{W_0}\text{Var}(\tilde{R}_{OTR}))]. \end{aligned} \tag{1.22}$$

We know from the portfolio optimization problem (see Stoll, 1978, p. 1140, footnote 8):[49]

$$E(\tilde{R}_{OTR}) - R_F = (E(\tilde{R}_e) - R_F)\frac{\text{Cov}(\tilde{R}_e, \tilde{R}_{OTR})}{\text{Var}(\tilde{R}_e)} \tag{1.23}$$

$$k = \frac{E(\tilde{R}_e) - R_F}{aW_0\text{Var}(\tilde{R}_e)}. \tag{1.24}$$

This simplifies the decision problem to:

$$\frac{1}{2}aQ_i^2\text{Var}(\tilde{R}_{OTR}) + aQ_iQ_{OTR}\text{Var}(\tilde{R}_{OTR}) + Q_iOC_i - C_i(1 + R_F) = 0. \tag{1.25}$$

Solving for C_i leads to:

$$C_i = \frac{\frac{1}{2}aQ_i^2\text{Var}(\tilde{R}_{OTR}) + aQ_iQ_{OTR}\text{Var}(\tilde{R}_{OTR}) + Q_iOC_i}{(1 + R_{GC})}. \tag{1.26}$$

Converting into per-unit terms:

$$c_i = \frac{C_i}{Q_i} = \frac{\frac{1}{2}aQ_i\text{Var}(\tilde{R}_{OTR}) + aQ_{OTR}\text{Var}(\tilde{R}_{OTR}) + OC_i}{(1 + R_{GC})}. \tag{1.27}$$

[49]Equation (1.23) denotes the classical beta representation of a return in the capital asset pricing model (CAPM), assuming $\beta = \frac{Cov(\tilde{R}_e, \tilde{R}_{OTR})}{\text{Var}(\tilde{R}_e)}$. Equation (1.24) depicts the optimal fraction invested in the market tangency portfolio, assuming a mean-variance portfolio optimization under negative exponential utility and normally distributed returns.

Derivation of the relative bid-ask spread

This note details the derivation of the relative bid-ask spread. The relative bid-ask spread is defined as follows:

$$Rel.BAS_i = \frac{P^A - P^B}{0.5(P^A + P^B)}. \tag{1.28}$$

In terms of the model variables, note the following: $P^A = P^* + C_i^A$ for the purchase of one unit by the investor from the dealer at the ask ($Q^A = -1$). By this trade, the size of the dealer's trading portfolio decreases by one bond. And $P^B = P^* - C_i^B$ for the sale of one unit from the investor to the dealer at the bid ($Q^B = 1$). By this trade, the size of the dealer's trading portfolio increases by one bond. This leads to:

$$Rel.BAS_i = \frac{C_i^A + C_i^B}{0.5(2P^* + C_i^A - C_i^B)}. \tag{1.29}$$

The cost C_i^A and C_i^B are defined as:

$$C_i^A = \frac{\frac{1}{2}aVar(\tilde{R}_{OTR}) - aQ_{OTR}Var(\tilde{R}_{OTR}) - OC_i}{(1 + R_{GC})} \tag{1.30}$$

$$C_i^B = \frac{\frac{1}{2}aVar(\tilde{R}_{OTR}) + aQ_{OTR}Var(\tilde{R}_{OTR}) + OC_i}{(1 + R_{GC})}. \tag{1.31}$$

This leads to:

$$C_i^A + C_i^B = \frac{aVar(\tilde{R}_{OTR})}{(1 + R_{GC})}, \tag{1.32}$$

and

$$C_i^A - C_i^B = \frac{-2aQ_{OTR}Var(\tilde{R}_{OTR}) - 2OC_i}{(1 + R_{GC})}. \tag{1.33}$$

Inserting Equations (1.32) and (1.33) into (1.29) leads to the following spec-

ification of the relative bid-ask spread:[50]

$$Rel.BAS_i = \frac{\frac{aVar(\tilde{R}_{OTR})}{(1+R_{GC})}}{0.5(2P^* + \frac{-2aQ_{OTR}Var(\tilde{R}_{OTR})-2OC_i}{(1+R_{GC})})}. \tag{1.34}$$

This simplifies to:

$$Rel.BAS_i = \frac{aVar(\tilde{R}_{OTR})}{P^*(1+R_{GC}) - aQ_{OTR}Var(\tilde{R}_{OTR}) - OC_i}. \tag{1.35}$$

We observe that the relative bid-ask spread increases in the opportunity cost of the bond and the total size of the trading portfolio, as is expected:

$$\frac{\partial Rel.Bas_i}{\partial OC_i} = \frac{aVar(\tilde{R}_{OTR})}{(P^*(1+R_{GC}) - aQ_{OTR}Var(\tilde{R}_{OTR}) - OC_i)^2} > 0 \tag{1.36}$$

$$\frac{\partial Rel.Bas_i}{\partial Q_{OTR}} = \frac{(aVar(\tilde{R}_{OTR}))^2}{(P^*(1+R_{GC}) - aQ_{OTR}Var(\tilde{R}_{OTR}) - OC_i)^2} > 0. \tag{1.37}$$

[50]Note that this derivation is based on the assumption that both traded quantities equal one unit. It is possible to include different market depths on the two sides ($|Q^A| \gtrless |Q^B|$) to obtain a more general result, but this derivation does not simplify.

Chapter 2

Safe asset carry trade

Benedikt Ballensiefen and Angelo Ranaldo[1]

We provide the first systematic asset pricing analysis of one of the main safe asset categories, the repurchase agreement (repo). Based on the temporal and cross-sectional variation in short-term rates, we form a *carry* that, together with a market factor, prices these near-money assets in a linear pricing model. The carry depicts heterogeneity in non-pecuniary convenience yields of collateral assets and increases in the safety premium and the liquidity premium reflecting opportunity cost. Our carry helps explain the cross-section of short-term rates as well as long-term bond returns after accounting for standard bond pricing factors.

Keywords: Safe Asset, Repo, Bond, Convenience Premium.
JEL Classification: E40, E41, G00, G01, G10, G11.

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Investors pay a "convenience premium" for the safety and liquidity benefits provided by safe assets.[2] Prior research has shown that the convenience premium varies across securities (Krishnamurthy and Vissing-Jorgensen, 2012) and market conditions, such as the opportunity cost of holding money (Nagel, 2016) and uncertainty (Moreira and Savov, 2017). However, our understanding of the asset pricing implications and economic determinants of the temporal and cross-sectional variation in convenience premia and safe asset prices is still limited.

Our first contribution is to provide a systematic asset pricing analysis of one important category of safe assets, the repurchase agreement (repo). We find that a standard factor model with two factors, a *market factor* and a *carry factor*, is able to price these near-money assets. While the market factor determines the level of short-term interest rates, the carry factor accounts for their cross-sectional dispersion. The carry factor involves a long position in repos with higher rates and a simultaneous short position in repos with lower rates and thus captures the within- and cross-country variation in short-term rates. Our second contribution is to explain the economic determinants of non-pecuniary convenience yield stemming from the collateral asset (e.g., Gorton, 2017 and Infante, 2020). From the perspective of the safe asset literature, our carry factor reflects the differential in convenience yields provided by truly and quasi-safe assets. We provide empirical evidence that our carry factor increases with the safety premium and the liquidity premium reflecting the opportunity cost of holding money. Our carry factor helps explain the cross-sectional variation in short-term rates as well as long-term bond returns beyond the standard bond pricing factors, which points towards the external relevance of the carry for other asset classes.

The European repo market is particularly well suited for analyzing the asset pricing implications and economic determinants of heterogeneous convenience premia for several reasons. First, euro repos are overnight loans secured by government bonds with heterogeneous safety and liquidity attributes as they are issued by different euro area countries. This offers a new perspective to the extant literature on the convenience yield of safe assets that has predominantly focused on U.S. Treasuries. Second, the market characteristics enable us to

[2]In this work, we refer to convenience yield as "non-pecuniary returns...in the form of liquidity or moneyness and safety" (Gorton, 2017).

isolate safety and liquidity benefits by eliminating many confounding factors to convenience yields, such as term premia, counterparty, and currency risk.[3] Third, the legal framework prescribes that any collateral income payments during the repo term are transferred to the borrower who pledges the collateral. Hence, any convenience yield for the lender who receives the collateral for the term of the repo must consist of non-monetary benefits (e.g., strong protection and broad re-usability in case of truly safe assets). And fourth, it is the largest repo market worldwide, and our data includes transactions covering more than 70% of the entire European repo market. The size and importance of the euro area repo market, as well as the representativeness of our data, provide general validity to our results.

We observe an increase in the dispersion in short-term rates between countries during the European sovereign debt crisis as well as since the period of quantitative easing (QE). While the former suggests the existence of the safety premium for truly safe assets, the latter points towards the liquidity premium. Further evidence of the liquidity premium is an increase in the dispersion within, for example, German repo rates during the QE period. Based on this temporal and cross-sectional variation in short-term rates, we form our carry factor. On a daily basis, we build eight portfolios sorted by the respective repo rates: the first (last) portfolio contains the repos with the lowest (highest) repo rates observed during the previous trading day. By going long in the last portfolio (via a reverse repo) while shorting the first (via a repo), we create a collateral swap of assets with a higher convenience premium for those with a lower convenience premium. The carry, therefore, captures *daily* movements in non-monetary convenience benefits.[4] Our carry measures the return of an in-

[3]The euro area repo market infrastructure is based on central clearing and anonymous centralized electronic order book platforms, which guarantees homogeneous counterparty credit risk and an efficient price formation.

[4]In the European setting, the borrower remains the beneficial owner of the collateral which he pledges and therefore continues to receive the income cash-flows on the collateral for the term of the repo. A hypothetical repo carry trader operates on two fronts for the duration of one day: (i) he lends cash and temporarily receives a relatively low-convenience collateral (with higher rates), and (ii) he borrows cash and temporarily sells a high-convenience collateral (with lower rates). Note that the carry trader is not entitled to receive the cash-flows accrued from the collateral obtained in (i) while he continues to receive those from the collateral temporarily sold in (ii). Engaging in the carry trade, therefore, does not affect which counterparty receives the monetary cash-flows (i.e., coupon payments and exposure to bond price movements). Thus, by construction, our carry neatly isolates the non-monetary convenience benefits from monetary income and allows us to crystallize in a novel and clean way the cross-sectional differential in day-to-day convenience yield movements.

vestor who holds bonds with high convenience yield and is disposed to exchange them for other bonds with lower convenience yield on a day-by-day basis.[5]

Although our results are of general validity, we focus on spot-next repos, which constitute the lion's share of repos in the euro area. For those repos, settlement takes place two business days after the trading date. Given the length of the loan contract (one day), the collateral is returned on the third day. Hence, the carry reflects the forgone benefits on the high-convenience collateral and the gained benefits on the low-convenience collateral between day two and day three. The repo rate at which the carry trade is executed represents the *expectation* (Longstaff, 2000) about the convenience yield difference between the assets in portfolio 1 and 8. This is different from the actual future *realization* of the convenience yield as repo rates could have changed in the meantime due to changes in interest rates and collateral quality. To capture this, we compare forward rates (spot-next rates at time t) with realized rates (overnight rates at time t+2). Our carry, therefore, represents not only a compensation for the quality differential (safety and liquidity benefits) but also a compensation for the uncertainty in the realization of the convenience yield.

Figure 2.1 depicts the time-development of our carry return net of transaction cost formed across all euro area countries (green line) and without GIIPS countries (dashed grey line).[6] The average annualized carry return amounts to 0.39%, and the standard deviation of the difference between the expected and realized carry, which is a proxy for the time-varying uncertainty of the convenience yield, is 0.18%. When uncertainty increases, for instance, during the European sovereign debt crisis, the carry return formed without GIIPS countries is lower, pointing towards the safety premium of truly safe assets and a lower dispersion in rates within those countries. Since 2015, when the European Central Bank (ECB) set up the negative nominal rate regime and conducted asset purchasing programs, the spread of the carry return to the ECB's deposit facility rate has also increased. Both carries are almost identical during this pe-

[5]Our approach to calculating the carry captures one-day movements in nonpecuniary convenience yields. We consider an alternative carry that incorporates the cash-flows from buying and selling the underlying bonds. However, bond price changes not only capture movements in one-day convenience yield but also changes in the present value of all future convenience yields over the life of the bond and monetary benefits. We, therefore, feel that focusing on the repo trade is a more precise way of measuring daily movements in convenience yield.

[6]GIIPS countries are Greece, Ireland, Italy, Portugal, and Spain.

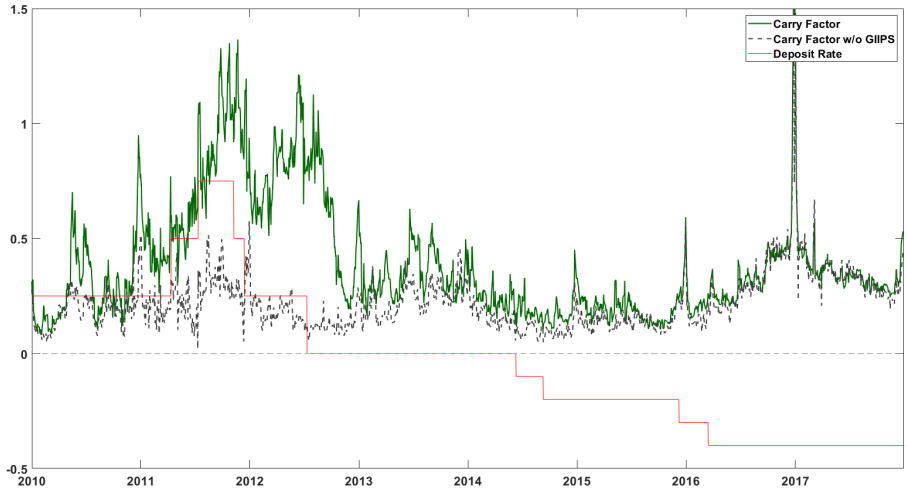

Figure 2.1: Development of the safe asset carry factor with/without GIIPS countries

riod, pointing towards the liquidity premium and an increasing rate dispersion even within truly safe assets.

Based on the portfolio results and the formation of our carry factor, we propose a simple two factor asset pricing model. For the asset pricing estimation, we apply a linear factor model and employ a generalized method of moments (GMM) estimation following Hansen (1982). We define the market factor to be the average repo market rate and the carry factor to be the high-minus-low carry return. The results reveal that our two pricing factors are able to explain a very large share of the price variation in near-money assets. The factor betas for the market factor are essentially all equal to one, while the factor betas for the carry factor increase monotonically from -0.80 for the first portfolio to 0.38 for the last portfolio. The results support the notion that the market factor explains the level of short-term interest rates, while the carry factor accounts for the cross-sectional dispersion. The market price of the carry factor is highly statistically significant at a level of 0.42% per annum. The 0.42% carry premium reflects the expected compensation for swapping assets in portfolio 1 and 8 over a one-year period.

In the second part of our paper, we employ the carry factor to gain insights into the economic determinants of convenience yields. Since the carry factor

measures the difference in the convenience yields offered by truly safe assets (in the low-rate portfolio) versus quasi-safe assets (in the high-rate portfolio), we are able to explore how the varying degrees of safety and liquidity attributes of European collateral assets drive convenience. In the safe asset literature, convenience yield is associated with the safety and liquidity premium. Against this background, three hypotheses about the carry factor can be brought forward: First, the larger the safety premium of truly compared to quasi-safe assets, the higher the carry factor. Second, when truly safe assets become scarcer compared to quasi-safe assets, their liquidity premium increases, and so does the carry. And third, since truly and quasi-safe assets are imperfect substitutes, the liquidity premium of truly safe assets, which provide more utility and are in short supply, increases more with the opportunity cost.

To test these hypotheses, we construct variables capturing the different drivers of convenience yield following the literature (i.e., "CDS," "asset supply," and "opportunity cost"). We then proceed in three steps: First, we perform a panel regression of our eight repo portfolio returns on the different economic determinants of convenience yield. Our results show that the rates of the assets in portfolio 1 (with the higher convenience yield) are comparatively lower when risk increases ("safety premium") and when the opportunity cost is higher ("liquidity premium"). Second, we regress our carry factor (instead of the portfolio rates) on the different economic drivers of convenience yield. Our results support the safe asset predictions showing that the convenience yield embedded in our carry factor increases in the safety premium and the liquidity premium reflecting opportunity cost. Importantly, the opportunity cost of holding money drive away the explanatory power of asset supply in line with Nagel (2016), which highlights the importance of the level of short-term interest rates in explaining the liquidity premium.[7]

And third, we analyze how the liquidity premium interacts with sovereign default risk. For this, we consider the within-country dispersion in short-term rates. This within-country dispersion can only relate to differences in the liquidity premium since the sovereign risk is the same across all bonds of the same country. The carry factor explains more of the within-country rate dispersion for truly safe assets, which implies a larger variation in the liquidity

[7]We perform a number of additional tests to ensure that our results are robust across subsegments, term types, and market venues and thus have general validity.

benefits offered by those assets. However, during flight-to-safety periods, such as during the European sovereign debt crisis, the differences in the liquidity premium of safe assets are smaller, suggesting that safety attributes gain in importance. This is reflective of the carries depicted in Figure 2.1. The carry formed only with truly safe assets (as opposed to including quasi-safe assets as well) is smaller during the European debt crisis, pointing towards a smaller rate dispersion among truly safe assets during those moments of uncertainty. The rate dispersion within those countries has, however, increased during the QE period, pointing towards differences in the liquidity premium, even within the universe of truly safe assets.

As a final step, we want to understand the explanatory power of our carry factor in terms of its external relevance. For this, we perform an asset pricing analysis of European government bonds. Our results highlight that the repo carry factor helps explain the cross-section of bond returns even after accounting for standard bond pricing factors, following Nelson and Siegel (1987), and controlling for *bond* safety and liquidity. The unexplained yield component of long-term bonds increases with our carry factor, suggesting that the carry captures additional convenience attributes such as the short-term funding ability (e.g., fungibility and (re-)pledgeability) with the advantage of being available in a timely fashion and at high frequencies.

Our analysis contributes to two strands of the literature. First, we contribute to the asset pricing literature. Fama and French (1993) document common factors in equity and bond markets, and more recent research shows that common factors explain other assets such as currencies (Lustig et al., 2011).[8] Koijen et al. (2018) provide an overview of different carries in equity, fixed income, and options markets. We are the first to carry out a factor pricing analysis of near-money assets and to uncover two common pricing factors.[9] We also add to the bond pricing literature of, for example, Cochrane and Piazzesi

[8]Lustig et al. (2011) identify a market-related dollar factor and a carry trade factor, inspiring our methodology to build the level and slope factors.

[9]Although no study before ours proposes a repo asset pricing analysis, a growing body of the literature analyzes the cross-sectional dispersion in repo rates including, e.g., Gorton and Metrick (2012), Copeland et al. (2014), Krishnamurthy et al. (2014), Infante (2020) and Ranaldo et al. (2021). Some papers focus on special repos, for instance, Duffie (1996), Jordan and Jordan (1997), Buraschi and Menini (2002), Krishnamurthy (2002), D'Amico et al. (2018), Arrata et al. (2020), and Corradin and Maddaloni (2020). Other studies investigate GC repos, for instance, Bartolini et al. (2011), Mancini et al. (2016), and Boissel et al. (2017). We study both special and GC repos.

(2005) and Fontaine and Garcia (2012) by showing that our (short-term) repo factors help explain the cross-section of (long-term) bond returns beyond the standard bond pricing factors.

Second, we add to the growing literature on safe assets.[10] We provide empirical support for safe asset theories predicting cross-sectional dispersion in (quasi-) safe assets and convenience yields (e.g., Krishnamurthy, 2002; Krishnamurthy and Vissing-Jorgensen, 2012; Stein, 2012; Sunderam, 2015; Caballero et al., 2016; Nagel, 2016; Moreira and Savov, 2017; He et al., 2019). By taking an asset pricing approach, we add to the related empirical literature (e.g., Longstaff, 2004; Fleckenstein et al., 2014; Greenwood and Vayanos, 2014; Krishnamurthy and Vissing-Jorgensen, 2015; Du et al., 2018a; and Kacperczyk et al., 2021).

2.1 Repo market

We start by explaining the main characteristics of the European repo market and our data.

2.1.1 Market structure

In a repo contract, two counterparts exchange cash for collateral (first leg) for a predefined time period with a fixed repurchase obligation (second leg). The asset being used as collateral can be a particular asset ("special repo") or any asset from a predefined basket of assets ("general collateral repo").[11] Repurchase agreements are a form of short-term borrowing as collateral is typically sold on an overnight basis.

We analyze the European repo market, which is the largest repo market in the world with more than EUR 9.0 trillion in outstanding contracts (International Capital Market Association, 2022). Several characteristics of its infrastructure are noteworthy: The core segment is the interbank market in which banks trade anonymously via centralized electronic order book plat-

[10] The shortage of safe assets and the macroeconomic and financial stability implications are analyzed in, e.g., Caballero and Krishnamurthy (2009), Caballero et al. (2017), and Caballero and Farhi (2017).

[11] In the U.S., a special repo is sometimes referred to as a "specific" repo, with the term "special" referring to specific repo rates being below prevailing short-term money market rates.

forms supporting liquidity and a transparent price discovery process.[12] We focus on trades operated through central counterparties (CCP). CCP-based repos constitute the majority of trades in the euro interbank repo market.[13] For those trades, CCPs interpose themselves between each lender and borrower. This means the CCP is the borrower to every lender and the lender to every borrower, i.e., the structure eliminates any concerns regarding individual counterparty risk. The CCP acts as a clearinghouse and applies the same collateral and (credit) risk policies to all CCP members.[14] If the CCP is the counterparty to a trade, it guarantees scheduled settlement of the repo in case a CCP member defaults.[15]

The usual repo 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. The most common collateral assets are government bonds, on which we focus in our analysis. A repo represents a true sale and repurchase of the collateral asset, i.e., the buyer (lender) becomes the legal owner of the collateral at the purchase date. While the buyer of the collateral is the owner of the asset during the term of the repo, the seller retains the risk of the asset as he has agreed to buy it back at the repurchase date. Any income arising from the asset during the repo term (e.g., coupon payments) is therefore transferred to the seller.

We focus on repo trades that (i) are CCP-based, (ii) mature after one day,

[12]Market participants include commercial, retail, and investment banks, as well as other financial institutions (e.g., public banks, cooperatives, and saving banks).

[13]CCP-based repos account for more than two-thirds of the total turnover (European Central Bank, 2018). The CCP inserts itself as a counterparty into each transaction through "novation."

[14]Initial margins or haircuts, which are reflected in the repo rate, were relatively stable during our sample period. The CCP determines ex-ante haircuts that are exogenous and thus the same for all market participants, which is different from the U.S. market practice (e.g., Gorton and Metrick, 2012 and Copeland et al., 2014).

[15]In case of a member default, the CCP will replace the positions of the defaulting member and seek to recover any associated cost by drawing on a series of capital buffers (in the form of initial margins posted by members, committed and contingent contributions by members to a default fund, reserves, and equity capital). Besides the different layers of capital buffers, the CCP also needs to follow conservative investment policies (Ranaldo et al., 2021). Based on those protections, financial market regulators have concluded that there is no systemic default risk in clearing houses (European Securities and Markets Authority, 2015, 2017, 2020). Arguably, there could be (rare) states of the world in which CCP members default, sovereign issuers of the collateral asset default, and the CCP's buffers and equity capital fails. We provide a variety of additional tests showing that the cross-sectional dispersion of European repo rates depends on heterogeneous convenience yields rather than a compensation for such a systemic risk.

and (iii) are collateralized by government bonds which are classified as high-quality liquid assets by regulators. In this setting, given that income payments during the repo term are passed back to the borrower (even though the lender is the legal owner), any convenience yield for the lender must consist of non-monetary benefits (e.g., the ability to re-use the collateral). Hence, the temporal and cross-sectional variation in repo rates mostly stems from the difference in the convenience offered by the collateral asset as well as the uncertainty about the realization of the convenience yield. While the extant literature has predominantly focused on the U.S. Treasury market, our approach of looking at the European repo market is a novel way to capture cross-sectional differences in convenience yield.

2.1.2 Data

Our repo data consists of the near-total universe of all electronically traded interbank repo transactions in euro from the beginning of 2010 to the end of 2017. We obtain data from the three major trading platforms: BrokerTec, MTS, and Eurex. These trading venues account for transactions covering more than 70% of the total European repo market. For each transaction, we observe the trade date, the term, the trade volume, the rate, the collateral identified by a unique ISIN or basket, the aggressor type, and the trading platform. In our analysis, we focus on CCP-based euro repos with overnight tenors with general and specific collateral, which represent the majority of all euro repos.

To be conservative, we exclude a very small fraction of repo contracts and trading days that, by their nature, would increase the rate dispersion: First, we remove bilateral repos and prearranged trades.[16] Second, we exclude repos with term types other than ON, TN, and SN.[17] Third, we focus on sovereign bonds as a collateral asset as non-government bonds present a different risk pro-

[16] On Eurex, all transactions are CCP-based, whereas, on BrokerTec and MTS, a very small fraction of repos are bilaterally traded. After prearrangement, a bilateral trade can also be reported to and cleared by the CCP. Since counterparties in those transactions are not anonymous anymore, we exclude those trades, which represent about 5% of our data.

[17] This includes repos with a maturity longer than one day and transactions with open term. Together, we exclude only about 3% of our data.

file and are rarely traded.[18] Fourth, we exclude repos with a floating rate.[19] Fifth, we exclude infrequently traded repos to guarantee the general validity of our carry factor and ease illiquidity issues.[20] Finally, we perform our main regression analyses based on a sample period that excludes transaction days that, for institutional reasons, are characterized by a greater dispersion of interest rates; namely trading days at the end of the month and the end of the ECB maintenance periods when repo rates vary considerably more during these (uncertain) times.[21] However, we return to the variation on those days specifically in Table 2.2 when we show descriptive statistics of our carry factor.

Our data sample construction has two main advantages: On the one hand, it guarantees the general validity of our results because only a small fraction of euro repos are excluded, and we ascertain that our findings hold true across all the main market segments. On the other hand, it eliminates many confounding factors such as term premia and currency risk, thus buttressing the measurement accuracy of our results.

Table 2.1 summarizes our data set which totals more than 441 trillion euro of transactions. Special repos secured by government bonds and repos of term type SN constitute the largest share of our data. While BrokerTec and MTS are the two largest trading platforms, Eurex mainly covers the GC pooling

[18]This is true for special repos and GC trades whose baskets mostly contain government bonds. For special collateral, our data set essentially covers the universe of government bonds. Only about 2,000 trades with a trading volume of 0.02 EUR tn are collateralized by government-related and supra-national agencies (i.e., the German development agency KfW, the European Investment Bank, and the European Fund for Southeast Europe). For GC trades, those baskets mostly contain only government bonds as collateral. On Eurex, two GC pooling baskets allow highly-rated assets (i.e., investment-grade bonds), including assets issued by regional governments or "Pfandbrief" instruments of credit institutions, to be delivered. The two baskets do not play a major role in our analysis since we do not weight our portfolios by trading volume. Our results are unchanged if we exclude those special repos collateralized by government-related and supra-national agencies and the two GC pooling baskets from our analysis.

[19]Floating rate repos are quoted as a spread to the EONIA rate and represent about 10% of the total trading volume.

[20]To be included in our analysis, a repo needs to be traded on at least 200 trading days (i.e., one year of data) and needs to be traded at least once a week, on average. We exclude repos that represent less than 3% of the total trading volume in the remaining data.

[21]For each term type, we exclude month-end dates and between 8 to 12 end-of-ECB maintenance period dates during a year. The exact date is different for each term type. For example, for the end of the ECB maintenance period on the 19th of December 2017, we exclude the 19th of December 2017 for an ON repo, while for a TN repo, we exclude the 18th of December 2017. For robustness purposes, we also ensure that the results are consistent if we exclude the entire weeks surrounding quarter-ends. The inclusion of these subsets of data and trading days boosts the performance of our carry factor, as we show later in the paper.

Table 2.1: Breakdown of the repo data

	Transactions (in mn)	Volume (in EUR tn)	Transactions (share in %)	Volume (share in %)
Centrally cleared euro repos	16.87	441.39	100.00%	100.00%
General collateral	1.49	136.18	8.82%	30.85%
Special collateral	15.38	305.21	91.18%	69.15%
of which are government bonds	*15.38*	*305.19*		
BrokerTec	10.35	241.88	61.38%	54.80%
Eurex	0.27	56.06	1.61%	12.70%
MTS	6.24	143.45	37.01%	32.50%
Overnight	0.61	48.46	3.63%	10.98%
Tomorrow-next	3.22	95.28	19.06%	21.59%
Spot-next	13.04	297.65	77.31%	67.44%
Austria	0.71	10.88	4.49%	2.59%
Belgium	1.34	24.84	8.49%	5.91%
Germany	4.84	135.52	30.63%	32.22%
European Union	0.22	53.51	1.40%	12.72%
Finland	0.44	6.25	2.77%	1.49%
France	0.10	14.35	0.61%	3.41%
Ireland	0.31	3.49	1.99%	0.83%
Italy	6.26	143.24	39.68%	34.06%
Netherlands	1.12	22.86	7.08%	5.44%
Portugal	0.45	5.64	2.86%	1.34%
Spain	1.09	20.81	6.89%	4.95%

The table shows the breakdown of our repo data. Our data only include centrally cleared repos denominated in euro. The data are broken down by repo type, trading venue, tenor, and the collateral's country of origin. For special collateral, our data set essentially covers the universe of government bonds. Only about 2,000 trades with a trading volume of 0.02 EUR tn are collateralized by government-related and supra-national agencies (i.e., the German development agency KfW, the European Investment Bank, and the European Fund for Southeast Europe). For GC trades, those baskets typically contain only government bonds as collateral. On Eurex, two GC pooling baskets allow highly rated quasi-safe assets (i.e., investment-grade bonds) to be delivered. The two baskets do not play a major role in our analysis since we do not weight our portfolios by trading volume. These are only two baskets out of a cross-section of 943 repos. Our results are unchanged if we exclude those two baskets from our analysis.

market. Germany and Italy constitute the largest share by the origin of the collateral, with representative shares for other European countries.[22] Overall, our data sample covers the largest segment of the euro area money market, and the repo rates under inspection are the most representative available.

For all transactions in our data, we compute the daily volume-weighted average repo rate of each GC basket and ISIN, separately for each term type, based on the trade date and across trades executed on the three repo trading venues. We include both GC and special repos in our sample. We choose this approach to provide general validity and the highest representativeness to our results. However, we ensure that our results are not biased by any specific segment or repo type as we provide robustness checks for each subcategory. Specifically, we show that our results do not depend on specialness (because they hold for GC only), illiquidity (because we exclude illiquid repos), term type (because we perform subsampling analysis for each term type), trading venues (because the results are valid for BrokerTec only), and currency (because we only consider euro repos). Our final data set features a cross-section of 943 repos, of which 907 are special repos, and 36 are GC repos. Regarding the tenor, 75, 864, and 818 different repos are included in the ON, TN, and SN market segments, respectively. We compute transaction costs for each repo separately.[23]

To carry out the bond asset pricing analysis, we obtain bond quotes and trades from the MTS Cash market. The MTS 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. We focus on the cross-section of European sovereign bonds that are posted as repo collateral and include all zero and fixed-coupon bonds.[24] For each day between a bond's issuance and maturity, we compute the daily volume-weighted average mid-

[22]Our sample includes a relatively small share of French collateral for two reasons: First, French repos are mainly floating rate. Second, certificates of deposit are another source of short-term funding that is mainly common in the French market (Pérignon et al., 2018).

[23]We compute transaction cost as the difference in repo rates between borrower-initiated and lender-initiated trades. Borrower-initiated trades refer to the counterparty borrowing cash in the repo market as the aggressor (i.e., "ask" rate), whereas lender-initiated trades refer to the counterparty lending cash in the repo market as the aggressor (i.e., "bid" rate). The aggressor variable specifies whether a borrower or a lender has initiated a trade against the prevailing quotes; we, therefore, derive transaction cost from the prevailing bid and ask quotations against which trades are executed.

[24]In the construction of our data, we exclude suspicious quotes that show up as outliers relative to surrounding quotes. Those quotes represent a minimal share of 0.03% of our data.

quote, transaction price, and transaction cost. The size and liquidity of the MTS market make our bond data highly representative.

2.2 Carry factor and repo pricing

We begin our analysis by looking at the *cross-country* dispersion in near-money rates. Figure 2.2 shows the development of GC repo rates for Germany (green line) and Italy (dashed blue line) in relation to the ECB's rates on the deposit and marginal lending facility (red lines). Three patterns stand out. First, repo rates for Germany are lower than those for Italy. Second, the spread between the two countries increased during the European sovereign debt crisis. And third, since 2015, German repo rates have fallen below the ECB's deposit facility rate, while Italian repo rates have stayed above or at the level of the deposit rate, which is indicative of the greater convenience services of the former over the latter.

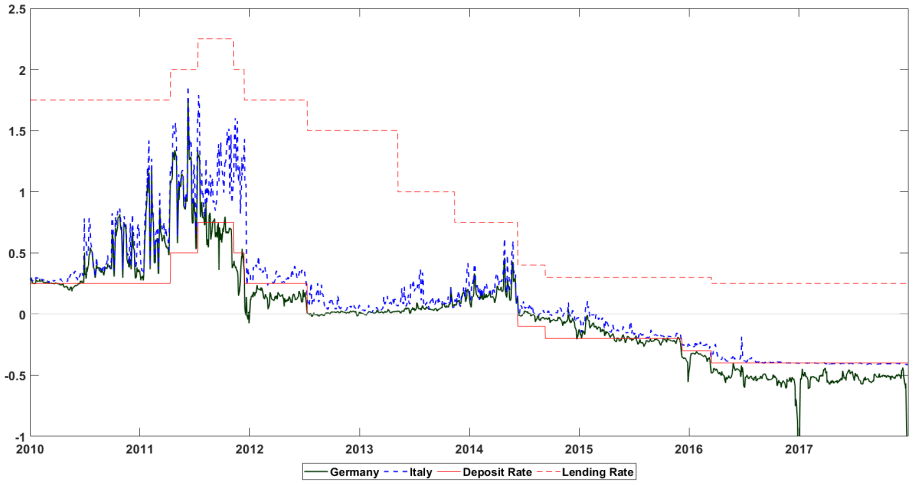

Figure 2.2: General collateral repo rate development

The safe asset literature suggests the following interpretation. First, the cross-country dispersion in GC repo rates points towards heterogeneity in convenience yields which are systematically higher for countries such as Germany. Second, an increasing dispersion during the European sovereign debt crisis suggests the existence of a safety premium for truly safe assets. And third, the

increasing dispersion after 2015 coincides with collateral scarcity due to quantitative easing (Arrata et al., 2020) and prudential regulation (Ranaldo et al., 2021). The consequent reduction in the supply of safe assets seems to be leading to higher liquidity premia embedded in truly safe assets. At the same time, banks are not willing to accept a lower interest rate to receive an Italian collateral asset compared to storing their funds at the ECB's deposit facility, which reinforces the lower bound on Italian rates and indicates that the convenience benefits of quasi-safe assets are valued less.

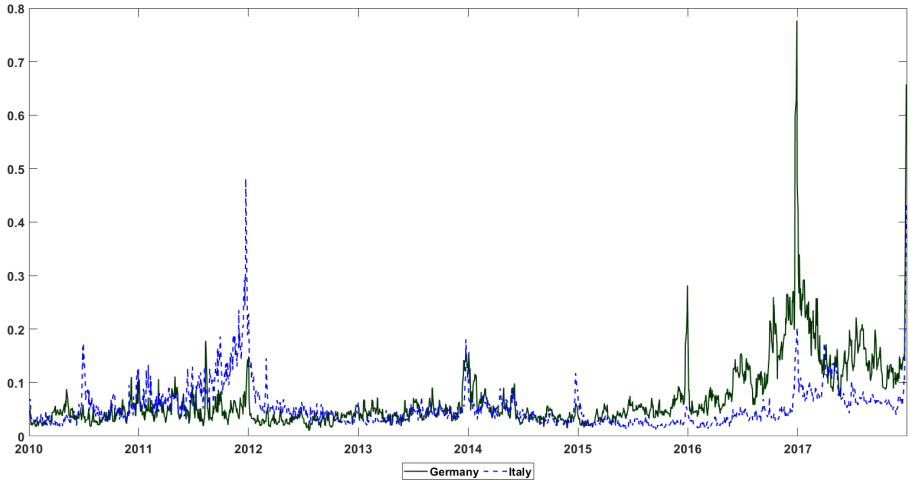

Figure 2.3: Repo rate dispersion

Another aspect is the *within-country* dispersion in repo rates of the same sovereign country as depicted in Figure 2.3. We calculate the dispersion as the interquartile range across the set of each country's daily repo rates. Until 2015, the dispersion in rates has been similar between German and Italian collateral; however, since 2015, the dispersion in German repo rates has increased. This underlines the importance of different liquidity benefits even within the universe of bonds of the same sovereign issuer.

2.2.1 Safe asset portfolios

To capture the dispersion in repo rates, we build portfolios of repos. For this, we focus on spot-next repos, which constitute the lion's share of the repos in the euro area. At the end of each trading day *t-1*, we sort the repos in our

sample according to the repo rate observed during that day. Based on this sorting, we allocate each of the repos into eight portfolios in which we invest on the following trading day t: The first portfolio contains the repos with the lowest rate during the previous day, while the last portfolio contains the repos with the highest rate.[25] Portfolios are rebalanced daily. Since we focus on SN repos, settlement of the repo takes place two business days after the trading date, i.e., the first leg settles at t+2, while the final repayment takes place at t+3. A repo borrower (lender) therefore forgoes (enjoys) the convenience of the collateral asset for the period between t+2 and t+3. This concept is illustrated in Figure 2.4.

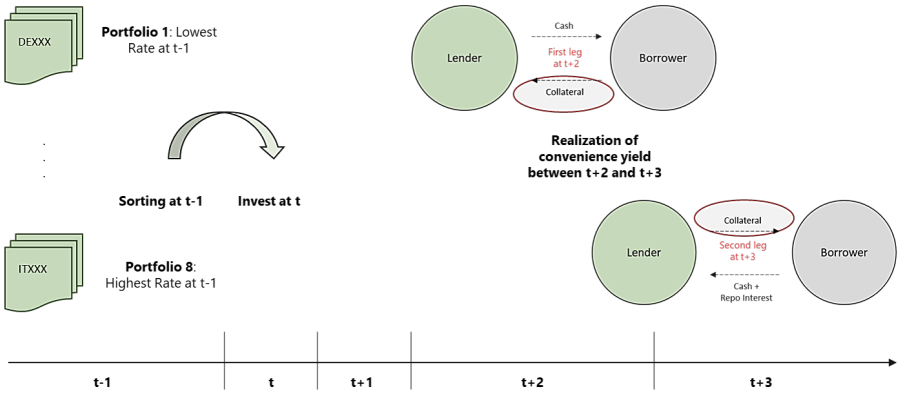

Figure 2.4: Convenience yield in repo trade

The repo rate at which the trade is executed at time t represents the *expectation* about the convenience yield embedded in the collateral. This is different from the actual *realization* of the convenience yield between t+2 and t+3 as repo rates could have changed in the meantime. Potential reasons include general movements in the funding demand and supply or changes in the net demand for individual securities due to, for example, (i) short-sellers, (ii) deliverability into futures contracts, (iii) inventory rebalancing of market makers, (iv) movements in collateral prices, and (v) supply changes (e.g., induced by quantitative easing or bond issuances).

To study the actual realization in the convenience yield, we revisit the

[25] Our results remain unaffected by a change in the number of portfolios to two or four, as reported in the online appendix.

previous literature testing the expectations hypothesis using short-term interest rates (e.g., Longstaff, 2000; Della Corte et al., 2008) and take advantage of the euro repo market set-up. More precisely, we study portfolio returns at time $t+2$ by weighting the ON rates at $t+2$ with the portfolio constituents embedded in the initial trade that was executed at time t. Alternatively, we calculate the realization using the tomorrow-next term type, which features higher trading volumes. For this, we analyze portfolio returns at time $t+1$ by weighting the TN rates at $t+1$ with the portfolio constituents embedded in the initial trade that was executed at time t.[26] Since our setting eliminates many confounding factors to convenience yield, such as term premia, counterparty, and currency risk, this is the most suitable approach to capture the convenience yield realization.[27] Applying the same intuition as in the expectations hypothesis, forward interest rates should be aligned with realized interest rates if there were no time-varying risk premia. In our context, we should empirically observe that forward interest rates (captured by SN repo rates at time t) coincide with realized interest rates (captured by ON repo rates at time t+2). Conversely, the dispersion in their difference suggests uncertainty in the realization of the convenience yield.

Table 2.2 provides an overview of the performance of the eight repo portfolios. For each portfolio n, we report the average expected portfolio returns gross and net of transaction cost;[28] the return on the high-minus-low investment strategy, which shorts portfolio n=1 while going long in portfolios n=2, 3,...,8; as well as the standard deviation between the expected net return (using

[26]ON repo trading volumes are lower than SN volumes. We account for this in the calculation of the realized carry by adjusting the portfolio weights in each of the portfolios in case fewer rates are observed on any given day. The analysis based on TN repos delivers consistent results suggesting that the lower trading volume in ON repos does not bias our results. The results can be found in the online appendix.

[27]The use of overnight repos allows us to remove term premia and uncertainty over longer horizons. In addition, focusing on repos that are traded via a central counterparty and that are overcollateralized by government bonds reduces credit risk as it makes repos information insensitive (e.g., Gorton and Ordonez, 2014). We could look at longer-term repos, e.g., one-week repos, and compare them to overnight rates as an alternative to capture the realization in the convenience yield. This approach, however, has the disadvantage that longer-term repos are less frequently traded and that they carry a term premium.

[28]For the purpose of computing portfolio returns net of transaction cost, we assume borrower-initiated trades for portfolio n=1 (i.e., "ask" rate to borrow money) and lender-initiated trades for portfolios n=2, 3,...,8 (i.e., "bid" rate to lend money). We compute a volume-weighted average repo rate across borrower- and lender-initiated trades for each repo separately. We, therefore, add half the repo-specific borrower-lender spread to the average rate for repos in portfolio 1, while we subtract half the borrower-lender spread from the average rate for repos in portfolios n=2, 3,...,8.

the SN rate at time t) and the realization of the net return (using the same portfolio constituents at the ON rate at time t+2). It is well-known that euro area repo rates tend to spike at reporting dates such as quarter-end periods (e.g., Ranaldo et al., 2021). We, therefore, present the portfolio results for a sample (i) where we exclude end of month and end of ECB maintenance period trading days (baseline), (ii) where we additionally exclude the entire trading weeks surrounding quarter ends, and (iii) where we only include those periods.

Table 2.2: Portfolio return (%)

(i) without end of month and end of ECB maintenance periods (baseline)

	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8
Expected gross return	−0.35	−0.07	−0.03	−0.01	0.01	0.05	0.08	0.11
Expected net return	−0.30	−0.09	−0.04	−0.02	0.00	0.03	0.07	0.09
Expected high-minus-low net return	-	0.21	0.26	0.28	0.30	0.33	0.36	0.39
Standard deviation of expected minus realized net return	0.20	0.13	0.14	0.12	0.10	0.11	0.12	0.11

(ii) without end of month, end of ECB maintenance periods, and end of quarter

	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8
Expected gross return	−0.34	−0.06	−0.02	−0.01	0.01	0.05	0.08	0.11
Expected net return	−0.29	−0.08	−0.04	−0.02	0.00	0.03	0.07	0.10
Expected high-minus-low net return	-	0.21	0.25	0.27	0.29	0.32	0.36	0.38
Standard deviation of expected minus realized net return	0.20	0.14	0.14	0.12	0.10	0.11	0.12	0.11

(iii) at end of month, end of ECB maintenance periods, and end of quarter

	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8
Expected gross return	−0.40	−0.10	−0.06	−0.03	0.00	0.07	0.11	0.15
Expected net return	−0.34	−0.13	−0.08	−0.05	−0.02	0.04	0.09	0.13
Expected high-minus-low net return	-	0.21	0.26	0.29	0.32	0.38	0.43	0.46
Standard deviation of expected minus realized net return	0.38	0.29	0.25	0.25	0.22	0.16	0.17	0.17

The table shows the average, annualized expected portfolio returns for portfolios n=1, 2,...,8, gross and net of transaction cost using SN repo transactions; the return on the high-minus-low investment strategy relates to the expected net portfolio return and shorts portfolio n=1 while going long in portfolios n=2, 3,...,8; and the standard deviation of the difference between the expected portfolio net return (using the SN rate at time t) and the realized portfolio net return (using the same portfolio constituents at the ON rate at time t+2). "Without end of month and end of ECB maintenance periods" excludes end of month and end of ECB maintenance period tradings days; "without end of month, end of ECB maintenance periods, and end of quarter" excludes end of month and end of ECB maintenance period tradings days as well as end of quarter trading weeks; and "at end of month, end of ECB maintenance periods, and end of quarter" includes only end of month and end of ECB maintenance period tradings days as well as end of quarter trading weeks.

In our baseline (i), the expected annualized net return increases monotonically from −0.30% for the repos in the first portfolio to 0.09% for the repos in the last portfolio. Similarly, the average annualized return on the high-

minus-low investment strategy increases from 0.21%, considering the second portfolio, to 0.39%, considering the last portfolio. The high-minus-low return is largely driven by the low rates on the assets in portfolio 1, pointing towards (safety and liquidity) benefits of holding those truly safe assets. The standard deviation between the expected and realized rates is also highest for the assets in portfolio 1 as those assets tend to carry the highest convenience benefits. This variability, which is at least half as large as the carry, points towards the non-negligible role of uncertainty in the realization of the convenience yield. Additionally, excluding the entire weeks surrounding quarter ends (ii) does not change the results materially. When we focus on those periods of higher volatility in (iii), the high-minus-low return increases to 0.46%, in line with the idea that convenience benefits are more valuable on those days. While the overall effect seems to be small, it represents a more than 15% increase in the high-minus-low return. At the same time, the volatility indicator of convenience yield uncertainty also tends to be higher. While we show that this uncertainty exists, we do not include it in the calculation of the expected carry at time t on which we focus in the remaining part of the paper.

The daily transaction volume for all portfolios is substantial in absolute terms but not relative to the large market size, which ensures the rebalancing.[29]

To assess the importance of the geographic origin, we analyze the composition of the long and short portfolios. Table 2.3 shows the average fraction that each country's collateral contributes to each portfolio. In support of the idea that the first portfolio hosts assets with a higher safety premium compared to the last one, countries associated with a strong economy and political stability have a larger share in portfolio 1. For instance, the average shares of Germany (Italy) in portfolios 1 and 8 are 30.7% and 0.8% (11.7% and 67%), respectively. However, bonds issued by the same sovereign country can differ quite a lot in repo rates as well; for example, German government bonds have a substantial share not only in portfolio 1, but also in portfolios featuring repos with higher rates, thus hinting at the time-varying liquidity premium as an additional determinant of convenience yield which helps explain the within-country variation

[29]The average daily trading volume of portfolios 1 and 8 is more than euro 2 billion, respectively; the daily trading volume for any of the two portfolios never falls below euro 500 million. In Section 2.3, we return to the variation in trading volumes of portfolios 1 and 8 as a potential economic determinant for the cross-sectional dispersion in near-money rates.

Table 2.3: Portfolio constituents

	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8
Austria	3.8%	5.8%	7.9%	13.0%	12.4%	4.4%	1.1%	0.6%
Belgium	8.0%	9.7%	11.3%	15.1%	22.8%	7.4%	1.5%	0.8%
EU	0.9%	0.5%	0.2%	0.2%	0.3%	1.4%	1.1%	2.1%
Finland	3.8%	5.3%	6.7%	8.0%	5.9%	2.2%	0.6%	0.4%
France	0.1%	0.1%	0.1%	0.2%	0.8%	1.6%	0.9%	1.3%
Germany	30.7%	38.6%	39.7%	33.2%	18.5%	4.8%	1.0%	0.8%
Ireland	8.6%	3.1%	1.8%	1.5%	2.7%	3.8%	2.3%	5.1%
Italy	11.7%	11.1%	8.9%	8.8%	15.7%	45.5%	73.3%	67.0%
Netherlands	4.9%	11.3%	15.3%	13.3%	7.1%	2.5%	0.7%	0.3%
Portugal	11.5%	3.4%	1.9%	1.7%	3.0%	4.0%	2.6%	6.1%
Spain	15.9%	11.1%	6.1%	5.2%	10.8%	22.5%	14.9%	15.6%

The table shows the average percentage that each country's collateral constitutes of the collateral in portfolios n=1, 2,...,8. On each day and for each portfolio, we compute the ratio of the number of collateral securities associated with a country relative to the total number of collateral securities in a portfolio. We compute the average of the daily shares for each country in each portfolio to account for changes in the number of portfolio constituents across time.

in rates.[30]

2.2.2 High-minus-low

Our goal is to capture the convenience premium differential between the set of assets comprising the high- and low-rate portfolios. The portfolio results, therefore, provide the motivation for our carry trade: By going long in the last portfolio with the highest repo rates (via a reverse repo) while shorting the first portfolio with the lowest rates (via a repo), we create a *collateral swap* that captures the convenience premium differential. The schematic view is illustrated in Figure 2.5.

The trader in our example pledges the assets in the low-rate portfolio to borrow cash (repo); he then lends this cash in a reverse repo transaction for which he obtains the assets in the high-rate portfolio as collateral. As such, we consider matching repo/reverse repo transactions with different collateral bonds but the same settlement date.[31] Haircuts on the high-rate portfolio tend to be larger than the ones on the low-rate portfolio, i.e., the amount borrowed

[30] A breakdown of the portfolio transition matrix, i.e., what is the likelihood of a bond that is in a certain portfolio to stay in that portfolio tomorrow, is presented in the online appendix. As expected, there is persistence, but we also observe movements across portfolios.

[31] Since we exclude end of quarter and end of ECB maintenance period reporting dates, those matching repo/reverse repo trades do not affect the size of a bank's balance sheet as reported for regulatory purposes (Bank for International Settlements, 2017).

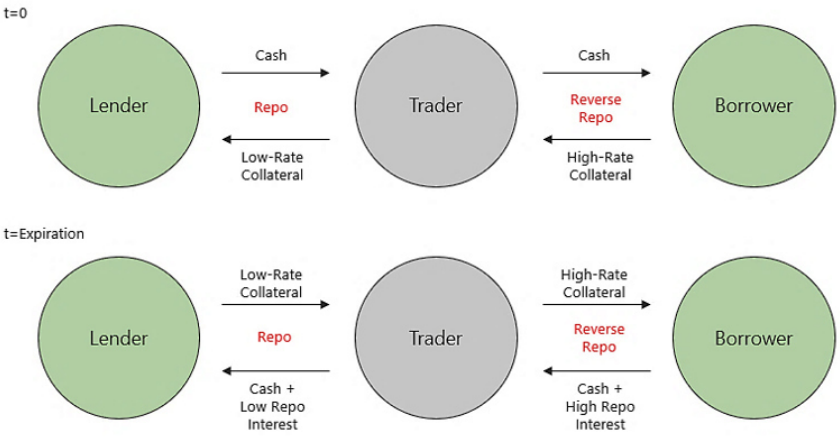

Figure 2.5: Carry trade

by the trader is larger than the amount lent on the reverse repo side. In our analysis, we abstract from haircuts to be conservative.[32] Once the two positions are unwound on the next day, the carry materializes as the difference between the two repo rates. The trader receives the high repo rate (on the reverse repo side) while he pays the low repo rate (on the repo side). At the same time, he returns the high-rate collateral while he receives back the low-rate collateral.

The development of the carry return (green line), as well as the difference between the expectation and the actual realization (dashed grey line), is depicted in Figure 2.6; detailed summary statistics can be found in Table 2.4.[33] The average annualized carry return is 0.39%, with an annualized standard deviation of the difference between the expected and realized carry of 0.18%. Cross-sectional differences in convenience yield are time-dependent. We observe the highest annualized returns during the European sovereign debt crisis in 2011 and 2012 (0.73% and 0.70%, respectively), pointing towards the role of

[32]The ECB's collateral framework serves as a reference for the CCP's haircuts (https://www.ecb.europa.eu/paym/coll/assets/html/list-MID.en.html). For example, at the end of our sample, ECB haircuts were about 3%-points higher for assets in portfolio 8 compared to assets in portfolio 1.

[33]A visual comparison between the realization of the carry return using the ON respectively TN rates is presented in the online appendix.

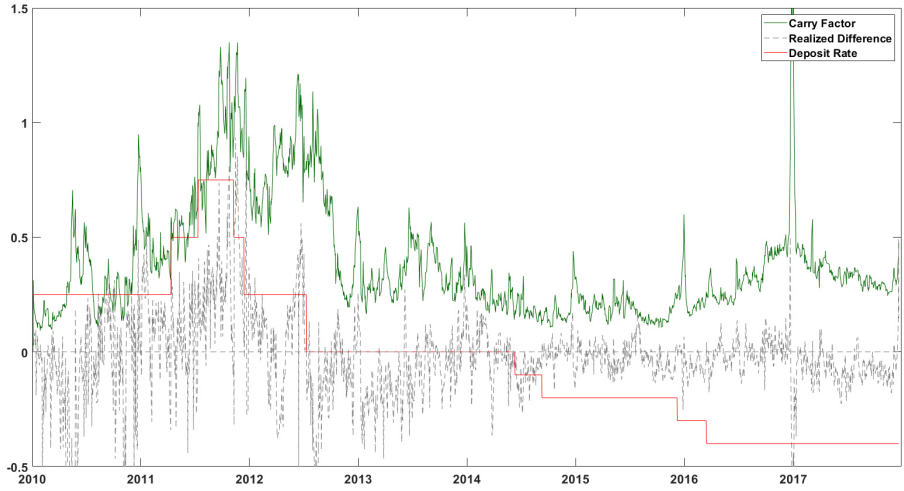

Figure 2.6: Carry factor and carry factor realization

Table 2.4: Summary statistics (%)

Mean	0.39	Percentile		Percentile	
Minimum	0.08	1%	0.11	75%	0.47
Maximum	1.90	5%	0.14	95%	0.95
Standard deviation	0.18	25%	0.22	99%	1.21

The table reports summary statistics for the carry factor. It shows the mean, minimum, and maximum of the annualized carry return as well as the standard deviation of the difference between the expected and realized carry factor; it also lists the standard percentiles of the carry return.

the safety premium. We also observe an increase in the carry return to about 0.36% in 2017 during the period of unconventional monetary policy, pointing towards the role of the liquidity premium.[34] The Dickey and Fuller (1979) and Phillips and Perron (1988) tests provide evidence that the null hypothesis of unit root can be rejected.[35]

[34]Despite the removal of year-end trading days, we observe window dressing effects in the days leading up to the end of the year (in particular in 2016 and 2017), which are reflected in the spikes of our carry return.

[35]Stationarity is the natural result of the tight connection of repo rates with the monetary policy rate. To ensure stationarity, our carry trade could also be implemented relative to the ECB's deposit facility rate since repo market rates are cointegrated with the ECB's target rate.

2.2.3 Economic interpretation

Within the context of the safe asset literature, the carry captures the convenience premium differential between the assets carrying a higher convenience (lower rate) and the ones carrying a lower convenience (higher rate). More precisely, the carry captures the forgone utility of one asset (or basket) against the utility of receiving and reusing another asset (or basket) for the time between the purchase and repurchase. We also observe that there is sizeable volatility in the realization of the convenience yield. Our carry factor thus represents both a compensation for the quality differential (safety and liquidity benefits) as well as a compensation for the uncertainty in the realization of the convenience yield.

To operate the repo leg, the collateral asset must already be held in order to be sold; this collateral swap is not self-financing. The carry is thus a return available to an investor with these high convenience yield bonds in hand and the ability/willingness to potentially use a lower convenience yield collateral on a day-by-day basis. An alternative carry trade would be to incorporate the cash-flows on the underlying bonds. For example, one could consider the cash-flows and price movements of the low-rate bonds which the trader needs to hold to implement this trade. However, what we are aiming to measure is the non-pecuniary convenience of having a collateral at one's disposal for a period of one day. This convenience accrues to the counterparty receiving the pledged collateral. In the European setting, income cash-flows on the collateral during the repo term are passed to the borrower. Hence, incorporating cash-flows from the underlying bonds implies that our non-pecuniary convenience benefits are combined with monetary income (price change, accrued interest). By contrast, the way we choose to construct and measure the carry does not affect who receives the monetary cash-flows. Thus, by construction, our carry neatly isolates the non-monetary convenience benefits from monetary income and allows us to crystallize the cross-sectional differential in one-day convenience premia.

Following Krishnamurthy (2002), the bond price contains information about the convenience yield. However, bond price movements not only capture movements in one-day convenience yield but also changes in the present value of all future convenience yields over the life of the bond as well as monetary benefits. Our method is more tailored to the purpose of our analysis in the sense that the

repo carry factor reflects the part of the bond price change related to holding the bond for a period of one day. We show that the performance of our carry factor remains positive and increases once we account for the bond portfolio return (see online appendix). However, the overall return is dominated by bond price movements, which is consistent with the idea that the largest part of the price movements in the bond reflects changes in the present value of all future convenience yields as well as monetary benefits.

Regarding the repo rate dispersion, one may argue that our results can be explained by specialness, market segmentation, and systemic risk of defaulting clearing houses. Although these explanations are not at odds with our explanation, we perform various analyses that clearly discard these alternative explanations. First, we find that the carry factor is present for both GC and special repos separately, indicating that the carry return cannot only be driven by "specialness" (Duffie, 1996). Second, there could be market segmentation in the sense that agents prefer specific tenors, market venues, and collateral (Cœuré, 2019). Subsampling analyses show that our results are robust across different repo tenors and if we only consider trades executed on BrokerTec.[36] Third, explaining the carry return with the systemic risk of a joint default of a clearing house along with the sovereign issuers of collateral assets in the spirit of Boissel et al. (2017) does not square well with our empirical patterns. For example, as is displayed in Figure 2.1, the carry remains present when we exclude all GIIPS countries from the construction of our carry factor (which removes sovereign default risk from our carry factor). Financial market regulators have also repeatedly documented that there is no systemic default risk in clearing houses (European Securities and Markets Authority, 2015, 2017, 2020).[37]

2.2.4 Common factors

Based on our portfolio results and the formation of our carry factor, we propose a simple two factor asset pricing model. We motivate our asset pricing approach by a principal component analysis (PCA) of our portfolio returns.[38]

[36] A visual comparison of the different carries as well as detailed results are reported in the online appendix.

[37] It should be noted that the framework of Boissel et al. (2017) cannot explain the developments of the repo market since 2015, when some of the repo rates (including GC rates) have fallen below the rate of the ECB's deposit facility. Instead, our explanation of time-varying convenience yields is consistent with these patterns.

[38] The results of the PCA are reported in the online appendix.

The first principal component accounts for about 95% of the common variation in portfolio returns and can be interpreted as the level factor since all portfolios load equally on it. The second principal component accounts for the largest part of the remaining 5% of the common variation and can be interpreted as the slope factor since the portfolio loadings increase monotonically from the portfolio containing the repos with the lowest rate to the portfolio containing the repos with the highest rate. As we expect, the largest part of the common variation in short-term interest rates is explained by the level factor.[39] Still, as portfolio returns increase monotonically from the first to the last portfolio, we expect the slope factor to be the most plausible candidate to account for the cross-sectional dispersion in short-term interest rates.[40]

We build two pricing factors to mimic the explanatory power of the first two principal components: a market factor representing the first principal component and our carry factor representing the second principal component. We define the market factor to be the average repo rate across the repo market universe that represents the average borrowing cost[41] and the carry factor to be the high-minus-low carry return that represents the cross-sectional dispersion in repo rates. We compute both factors net of transaction cost. The correlation of the first principal component with our market factor is 0.99, and the correlation of the second principal component with our carry factor is 0.93. We can say that the first principal component measures the collateral quality and convenience yield level, while the second principal component measures the difference in collateral quality and convenience yield.

[39] All repo rates have a common driver in the level of short-term interest rates, such as the monetary policy rate, and it is possible to form unbiased expectations about their short-term development (Longstaff, 2000). Repos are also less affected by risk and term premia, especially if they benefit from a safe market environment, as in our case. Consistent with our results, Lustig et al. (2011) show that the first principal component in the relatively more risky FX carry trade explains about 80% of the common variation in currency portfolio returns for developed countries.

[40] Our first two principal components measure most of the variation in short-term rates; there is very little variation that could be explained by other factors. Other term structure models also consider a convexity factor which is of less relevance in our setting due to the short-term nature of repos. Koijen et al. (2018) consider momentum; they use the return of the last 12 months, excluding the most recent month in their bond analysis, and find mixed results. Given that we are considering daily rates, momentum, as constructed over a longer time horizon, is not as relevant to our analysis.

[41] We compute the market factor as a volume-weighted average repo rate across the entire repo market, consistent with the methodology proposed by the European Money Market Institute (EMMI).

For our estimation, we employ the GMM estimation based on Hansen (1982).[42] The results of our asset pricing estimation are depicted in Table 2.5. Columns (1)–(8) report estimates of the factor loadings for the eight portfolios, while column (9) depicts estimates of the two factor premia.

Table 2.5: Factor analysis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8	GMM
a	-0.02^{***}	0.00	-0.01^{***}	-0.01^{***}	0.02^{***}	0.00	0.00	0.01^{**}	
	(-3.36)	(-1.64)	(-3.32)	(-2.85)	(4.92)	(0.47)	(0.35)	(2.23)	
β^{Market}	0.97^{***}	1.06^{***}	1.02^{***}	1.00^{***}	1.00^{***}	0.97^{***}	0.97^{***}	0.98^{***}	
	(95.16)	(107.00)	(99.65)	(103.44)	(200.84)	(175.77)	(119.01)	(124.48)	
β^{HML}	-0.80^{***}	-0.05^{***}	0.05^{***}	0.09^{***}	0.09^{***}	0.22^{***}	0.32^{***}	0.38^{***}	
	(-35.42)	(-6.04)	(6.01)	(10.15)	(6.97)	(31.43)	(37.39)	(38.36)	
λ^{Market}									-0.07
									(-1.52)
λ^{HML}									0.42^{***}
									(14.88)
N									14,960
Time periods									1,870
adj. R^2									98.42%
χ^2									44.13%

The table reports the factor loadings for the eight portfolios and estimates of the premia for the market factor and the carry factor estimated via the GMM approach. The GMM results are estimated jointly as part of a single, overidentified estimation. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Error terms are adjusted according to Newey and West (1987) with the optimal number of lags chosen using the Bartlett kernel. p-values of χ^2 tests are reported in percentage points. Data are daily and include GC and special repos of term type SN for the period 2010–2017.

Factor loadings

Columns (1)–(8) report the constants (a_n) and the slope coefficients (β_n^k). The slope coefficients for the market factor are essentially all equal to one for each portfolio, which confirms our expectation that the market factor explains the level of short-term interest rates. All estimates are highly statistically significant. The slope coefficients for the carry factor increase monotonically

[42] Details about the GMM methodology and the different moment conditions are in the online appendix. For the estimation, we consider repo rates (instead of excess returns) as the dependent variable since our market factor captures the interest rate level. The intercept in the time-series regression, therefore, does not need to be zero and thus cannot be interpreted as a measure of mispricing.

from −0.80 for the first portfolio to 0.38 for the last portfolio. The first two portfolios have betas that are negative and significant, while the other portfolios have betas that are positive and significant. Clearly, the results suggest that the carry factor explains the dispersion in short-term interest rates.

Factor premia

Column (9) reports the estimates of the premia for the market and the carry factor. The premium of the carry factor is highly statistically significant at a level of 0.42% per annum. This means that a portfolio with a sensitivity of one to the carry factor earns a premium of 0.42% per annum, consistent with the average level of the carry factor. The carry measures the expectation of the convenience yield difference between portfolios 1 and 8 at time t for the collateral assets swapped between time t+2 and t+3. The 0.42% carry premium, therefore, reflects the expected compensation for swapping assets in portfolio 1 and 8 over a one-year period. The market factor has a slightly negative price, consistent with the negative level of short-term interest rates during our sample period. The standard errors on the market factor are large, as it is the carry factor that explains most of the cross-sectional dispersion in short-term interest rates. As all portfolios have a beta close to one with respect to the market factor, the market factor essentially serves as a constant in the cross-sectional regressions. Hansen's J-test of the overidentifying restrictions shows that the null hypothesis that the over-identifying restrictions are valid cannot be rejected. The adj. R^2 proves that most of the development in short-term rates can be attributed to the market and the carry factor.[43]

We are confident that our approach of implementing a factor structure with a level and a slope component is an innovative yet intuitive way to capture the dynamics within the universe of short-term interest rates. Our results confirm the notion that a standard factor model with two pricing factors, a market factor and a carry factor, is able to explain the price of near-money assets: the market factor determines the level of short-term interest rates, while the carry factor accounts for the cross-sectional dispersion.

To ensure the robustness of our results, we perform the asset pricing esti-

[43]The adj. R^2 is relatively high, consistent with the nature of the repo market. Koijen et al. (2018), for example, document an R^2 of 89% when considering fixed income carries in bond markets.

Table 2.6: Summary of robustness tests for the asset pricing estimation

	(1) Baseline	(2) TN	(3) GC	(4) Special	(5) Broker Tec	(6) FMB
λ^{Market}	−0.07	−0.10**	0.03	−0.07*	−0.09**	−0.06
	(−1.52)	(−2.33)	(0.77)	(−1.66)	(−2.14)	(−1.00)
λ^{HML}	0.42***	0.39***	0.15***	0.42***	0.42***	0.41***
	(14.88)	(16.39)	(14.96)	(14.79)	(14.82)	(12.10)
N	14,960	14,960	14,960	14,960	14,960	14,960
Time periods	1,870	1,870	1,870	1,870	1,870	1,870
adj. R^2	98.42%	95.65%	98.83%	98.39%	98.16%	98.28%
χ^2	44.13%	49.04%	28.96%	34.54%	15.93%	–

The table reports the estimates of the premia for the market factor and the carry factor estimated via the GMM approach using different carries in columns (1) to (5) and the FMB approach in column (6). The GMM results are estimated jointly as part of a single, overidentified estimation. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Error terms are adjusted according to Newey and West (1987) with the optimal number of lags chosen using the Bartlett kernel. p-values of χ^2 tests for the GMM estimation are reported in percentage points. Data include (1 & 6) the baseline set-up presented in the paper using GC and special repos of term type SN, (2) GC and special repos of term type TN, (3) GC repos of term type TN, (4) special repos of term type SN, and (5) GC and special repos of term type SN which have been traded on the BrokerTec platform. Data are daily for the period 2010–2017.

mation separately for repos of term type TN, for GC respectively special repos, and for trades executed on the BrokerTec platform, as well as by employing the two-stage OLS estimation following Fama and MacBeth (1973). Table 2.6 summarizes the results of those estimations, which are fully consistent and show that our two factors are relevant for and apply to the entire repo market (detailed results are presented in the online appendix).

2.3 Economic determinants of convenience yield

The asset pricing analysis has shown that our carry factor helps explain the cross-sectional dispersion in short-term rates. Table 2.7 provides a different illustration of it. Column (1) reports the results of the panel regression of the return on the eight repo portfolios net of the EONIA on a constant, the carry factor ("Carry") interacted with dummies for the eight repo portfolios, and each portfolio's lagged repo rate ("Lagged rate"), column (2) shows the Wald (1943) test for statistical equality between the coefficients for portfolios 1 and 8.

By employing the portfolio returns net of the EONIA rate, we remove the level from our analysis and just focus on the cross-sectional dispersion.[44] The

[44]The EONIA rate is the main short-term interest rate benchmark and represents a

Table 2.7: Safe asset dimensions of portfolio returns net EONIA

	(1) Return net EONIA b/t								(2) Wald test Portf. 1 & 8 p/F		
Panel A	#Portf. 1	#Portf. 2	#Portf. 3	#Portf. 4	#Portf. 5	#Portf. 6	#Portf. 7	#Portf. 8			
										N	14,952
Carry	−0.329***	−0.106***	−0.081***	−0.068***	−0.052***	−0.026***	−0.001	0.018	0.000	adj. R^2	0.806
daily	(−4.26)	(−3.94)	(−3.74)	(−3.59)	(−3.45)	(−3.09)	(−0.19)	(1.58)	(17.57)	Constant	Yes
										Lagged rate	Yes
Panel B											
										N	248
Carry	−0.755***	−0.229***	−0.171***	−0.144***	−0.111***	−0.052**	0.007	0.053	0.000	adj. R^2	0.926
quarterly	(−7.33)	(−4.34)	(−3.72)	(−3.51)	(−3.87)	(−2.51)	(0.25)	(1.38)	(55.52)	Constant	Yes
										Lagged rate	Yes

Column (1) reports the results of the panel regression of the return on the eight repo portfolios net of the EONIA on a constant, the carry factor ("Carry") interacted with dummies for the eight repo portfolios, and each portfolio's lagged repo rate ("Lagged rate"). ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Standard errors are clustered at the portfolio-year level. Column (2) shows the Wald (1943) test for statistical equality between the coefficients for portfolios 1 and 8. The p-value and F-statistic in parentheses are reported. Data are daily in Panel A and quarterly in Panel B. The coefficients in the daily panel are smaller as more variation in portfolio returns is captured by the lagged rate. All data include GC and special repos of term type SN for the period 2010–2017.

results confirm our intuition from the asset pricing analysis: While the assets in the low-rate portfolio (with the highest convenience) have a negative loading towards our carry, the assets in the high-rate portfolio (with the lowest convenience) have a positive loading. The Wald test confirms that the coefficients for portfolios 1 and 8 are statistically different from one another.

Panel A shows the results at a daily frequency and Panel B at a quarterly frequency. The quarterly data are calculated as the average of the daily data during a quarter after removing end of month and end of ECB maintenance period trading days. This way, the quarterly carry captures average convenience yield movements on "normal" trading days. We choose the quarterly regression frequency for the subsequent analysis since some of the economic variables proposed in the literature to capture convenience yield are only published quarterly. This approach is in line with the existing literature on convenience yield (e.g., Krishnamurthy and Vissing-Jorgensen, 2012; Nagel, 2016).[45] In fact, the adj. R^2, which reflects how much of the individual repo rate variation is captured by our carry factor, is higher at a quarterly frequency which reflects the smaller impact of daily spikes or movements in rates. Overall, the results at a daily and quarterly level are consistent so that the main message does not

weighted average of all overnight unsecured transactions in the euro interbank market.

[45] For example, Krishnamurthy and Vissing-Jorgensen (2012) use data at an annual frequency to measure convenience yield, while Nagel (2016) uses monthly data since he focuses on two-year U.S. Treasury notes which are issued on a regular monthly auction cycle. In line with our approach, Nagel (2016) computes monthly averages for data available at a daily frequency.

change depending on the frequency chosen. In both panels, the sensitivity to the carry is strongest for the assets in the low-rate portfolio. This points towards the idea that the carry factor is mainly driven by those truly safe assets with the highest convenience yield and hence raises the question about the economic determinants embedded in it.

2.3.1 Safety and liquidity benefits

The safe asset literature outlines differences across (quasi-) safe assets that make them imperfect substitutes (Sunderam, 2015). Each asset carries a different convenience yield; our carry factor thus reflects a differential in convenience yield as truly safe assets (in the low-rate portfolio) carry a higher convenience than quasi-safe assets (in the high-rate portfolio). An asset's convenience yield stems from its safety and liquidity attributes. For instance, Gary Gorton writes, "the specialness of safe assets implies the existence of non-pecuniary returns (called the convenience yield), in the form of liquidity or moneyness (the money-like property of an asset taken at face value with no questions asked) and safety" (Gorton, 2017).

Krishnamurthy (2002) develops a theoretical model that determines the repo market equilibrium. In his framework, investors value the liquidity services provided by the on-the-run U.S. Treasury security more than those provided by its off-the-run counterpart so that the repo secured by the former is traded at a lower rate. Our analysis extends to a larger and more complex repo market that features collateral assets with various degrees of safety and liquidity attributes. In addition to different liquidity services coming from risk-free assets issued by the same country as in Krishnamurthy (2002), the repo rates in our context are determined by differing convenience yields of their collateral assets that vary in terms of the safety premium and the liquidity premium, which in turn is determined by the scarcity of collateral assets (Krishnamurthy and Vissing-Jorgensen, 2012) and the opportunity cost (Nagel, 2016). Broadening the existing literature on convenience yield that largely concerns U.S. Treasuries, our euro (single currency) setting encompasses government bonds perceived as truly safe assets with high convenience yield and other government bonds with lower convenience yield perceived as quasi-safe assets.

Based on this understanding, three hypotheses about the economic determi-

nants of convenience yield can be brought forward: The first hypothesis is that the convenience yield of truly safe assets increases in the safety premium. In the case of secured debt instruments such as repos, heterogeneity in the safety premia depends on the collateral quality and risk. For government bonds, the primary source of risk stems from sovereign debt fragility and instability. If an asset is truly safe, it is "information insensitive" since economic agents have no reason to produce private information on fundamental risk and are not exposed to adverse selection (e.g., Gorton and Pennacchi, 1990; Dang et al., 2010; Gorton and Ordonez, 2014; Dang et al., 2017). In contrast, a larger public debt creates policy uncertainty, which raises default risk premia (Liu et al., 2021) so that collateral quality deteriorates with weak sovereign resources (He et al., 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. An increase in the perceived sovereign risk of quasi-safe assets relative to the overall risk levels in the economy leads to a weaker demand for those quasi-safe assets and a higher demand for assets such as German Bunds that remain safe even in flight-to-safety episodes such as the European sovereign debt crisis. Thus, truly safe assets feature the highest demand and convenience yield, in particular during periods of uncertainty.

The next two hypotheses refer to the liquidity premium. The second hypothesis postulates that the liquidity premium and thus the convenience of truly safe assets increases in their scarcity. A repo's liquidity premium stems from the liquidity benefits provided by the collateral asset. High-quality sovereign bonds are money-like instruments that provide stable fungibility and high (re-)pledgeability, whereas the liquidity services of quasi-safe (sovereign) assets are more unstable (Gorton and Metrick, 2012). The scarcer the safe assets, the more agents are willing to pay a premium for their liquidity services (Krishnamurthy and Vissing-Jorgensen, 2012). An increase in the relative scarcity of truly safe assets, therefore, leads to a lower repo supply of those scarce assets and thus a higher convenience yield.

The third hypothesis puts forward that the liquidity premium and thus the convenience yield of truly safe assets increases with the opportunity cost of holding money. Nagel (2016) shows that the liquidity premium increases with the level of short-term interest rates. If near-money assets are perfect

substitutes, their liquidity premia would perfectly correlate with the level of the short-term interest rate. If not, as we expect to be the case in the euro area context, heterogeneous effects would arise since safe assets providing more utility are more sensitive to the opportunity cost, and the liquidity premium also depends on the supply of safe assets. More specifically, controlling for asset supply, the liquidity premium of repos backed by assets that provide higher liquidity benefits should increase more with the opportunity cost.

We illustrate these mechanisms in a simple supply- and demand-framework which builds on Krishnamurthy (2002) as shown in the online appendix.

2.3.2 Safe asset dimensions of convenience yield

To test the empirical predictions, we follow the literature to build our empirical measures of convenience yield. Our main variable to capture risk reflecting the safety premium is the difference in 10-year CDS prices between the countries forming portfolio 8 (high rates) and portfolio 1 (low rates), weighted by the respective shares of the countries in each portfolio. In the spirit of Krishnamurthy and Vissing-Jorgensen (2012), we capture collateral asset supply by computing the difference in the log of the ratio of the face value of short-term debt to GDP between the countries forming portfolio 8 (high rates) and portfolio 1 (low rates), weighted by the respective shares of the countries in each portfolio.[46] The opportunity cost is measured via the main euro area short-term interest rate benchmark EONIA.[47]

We begin our empirical analysis by examining how the different economic determinants of convenience yield explain the return on the eight repo portfolios. To do so, we replace the carry factor with the different economic variables capturing the various aspects of convenience yield. More precisely, column (1)

[46] We consider short-term debt since it is a purer measure of near-money liquidity services than the overall debt level. Short-term debt includes all government securities issued with an original maturity of up to one year. We use static weights (i.e., the average share of a country in a portfolio over the sample) for the CDS price measure, while we use dynamic weights (i.e., the average share of a country in a portfolio during a quarter) for the short-term debt-to-GDP ratio. Sovereign credit risk is a dynamic measure that is available at a high frequency, while sovereign debt and GDP are static measures that are published less frequently. While we are confident that this approach best captures the economic determinants embedded in our carry factor, we show that the results are robust to a change in the weighting scheme.

[47] We expect the differential in the liquidity premium between assets in the high- and low-rate portfolio to be correlated with the level of interest rates. In an interpretation of the model of Nagel (2016), the correlation would be perfect as the model abstracts from risk and assumes certain model parameters to be constant (e.g., asset supply).

Table 2.8: Safe asset dimensions of portfolio returns

	(1) Return Portfolio b/t								(2) Wald test Portf. 1 & 8 p/F
	#Portf. 1	#Portf. 2	#Portf. 3	#Portf. 4	#Portf. 5	#Portf. 6	#Portf. 7	#Portf. 8	
CDS	−0.381**	−0.016	−0.021	−0.044**	−0.055***	−0.036	−0.011	−0.005	0.025
	(−2.64)	(−0.75)	(−1.08)	(−2.51)	(−3.59)	(−0.75)	(−0.17)	(−0.06)	(5.28)
Asset supply	−0.296	−0.322***	−0.222***	−0.136**	−0.072	−0.030	−0.002	0.042	0.138
	(−1.67)	(−4.94)	(−3.78)	(−2.58)	(−1.45)	(−0.37)	(−0.02)	(0.35)	(2.25)
Opportunity cost	0.490***	0.815***	0.828***	0.832***	0.843***	0.862***	0.890***	0.927***	0.000
	(9.10)	(21.01)	(21.58)	(21.86)	(22.49)	(22.71)	(22.65)	(22.36)	(67.90)
N	248								
adj. R^2	0.981								
Arbitrage deviation	Yes								
Lagged rate	Yes								

Column (1) reports the results of the panel regression of the return on the eight repo portfolios on the static weighted CDS price difference between portfolios 8 and 1 ("CDS"), the dynamic weighted difference in the log of the ratio of short-term debt to GDP between portfolios 8 and 1 ("Asset supply"), the EONIA rate ("Opportunity cost"), all variables interacted with dummies for the eight repo portfolios, as well as the absolute U.S. dollar euro CIP deviations ("Arbitrage deviation") and each portfolio's lagged repo rate ("Lagged rate"). ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Standard errors are clustered at the portfolio-year level. Column (2) shows the Wald (1943) test for statistical equality between the coefficients for portfolios 1 and 8. The p-value and F-statistic in parentheses are reported. Data are quarterly and include GC and special repos of term type SN for the period 2010–2017.

in Table 2.8 reports the results of the panel regression of the return on the eight repo portfolios on the CDS price difference between portfolios 8 and 1 ("CDS"), the difference in the log of the ratio of short-term debt to GDP between portfolios 8 and 1 ("Asset supply"), and the EONIA rate ("Opportunity cost"), all variables interacted with dummies for the eight repo portfolios, as well as the absolute U.S. dollar euro CIP deviations ("Arbitrage deviation") and each portfolio's lagged repo rate ("Lagged rate") as controls.[48] Column (2) adds the Wald test for the coefficients of portfolios 1 and 8.

Three main results emerge. First, portfolio 1 has a negative loading towards our risk measure, while portfolio 8's loading is close to zero and not significant. For example, a one-percentage point increase in our risk measure leads to a decrease in the rates of portfolio 1 by 38 basis points. This result speaks to the safety benefits of truly safe assets in portfolio 1, in particular during flight-to-safety periods. Once the CDS difference between the assets in portfolio 1 and 8

[48] We control for market frictions and arbitrage constraints, which can be particularly relevant in flight-to-quality periods (Longstaff, 2004), by computing deviations from the covered interest parity (CIP basis) as short-term interest rates are interconnected with FX rates (Du et al., 2018a,b; Ranaldo et al., 2021; Jiang et al., 2021). We compute the absolute CIP basis between the U.S. dollar and the euro in percentage points using the one-month London interbank offered rate (Libor).

increases, the repo rates for portfolio 1 fall since investors prefer to hold those truly safe assets during moments of uncertainty. At the same time, the rates for assets in portfolio 8 do not increase significantly, which is at odds with the systemic risk hypothesis (Boissel et al., 2017). This reinforces our explanation that the European repo market is a quintessential safe environment in which investors value the safety benefits of truly safe assets in portfolio 1 as opposed to requiring compensation for the higher risk of quasi-safe assets in portfolio 8.

Second, the repo rates on the assets in portfolio 1 tend to be lower once truly safe assets become scarcer. A one-percentage-point increase in the debt to GDP difference between portfolios 1 and 8 (i.e., a relative increase in the scarcity of truly safe assets) leads to a decrease in the rates of portfolio 1 by 30 basis points. The loadings for portfolio 8 tend to be close to zero. And third, portfolio 1 has the lowest loading on the opportunity cost at 0.49, while portfolio 8 has the highest loading, close to one. This result is in line with the idea that assets in the first portfolio carry a higher liquidity premium. More specifically, when the benchmark interest rate increases, two effects occur simultaneously: (i) the overall repo rate level increases, and (ii) the liquidity premium increases in line with Nagel (2016). An increase in the liquidity premium reduces short-term rates and thus goes in a different direction than the overall increase in levels. The weaker response of portfolio 1 to an opportunity cost increase, therefore, reflects the larger retention of the liquidity premium inherent in truly safe assets. Thus, a lower loading towards the opportunity cost reveals the larger liquidity value attributed by investors to the underlying assets. In this set-up, where we account for asset supply and opportunity cost as the two potential components of the liquidity premium, the asset supply variable is not significant for truly safe assets in portfolio 1. This suggests the prevailing effect of the opportunity cost of holding money in shaping the liquidity premium, which corroborates previous findings (Nagel, 2016).

The results in Table 2.8 suggest that the low-rate portfolio inherits the safety and liquidity benefits of truly safe assets while the high-rate portfolio's return is less sensitive to changes in the safety and liquidity premia of quasi-safe assets. The results also suggest that the carry factor is driven by the same determinants, predominantly by the repos in portfolio 1. This conjecture can also be visualized: Figure 2.7 graphs portfolio 1 and 8's repo returns (Figure 2.7a) and the carry factor (Figure 2.7b) against the "CDS" variable, while

(a) Portfolio returns against risk **(b)** Carry factor against risk

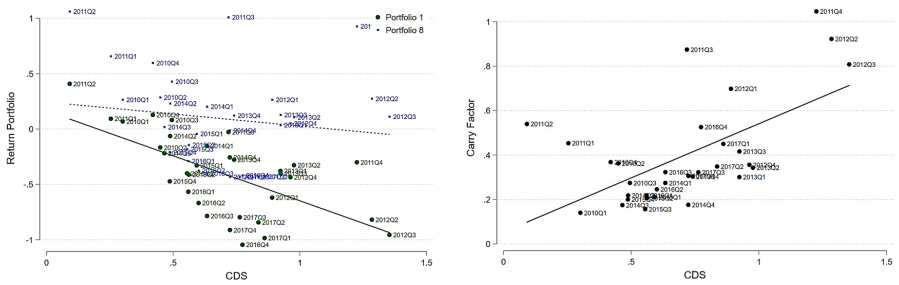

Figure 2.7a depicts the scatter plot of portfolio 1 and 8's repo returns against the difference in the CDS prices ("CDS"), while Figure 2.7b depicts the scatter plot of the carry factor against the CDS variable.

Figure 2.7: Scatter plot for safety premium

(a) Portfolio returns against opportunity cost **(b)** Carry factor against opportunity cost

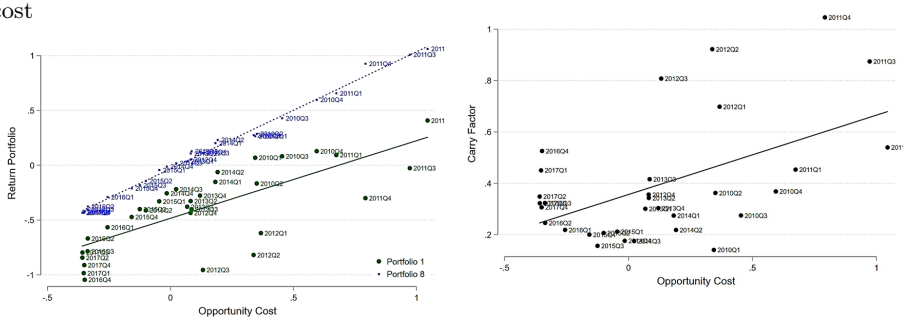

Figure 2.8a depicts the scatter plot of portfolio 1 and 8's repo returns against the EONIA ("Opportunity Cost"), while Figure 2.8b depicts the scatter plot of the carry factor against the opportunity cost variable.

Figure 2.8: Scatter plot for liquidity premium

Figure 2.8 graphs portfolio 1 and 8's repo returns (Figure 2.8a) and the carry factor (Figure 2.8b) against the "Opportunity Cost" variable. Both figures provide evidence for the convenience benefits of truly safe assets in portfolio 1 relative to quasi-safe assets in portfolio 8. When the risk of assets in portfolio 1 is low compared to assets in portfolio 8 (i.e., a high value of our risk measure using the CDS), investors value the safety benefits of truly safe assets, and their repo rates are lower (i.e., the carry factor is higher). Similarly, when the opportunity cost is high (i.e., a high value of the EONIA rate), investors value the liquidity benefits of the assets in portfolio 1 more, again reflected in their repo rates being lower (i.e., the carry factor being higher).

To substantiate these results, we relate our carry factor to the different economic determinants embedded in convenience yields. For this, we perform a set of time-series regressions to explain our carry return (instead of portfolio returns) using the same regressors as in the previous regression analysis (i.e., "CDS," "Asset supply," "Opportunity cost," "Arbitrage deviation," and now "Lagged carry"). In contrast to the repo portfolio returns, the carry factor only accounts for the cross-sectional dispersion in short-term rates. The results are shown in Table 2.9. Columns (1)–(3) report the results for the univariate time-series regressions, while column (4) reports those for the multivariate regression, which also accounts for arbitrage deviations and the lagged carry factor.

Three main results emerge. First, the carry factor significantly increases in risk, providing empirical support for the safety premium hypothesis. In the multivariate setting (4), a one-percentage-point increase in the CDS prices of portfolio 8 relative to those of portfolio 1 is associated with an increase in our carry factor of 40 basis points. Second, we find a positive relationship between our carry factor and the relative scarcity of assets in portfolio 1. A one-percentage-point increase in the difference in the log of the ratio of short-term debt to GDP between portfolios 8 and 1 is accompanied by an increase in our carry factor of 28 basis points. And third, the carry factor significantly increases with the opportunity cost of holding money, consistent with the imperfect substitutability of near-money assets. A one-percentage-point increase in the EONIA rate is associated with an increase in our carry factor of 45 basis points. In line with the portfolio results, when both liquidity variables capturing opportunity cost and asset scarcity are included in the encompassing

Table 2.9: Safe asset dimensions of carry factor

	(1) Carry b/t	(2) Carry b/t	(3) Carry b/t	(4) Carry b/t	(5) Carry b/t	(6) Carry b/t
CDS	0.526***			0.403***		0.396***
	(5.60)			(4.37)		(4.14)
Asset supply		0.638***		0.278		0.268
		(3.09)		(1.66)		(1.55)
Opportunity cost			0.355**	0.447***		0.415***
			(2.33)	(5.42)		(3.66)
Repo liquidity					−1.033***	−0.134
					(−3.32)	(−0.40)
N	31	31	31	30	31	30
adj. R^2	0.503	0.222	0.129	0.733	0.250	0.725
Arbitrage deviation	No	No	No	Yes	No	Yes
Lagged carry	No	No	No	Yes	No	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the results of the time-series regressions of our carry factor on a constant, the static weighted CDS price difference between portfolios 8 and 1 ("CDS"), the dynamic weighted difference in the log of the ratio of short-term debt to GDP between portfolios 8 and 1 ("Asset supply"), the EONIA rate ("Opportunity cost"), the static weighted difference in the log of the ratio of repo volume to debt between portfolios 8 and 1 ("Repo liquidity"), the absolute U.S. dollar euro CIP deviations ("Arbitrage deviation"), and the lagged carry factor ("Lagged carry"). ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Error terms are adjusted according to Cochrane and Orcutt (1949), following Wooldridge (2015). Data are quarterly and include GC and special repos of term type SN for the period 2010–2017.

specification (column 4), only the former remains significant driving away the explanatory power of the latter.[49]

In addition, the liquidity premium may not only originate from the collateral asset but also from the repo itself. To capture the repo supply, we compute the difference in the log of the ratio of repo volume to debt between the countries forming portfolio 8 (high rates) and portfolio 1 (low rates), weighted by the respective shares of the countries in each portfolio ("Repo liquidity"). Column (5) considers the repo liquidity variable in a univariate setting, while column (6) combines it with the previous convenience measures, including the supply of the collateral assets.

We expect the repo volume of quasi-safe assets (in portfolio 8) relative to truly safe assets (in portfolio 1) to decrease and the carry factor to rise with uncertainty and market stress. As the repo is produced by financial firms, this result would be consistent with the idea of a "fragile liquidity transformation" (Moreira and Savov, 2017) that shrinks when financial institutions deleverage (Stein, 2012) or experience funding strains and losses in long-term and illiquid investments (Krishnamurthy and Vissing-Jorgensen, 2015). As expected, in the univariate setting (5), an increase in the difference in the log of the ratio of lending volume to debt between portfolios 8 and 1 is accompanied by a decrease in our carry factor. This result highlights that a decrease in the production of quasi-safe assets relative to truly safe assets is accompanied by an increase in the liquidity premium, as reflected by an increase in the carry factor. However, in the multivariate setting (6), the repo supply measure loses its significance; this is consistent with the previous results for asset supply and reinforces the idea developed in this paper that the part of the convenience yield attributable to the liquidity premium is captured by the opportunity cost of holding money.

To validate our results, we perform a number of additional tests. First, we conduct various subsampling analyses, which clearly show that our main results hold if we only consider repos of the TN term type, GC and special repo transactions separately, and trades executed on the BrokerTec platform. The corresponding results are shown in columns (2)–(5) in Table 2.10. This shows the general validity of our results and confirms that, for example, "specialness" and segmentation cannot be the sole drivers of our carry factor. Second, column

[49]The partial variance decomposition, as well as the Shapley R^2, suggest that, in line with our results, our risk variable and the opportunity cost have the largest explanatory power.

Table 2.10: Summary of robustness tests for economic analysis

	(1) Baseline b/t	(2) TN b/t	(3) GC b/t	(4) Special b/t	(5) BrokerTec b/t	(6) Bond b/t
CDS	0.403***	0.374***	0.025	0.393***	0.485***	0.232**
	(4.37)	(4.77)	(1.21)	(4.25)	(4.43)	(2.51)
Asset supply	0.278	0.250*	0.175**	0.297*	0.111	−0.010
	(1.66)	(1.97)	(2.60)	(1.77)	(0.65)	(−0.06)
Opportunity cost	0.447***	0.324***	0.246***	0.437***	0.428***	0.133**
	(5.42)	(5.15)	(5.41)	(5.38)	(4.52)	(2.10)
N	30	30	30	30	30	30
adj. R^2	0.733	0.775	0.809	0.732	0.694	0.374
Arbitrage deviation	Yes	Yes	Yes	Yes	Yes	Yes
Lagged carry	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the results of the time-series regressions of our carry factor on a constant, the static weighted CDS price difference between portfolios 8 and 1 ("CDS"), the dynamic weighted difference in the log of the ratio of short-term debt to GDP between portfolios 8 and 1 ("Asset supply"), the EONIA rate ("Opportunity cost"), the absolute U.S. dollar Euro CIP deviations respectively the government bond OIS spread for Germany in column (6) ("Arbitrage deviation"), and the lagged carry factor ("Lagged carry"). ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Error terms are adjusted according to Cochrane and Orcutt (1949), following Wooldridge (2015). Data include (1) the baseline set-up presented in the paper using GC and special repos of term type SN, (2) GC and special repos of term type TN, (3) GC repos of term type TN, (4) special repos of term type SN, (5) GC and special repos of term type SN which have been traded on the BrokerTec platform, and (6) the baseline carry including the bond return using the Buy-and-Sell approach. Data are quarterly for the period 2010–2017.

(6) shows that our results are consistent if we employ the repo carry including the bond return. Interestingly, the explanatory power of the different economic determinants of convenience yield is lower in this set-up, which reinforces our interpretation that the repo carry is a more precise measure of convenience yield movements. And third, we provide additional robustness checks on different measures of convenience yield in the online appendix. There, we also account for ECB purchases under the public sector purchase program (PSPP). In contrast to the asset supply measure, PSPP purchases retain their significance in the multivariate setting. The results show that when the ECB purchases relatively more assets in portfolio 1 compared to portfolio 8 (i.e., the scarcity of assets in portfolio 1 increases), the carry also increases. This is consistent with the notion that the convenience yield stems from the collateral asset whose

scarcity is impacted more by QE purchases than by variations in the overall issuance volumes.

In sum, all the analyses carried out indicate that the convenience yield embedded in our carry factor increases with (i) the safety premium and (ii) the liquidity premium.

2.3.3 Interaction of sovereign default risk and the liquidity premium

Another interesting aspect is understanding how the liquidity premium interacts with sovereign default risk. For this, we consider the within-country dispersion in short-term rates. This within-country dispersion only relates to differences in the liquidity premium since the sovereign risk is the same across all bonds of a given country. We, therefore, assess the explanatory power of our carry factor for the within-country dispersion in rates.

Inspired by Eisenschmidt et al. (2020), we calculate each country's interquartile range as the difference between the 25th and 75th percentile repo rate ("Repo dispersion"). Table 2.11 reports the results of the panel regression of each country's repo dispersion on the country's CDS price ("CDS"), the carry factor ("Carry"), the interaction of the carry factor with a dummy variable for each country that is one if a country's CDS price is above the average CDS price for that country during the sample period ("Carry x High CDS"), all variables interacted with dummies for the different countries, and the lagged carry factor ("Lagged carry"). We return to a daily regression frequency as all variables change on a daily basis.

The results show that the repo dispersion increases in the carry factor. This points towards a dispersion in repo rates related to within-country differences in the liquidity premium. The significance and economic magnitude of the carry factor for explaining within-country rate dispersion is highest for truly safe assets such as Germany and decreases in the sovereign riskiness. For example, a one-percentage-point increase in the carry factor is accompanied by an increase in Germany's repo rate dispersion of 32 basis points (compared to 9 basis points for Italy). This means that for quasi-safe countries with a higher sovereign risk, the within-country dispersion in liquidity benefits and thus repo rates is lower.

During flight-to-safety periods, such as during the European sovereign debt crisis, the explanatory power of the carry factor for the rate dispersion in safe

Table 2.11: Explanatory power of the carry factor

	(1) Repo dispersion b/t						
	#DE	#NL	#AT	#FI	#BE	#ES	#IT
CDS	−0.065**	−0.038	−0.024	−0.035	−0.020	0.031***	−0.002
	(−2.12)	(−1.58)	(−1.66)	(−1.44)	(−1.67)	(5.27)	(−0.60)
Carry	0.319***	0.142**	0.094**	0.141***	0.167***	0.095***	0.092***
	(4.19)	(2.12)	(2.30)	(2.97)	(3.93)	(4.08)	(4.82)
Carry # High CDS	−0.225***	−0.083**	−0.043*	−0.090**	−0.112***	−0.054	−0.024
	(−4.19)	(−2.44)	(−1.73)	(−2.47)	(−3.31)	(−1.43)	(−0.85)
N	12,946						
adj. R^2	0.412						
Lagged carry	Yes						

The table reports the results of the panel regression of the repo rate dispersion defined as a country's difference between the 25th and 75th percentile repo rate on the country's CDS price ("CDS"), the carry factor ("Carry") as well as the interaction of the carry factor with a dummy variable for each country that is one if a country's CDS price is above the average CDS price for that country during the observation period ("Carry x High CDS"), all variables interacted with dummies for the different countries, and the lagged carry factor ("Lagged Carry"). ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Standard errors are clustered at the country-year level. We exclude Irish and Portuguese repos since they have been traded infrequently during part of our sample period. Data are daily and include GC and special repos of term type SN for the period 2010–2017.

collateral assets goes, however, down. This points towards smaller differences in the liquidity premium of truly safe assets during those periods when safety attributes gain in importance. This is consistent with the intuition obtained from our portfolio results. When uncertainty increases, such as during the European sovereign debt crisis, truly safe assets feature the highest demand and convenience yield. This means that during such flight-to-safety periods, all German bonds are considered to be convenient, and the highly valued safety benefits (of all German bonds) outweigh differences in liquidity benefits, leading to a lower repo rate dispersion. This can also be seen in Figure 2.9 which graphs Germany's (green line) and Italy's (blue line) repo rate dispersion against the carry factor. The line for Germany is broken down into two periods. During the European sovereign debt crisis (the periods on the right), there was little dispersion in German repo rates (i.e., all German collateral assets are consid-

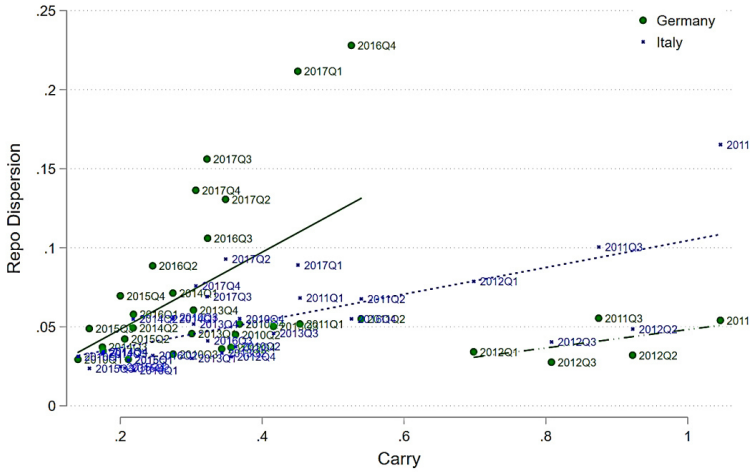

Figure 2.9: Scatter plot of Germany's and Italy's repo rate dispersion against the carry factor. The lower right dashed line refers to German repo rates during the European sovereign debt crisis.

ered to be safe). However, during the other low-risk periods, the carry factor tends to reflect repo rate dispersion within safe countries like Germany as it captures differences in the liquidity premium.

2.3.4 Convenience premium and asset prices

As a final step, we relate our repo factors, in particular the carry factor, to a broader class of asset returns. Specifically, we analyze whether the two repo pricing factors help explain the cross-section of bond returns after accounting for the standard bond pricing factors and measures of bond safety and liquidity.

For this, we consider the cross-section of European sovereign bonds that are posted as repo collateral. Our dependent variable is the Nelson-Siegel residual of the daily log return of bond i at time t.[50] We relate the unexplained part of the bond yield to our two repo factors, and we control for bond safety (i.e., log of the CDS spread of the sovereign issuer) and bond liquidity (i.e., log of the relative bid-ask spread). We interact the carry factor with country dummies to

[50]The Nelson-Siegel residual is calculated as the difference between the daily log return of bond i at time t and the log return of bond i at time t implied by the Nelson and Siegel (1987) model estimated via German government bonds.

Table 2.12: Convenience premium and bond prices

	(1) NS Residual b/t	(2) NS Residual b/t	(3) NS Residual b/t	(4) NS Residual b/t
Repo carry factor #				
Germany	−0.000	−0.001**		−0.014***
	(−1.455)	(−2.098)		(−5.220)
Netherlands	0.001***	0.000		−0.013***
	(8.969)	(0.769)		(−4.702)
Austria	0.006***	0.005***		−0.011***
	(40.370)	(10.547)		(−3.564)
Finland	0.002***	0.001***		−0.009***
	(48.842)	(5.093)		(−4.134)
Belgium	0.011***	0.011***		−0.007*
	(7.324)	(7.802)		(−1.903)
Spain	0.023***	0.022***		0.006*
	(42.696)	(23.248)		(1.873)
Italy	0.024***	0.023***		0.008**
	(29.424)	(27.561)		(2.572)
Ireland	0.044***	0.043***		0.018***
	(102.088)	(137.568)		(3.659)
Portugal	0.083***	0.082***		0.057***
	(15.115)	(14.968)		(8.752)
Repo market factor		0.007***		0.000
		(2.961)		(0.298)
Bond CDS			0.013***	0.012***
			(3.836)	(4.434)
Bond bid-ask spread			0.004***	0.003***
			(4.494)	(5.513)
N	560,784	560,784	560,782	560,782
adj. R^2	0.684	0.703	0.734	0.813
Bond FE	Yes	Yes	Yes	Yes

The table reports the results explaining the return on a cross-section of European sovereign bonds. The dependent variable is the Nelson-Siegel residual of the log return of bond i at time t. The Nelson-Siegel residual is defined as the difference between the log return of bond i at time t and the log return of bond i at time t implied by the Nelson-Siegel model estimated via German government bonds. The market and carry factors are the two repo pricing factors. Bond CDS denotes the log of the CDS spread, and bond bid-ask spread denotes the log of the relative bid-ask spread. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. All regressions include bond fixed effects and standard errors clustered at the maturity bucket-country level. Bonds are grouped into four different maturity buckets, with the remaining time to maturity being (i) less than one year, (ii) one to five years, (iii) five to ten years, and (iv) more than ten years. Data are daily for zero and fixed-coupon bonds for the period 2010–2017.

analyze the different sensitivities of low-risk countries and high-risk countries to the carry. Table 2.12 reports the results of our panel regression. Column (1) shows the regression results of the Nelson-Siegel residual on the repo carry factor interacted with country dummies; column (2) adds our repo market

factor; column (3) includes our measures for bond safety and liquidity alone; column (4) combines our two repo factors with our measures for bond safety and liquidity.

Column (1) confirms that our carry factor contains information for bond pricing. Countries with a strong and resilient economy have a slightly negative loading towards our carry factor, while countries with a weak and vulnerable economy have a positive loading. Column (2) adds our repo market factor. The market factor accounts for part of the Nelson-Siegel implied bond yield level and positively relates to the Nelson-Siegel residual. Column (3) confirms that both of our measures of bond safety and liquidity are positively related to the Nelson-Siegel residual, i.e., bonds issued by countries with a higher credit risk and more illiquid bonds carry a higher yield (lower price) than the ones estimated via (safe and liquid) German government bonds. Both factors account for a sizable increase in the R^2, and their inclusion reduces the high t-statistics in columns (1) and (2), which confirms that they serve as effective control variables. Column (4) shows that our carry factor has explanatory power for bond pricing even after accounting for standard bond pricing factors. The carry captures the cross-sectional variation in the convenience yield that is reflected in bond yields. For example, an increase in our carry is accompanied by lower yields on German government bonds (reflected in a lower Nelson-Siegel residual) as opposed to higher yields on Italian bonds (reflected in a higher Nelson-Siegel residual). In economic terms, a one-basis-point increase in our carry implies a decrease (increase) in the Nelson-Siegel residual for German (Italian) government bond yields of 1.4 basis points (0.8 basis points). The R^2 increases by about 8% compared to regression (3) which confirms the statistical relevance of our carry factor.

Figures 2.10 and 2.11 provide visual evidence of the link between our repo carry factor and the bond return. Figure 2.10 plots our repo carry factor (green line) and the first PCA of the unexplained part of the bond return, i.e., unexplained by the Nelson-Siegel model and by our measures of bond safety and liquidity (dashed red line). Clearly, the two time-series comove. Figure 2.11 shows a scatter plot of each country's loadings towards the carry factor and towards the first PCA of the unexplained part of the bond return. In line with our regression results, truly safe assets have a negative loading towards the carry factor and the bond PCA, while quasi-safe assets have a positive

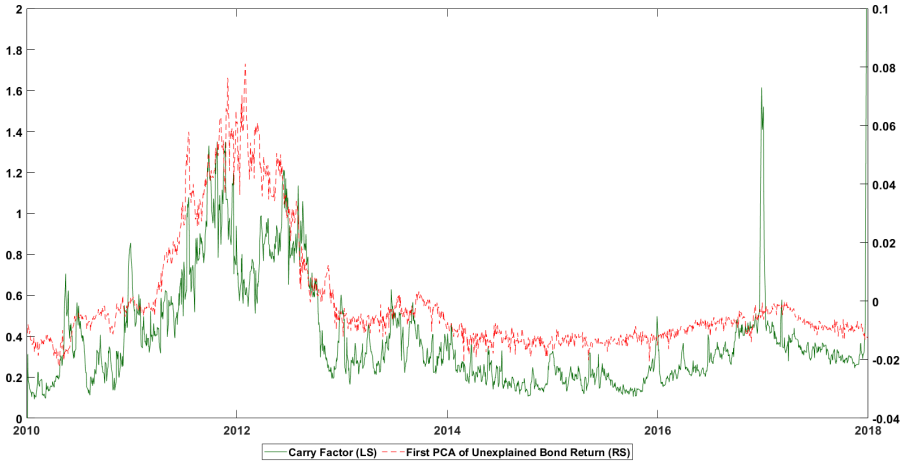

Figure 2.10: Carry factor and first PCA of unexplained bond return

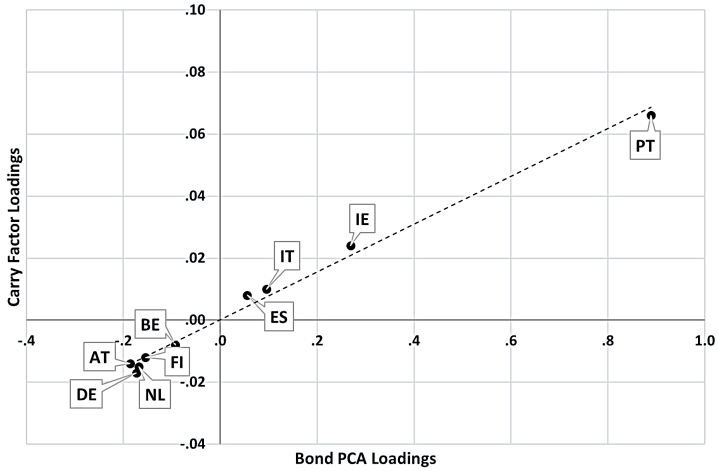

Figure 2.11: Scatter plot of each country's loadings on the carry factor and on the first PCA of the unexplained part of the bond return

loading.

Our results highlight that the two repo factors, in particular, the carry factor, have external relevance for pricing other asset classes. As we have shown in our economic analysis, the carry factor is a timely proxy for safety and liquidity benefits. These bond pricing results reveal that our near-money carry factor contains additional information about the cross-sectional variation in the convenience yield provided by long-term government bonds beyond standard bond pricing factors. Thus, our carry factor seems to capture the convenience services of a bond, such as the safety premium and the short-term funding ability.[51] The advantages of our factors include the high frequency at which they are measured and their timeliness which makes them suitable to capture, for example, the impact of monetary policy decisions.

2.4 Conclusion

We provide the first systematic asset pricing analysis of one of the main categories of safe assets, the repurchase agreement. Heterogeneity in repo rates is present within and across euro area countries. By going long in a portfolio consisting of repos with the highest rates while shorting a portfolio consisting of repos with the lowest rates, we create a carry trade that represents a collateral swap. The return on this carry trade, our carry factor, together with a market factor, is able to explain the price of near-money assets within a linear factor model: while the market factor determines the level of short-term interest rates, the carry factor accounts for the cross-sectional dispersion. Consistent with the safe asset literature, we rationalize the dispersion in repo rates captured by our carry factor with the idea that market participants value the different convenience premia embedded in truly and quasi-safe collateral assets. We provide empirical evidence that our carry factor is explained by the safety and liquidity premia.

Our results shed new light on the dynamics of the main short-term funding market, which is key for an efficient allocation of liquidity and assets, the implementation of monetary policy, as well as financial stability. We show that

[51] For example, a German government bond and a German agency bond have the same sovereign default risk; still, a German government bond is likely to carry a higher safety premium. The carry factor also captures funding aspects such as an asset's fungibility and (re-)pledgeability.

the two repo pricing factors explain the price variation of European repos and help explain that of European bonds. Future research could apply our approach to other repo markets, including the one in the United States, and investigate whether the repo carry factor has pricing implications for other asset classes such as equities and foreign exchange.

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Online appendix

OA2.1 Carry factor and repo pricing

Portfolio transition matrix

Table OA2.1.1: Portfolio transition matrix

		Portfolio today							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Portfolio yesterday	**1**	82.1%	13.3%	1.5%	0.7%	1.4%	0.5%	0.2%	0.2%
	2	12.5%	59.1%	17.8%	4.0%	4.4%	1.4%	0.5%	0.3%
	3	1.7%	16.3%	48.3%	20.1%	10.6%	2.0%	0.6%	0.3%
	4	0.7%	3.4%	17.0%	40.0%	34.2%	3.4%	0.9%	0.3%
	5	0.5%	1.5%	3.6%	13.3%	68.0%	10.7%	1.8%	0.6%
	6	0.5%	1.3%	1.9%	3.4%	27.2%	46.2%	16.1%	3.4%
	7	0.2%	0.6%	0.7%	1.1%	5.4%	17.7%	54.0%	20.4%
	8	0.2%	0.3%	0.4%	0.4%	1.7%	3.9%	20.6%	72.5%

The table reports the likelihoods of bonds in yesterday's portfolios n=1, 2,...,8 to be in today's portfolios n=1, 2,...,8. Data are daily and include GC and special repos of term type SN for the period 2010–2017.

Summary statistics of the carry for a different number of portfolios

Table OA2.1.2: Carry return (%): Eight portfolios

Year	Baseline	TN	GC	Special	Broker Tec	Quarterly sorting
2010	0.29	0.30	0.14	0.29	0.28	0.29
2011	0.73	0.66	0.37	0.72	0.75	0.73
2012	0.70	0.57	0.16	0.71	0.74	0.70
2013	0.34	0.31	0.09	0.35	0.35	0.35
2014	0.21	0.20	0.10	0.21	0.21	0.21
2015	0.19	0.16	0.07	0.19	0.19	0.19
2016	0.33	0.30	0.13	0.33	0.33	0.33
2017	0.36	0.34	0.12	0.36	0.36	0.36
avg.	**0.39**	**0.35**	**0.14**	**0.39**	**0.40**	**0.39**

The table shows the average annualized carry return by year of a carry trade strategy which goes long in repos with the highest rate (via a reverse repo) while shorting the repos with the lowest rate (via a repo). The results are broken down for forming eight daily portfolios. Data include (1) the baseline set-up presented in the paper using GC and special repos of term type SN, (2) GC and special repos of term type TN, (3) GC repos of term type TN, (4) special repos of term type SN, (5) GC and special repos of term type SN which have been traded on the BrokerTec platform, as well as (6) our baseline results with quarterly sorting at the first trading day of the quarter, after which portfolio weights apply for the entire quarter. Data are daily for the period 2010–2017.

Table OA2.1.3: Carry return (%): Four portfolios

Year	Baseline	TN	GC	Special	Broker Tec
2010	0.17	0.18	0.08	0.17	0.16
2011	0.46	0.43	0.30	0.46	0.45
2012	0.40	0.33	0.14	0.41	0.41
2013	0.21	0.19	0.07	0.21	0.21
2014	0.14	0.13	0.07	0.14	0.14
2015	0.13	0.12	0.06	0.13	0.13
2016	0.25	0.23	0.12	0.25	0.25
2017	0.26	0.25	0.10	0.26	0.26
avg.	**0.25**	**0.23**	**0.12**	**0.25**	**0.25**

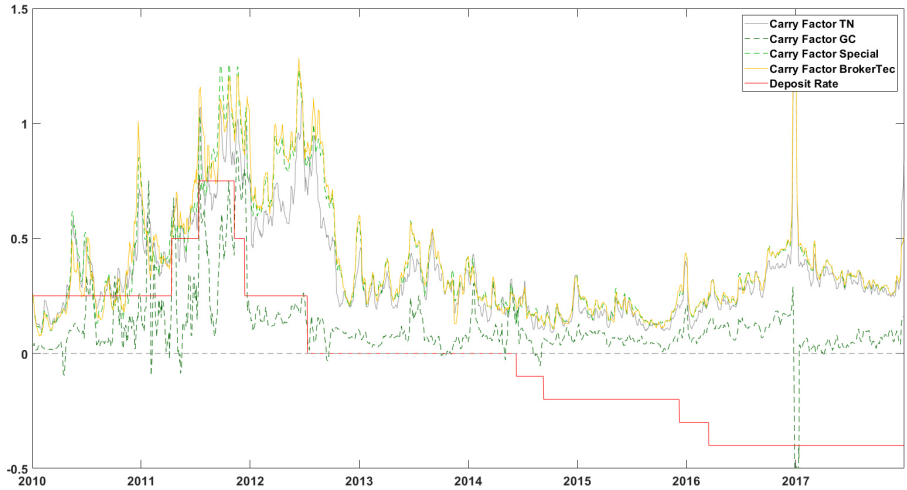
The table shows the average annualized carry return by year of a carry trade strategy which goes long in repos with the highest rate (via a reverse repo) while shorting the repos with the lowest rate (via a repo). The results are broken down for forming four daily portfolios. Data include (1) the baseline set-up presented in the paper using GC and special repos of term type SN, (2) GC and special repos of term type TN, (3) GC repos of term type TN, (4) special repos of term type SN, and (5) GC and special repos of term type SN which have been traded on the BrokerTec platform. Data are daily for the period 2010–2017.

Table OA2.1.4: Carry return (%): Two portfolios

Year	Baseline	TN	GC	Special	Broker Tec
2010	0.09	0.09	0.05	0.09	0.08
2011	0.27	0.20	0.18	0.26	0.23
2012	0.21	0.16	0.09	0.21	0.21
2013	0.11	0.09	0.04	0.11	0.11
2014	0.08	0.06	0.04	0.08	0.07
2015	0.07	0.06	0.04	0.07	0.07
2016	0.15	0.14	0.09	0.15	0.15
2017	0.15	0.14	0.07	0.15	0.15
avg.	**0.14**	**0.12**	**0.08**	**0.14**	**0.13**

The table shows the average annualized carry return by year of a carry trade strategy which goes long in repos with the highest rate (via a reverse repo) while shorting the repos with the lowest rate (via a repo). The results are broken down for forming two daily portfolios. Data include (1) the baseline set-up presented in the paper using GC and special repos of term type SN, (2) GC and special repos of term type TN, (3) GC repos of term type TN, (4) special repos of term type SN, and (5) GC and special repos of term type SN which have been traded on the BrokerTec platform. Data are daily for the period 2010–2017.

Graphical comparison of different carries



The figure displays the one-week moving average for illustrative purposes.

Figure OA2.1.1: Development of different safe asset carry factors

Summary statistics for carry factor realization

Table OA2.1.5: Portfolio return (%)

(i) without end of month and end of ECB maintenance periods (baseline)

	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8
Expected gross return	−0.35	−0.07	−0.03	−0.01	0.01	0.05	0.08	0.11
Expected net return	−0.30	−0.09	−0.04	−0.02	0.00	0.03	0.07	0.09
Expected high-minus-low net return	-	0.21	0.26	0.28	0.30	0.33	0.36	0.39
Standard deviation of expected minus realized net return	0.14	0.12	0.11	0.14	0.10	0.06	0.05	0.05

(ii) without end of month, end of ECB maintenance periods, and end of quarter

	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8
Expected gross return	−0.34	−0.06	−0.02	−0.01	0.01	0.05	0.08	0.11
Expected net return	−0.29	−0.08	−0.04	−0.02	0.00	0.03	0.07	0.10
Expected high-minus-low net return	-	0.21	0.25	0.27	0.29	0.32	0.36	0.38
Standard deviation of expected minus realized net return	0.07	0.05	0.04	0.04	0.04	0.05	0.05	0.05

(iii) at end of month, end of ECB maintenance periods, and end of quarter

	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8
Expected gross return	−0.40	−0.10	−0.06	−0.03	0.00	0.07	0.11	0.15
Expected net return	−0.34	−0.13	−0.08	−0.05	−0.02	0.04	0.09	0.13
Expected high-minus-low net return	-	0.21	0.26	0.29	0.32	0.38	0.43	0.46
Standard deviation of expected minus realized net return	0.21	0.16	0.16	0.17	0.15	0.13	0.13	0.14

The table shows the average, annualized expected portfolio returns for portfolios n=1, 2,...,8, gross and net of transaction cost using SN repo transactions; the return on the high-minus-low investment strategy relates to the expected net portfolio return and shorts portfolio n=1 while going long in portfolios n=2, 3,...,8; and the standard deviation of the difference between the expected portfolio net return (using the SN rate at time t) and the realized portfolio net return (using the same portfolio constituents at the TN rate at time t+1). "Without end of month and end of ECB maintenance periods" excludes end of month and end of ECB maintenance period tradings days; "without end of month, end of ECB maintenance periods, and end of quarter" excludes end of month and end of ECB maintenance period tradings days as well as end of quarter trading weeks; and "at end of month, end of ECB maintenance periods, and end of quarter" includes only end of month and end of ECB maintenance period tradings days as well as end of quarter trading weeks.

Graphical comparison of carry factor realization

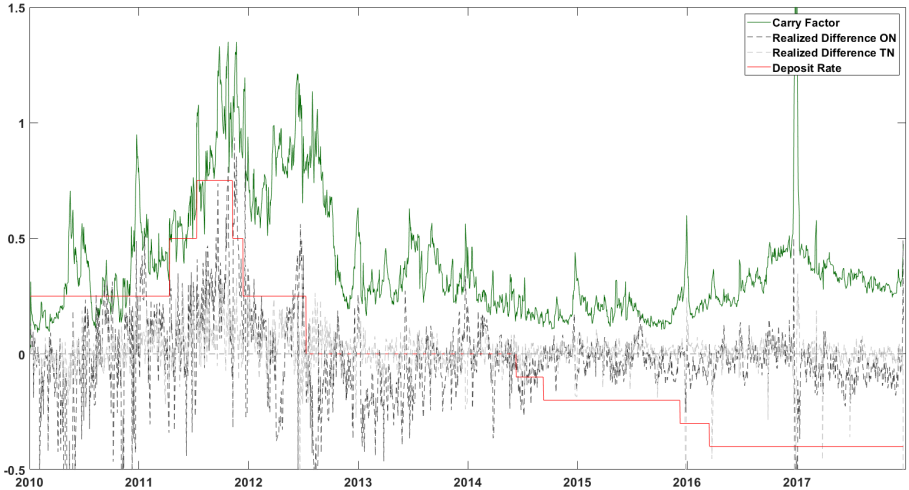


Figure OA2.1.2: Development of the safe asset carry factor as well as of the realization using TN and ON rates

Bond collateral

To establish the borrowing position in our carry trade, the hypothetical carry trader needs to own the collateral asset in the low-rate portfolio. The likelihood of holding or easily obtaining a given security depends on a bank's business model, size, and characteristics. For instance, dealer banks hold large portfolios, including government bonds, by acting as a market makers and by participating in government auctions. Similarly, CCPs hold large portfolios of government bonds due to their role as central counterparties. These institutions are best positioned to implement this carry trade.

Market participants could also establish a portfolio of government bonds. We consider the Buy-and-Sell approach for this. In this approach, the hypothetical carry trader buys and sells daily the securities needed to establish the high- and low-rate portfolios and is thus exposed to price changes on the underlying bonds. His position is positively (negatively) exposed to price changes of the securities pledged (obtained) on (from) the (reverse) repo side, i.e., the low-rate (high-rate) portfolio.[52] Table OA2.1.6 provides an overview of the return properties.

The Buy-and-Sell approach features returns that show a development consistent with our repo carry factor. However, in contrast to our repo carry, which measures day-to-day movements in non-pecuniary convenience yield, this return also reflects (i) monetary income flows (e.g., coupon payments), (ii) changes in bond prices due to changes in, for example, risk and liquidity, as well as (iii) changes in the bond price related to all future convenience yields. As a result, the return of this trading strategy is consistent with our repo carry; however, the overall magnitude is larger as it reflects other aspects than day-to-day movements in convenience benefits.

[52]In both approaches, we account for coupon returns and funding cost. For the list of securities (i.e., by ISIN level) in the high- and low-rate portfolio, we refer to the SN term type.

Table OA2.1.6: Bond collateral

	Buy-and-Sell	
Year	Return	St. Dev.
2010	5.55%	2.72%
2011	9.21%	6.72%
2012	8.00%	8.67%
2013	1.30%	2.04%
2014	2.75%	2.17%
2015	0.72%	3.24%
2016	5.82%	3.70%
2017	0.20%	2.83%

In the Buy-and-Sell approach, the hypothetical carry trader buys and sells daily the securities needed to establish the high- and low-rate portfolios. The carry trader is therefore positively (negatively) exposed to price changes of the securities pledged (obtained) on (from) the (reverse) repo side, i.e., the low-rate (high-rate) portfolio. We account for coupon returns and funding cost. For the funding cost, we consider the overnight (unsecured) EONIA rate since it implies that the carry trader does not need to hold any additional collateral to finance the portfolio. Since we want to capture the value changes of the collateral assets, we do not account for transaction cost. The Buy-and-Sell return is therefore defined as the positive (negative) price changes of the low-rate (high-rate) portfolio, plus coupon returns and less funding cost. We add the coupon returns (which are also reflected in the yield to maturity) since the owner of a government bond remains the beneficial owner even if a security is pledged as collateral. Since both approaches require a list of securities as well as the time period for which the securities need to be held, we refer to the SN term type.

Principal component analysis

Table OA2.1.7: Principal component analysis

	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6	PCA 7	PCA 8
Portf. 1	0.28	−0.90	0.32	−0.01	−0.02	0.02	0.02	0.00
Portf. 2	0.37	−0.06	−0.44	0.66	−0.08	−0.35	−0.28	−0.16
Portf. 3	0.36	−0.01	−0.41	0.12	0.05	0.62	0.42	0.35
Portf. 4	0.36	0.01	−0.33	−0.61	−0.45	−0.39	0.17	0.00
Portf. 5	0.36	0.06	−0.12	−0.37	0.38	0.34	−0.52	−0.43
Portf. 6	0.36	0.16	0.20	−0.07	0.57	−0.40	−0.03	0.56
Portf. 7	0.36	0.25	0.37	0.15	0.11	−0.08	0.57	−0.55
Portf. 8	0.37	0.30	0.48	0.11	−0.55	0.24	−0.35	0.23
% Variance	94.99%	4.28%	0.60%	0.06%	0.03%	0.02%	0.01%	0.01%

The table reports the portfolio loadings of portfolios n=1, 2,...,8, on the eight principal components, as well as the share of the total variance explained by each principal component. Data are daily and include GC and special repos of term type SN for the period 2010–2017.

GMM methodology

We consider the following linear asset pricing model in which the expected return is equal to the factor premia times the respective betas of each portfolio:

$$E[R] = \beta^{Market} \cdot \lambda^{Market} + \beta^{HML} \cdot \lambda^{HML}. \tag{2.1}$$

We consider repo rates (instead of excess returns) as the dependent variable since our market factor captures the interest rate level. Our carry trade involves a collateral swap in which the collateral quality (differential) is ex-ante unknown. For example, the safety and liquidity benefits of an asset can change during the day. The difference in convenience yield across assets is therefore uncertain and varies across time.[53]

For our estimation, we employ the GMM estimation based on Hansen (1982). Following Cochrane (2009), and by referring to the respective factor $k \in [Market, HML]$, we account for the three moment conditions illustrated in Equation 2.2:

$$\begin{bmatrix} E(R_{n,t} - a_n - \beta_n^k \cdot f_t^k) \\ E[(R_{n,t} - a_n - \beta_n^k \cdot f_t^k) * f_t^k] \\ E(R_n - \beta_n^k \cdot \lambda^k) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}. \tag{2.2}$$

The first two conditions require the error terms of the time-series regression $\epsilon_{n,t}$ to be estimated such that $E(\epsilon_{n,t}) = 0$ and $\text{Cov}(\epsilon_{n,t}, \mathbf{f_t^k}) = 0$. The third condition relates to the cross-sectional regression and requires the cross-sectional error term ζ_n to be estimated such that $E(\zeta_n) = 0$. For the estimation, we translate Equation 2.2 into the following moment conditions:

$$R_{n,t} - a_n - \beta_n^{Market} \cdot f_t^{Market} - \beta_n^{HML} \cdot f_t^{HML} = 0 \tag{2.3}$$

$$(R_{n,t} - a_n - \beta_n^{Market} \cdot f_t^{Market} - \beta_n^{HML} \cdot f_t^{HML}) \cdot f_t^{Market} = 0 \tag{2.4}$$

$$(R_{n,t} - a_n - \beta_n^{Market} \cdot f_t^{Market} - \beta_n^{HML} \cdot f_t^{HML}) \cdot f_t^{HML} = 0 \tag{2.5}$$

$$R_n - \beta_n^{Market} \cdot \lambda^{Market} - \beta_n^{HML} \cdot \lambda^{HML} = 0. \tag{2.6}$$

[53] The uncertainty is related to the funding side of the repo (e.g., aggregate liquidity shock, liquidity hoarding, and unexpected monetary policy effects) as well as to the collateral side (e.g., asset price movements and margin calls).

In the estimation, n refers to the respective portfolio $n \in [1, .., 8]$. Thus, β_n^{Market} denotes portfolio n's sensitivity to the market factor, β_n^{HML} denotes portfolio n's sensitivity to the carry factor, and λ^{Market} and λ^{HML} represent the respective factor premia. Equations 2.3 and 2.6 require the error terms of the time-series and cross-sectional regressions to be zero in expectation, and Equations 2.4 and 2.5 require the covariances of the error terms of the time-series regressions with the respective factors to be zero in expectation. For $n \in [1, .., 8]$, we derive 32 conditions that we account for in the GMM estimation.

Robustness for GMM estimation

Table OA2.1.8: Factor analysis: TN term type

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8	GMM
a	−0.01	0.03***	0.03***	0.03***	0.03***	0.03***	0.03***	0.04***	
	(−1.63)	(5.12)	(6.55)	(6.95)	(6.36)	(6.10)	(6.46)	(7.19)	
β^{Market}	1.00***	1.07***	1.05***	1.03***	1.01***	0.98***	0.98***	1.01***	
	(55.41)	(75.46)	(107.70)	(131.69)	(171.75)	(153.52)	(93.70)	(92.10)	
β^{HML}	−0.94***	−0.13***	0.02*	0.10***	0.16***	0.23***	0.33***	0.42***	
	(−37.61)	(−9.37)	(1.86)	(7.42)	(11.44)	(17.83)	(26.59)	(24.12)	
λ^{Market}									−0.10**
									(−2.33)
λ^{HML}									0.39***
									(16.39)
N									14,960
Time periods									1,870
adj. R^2									95.65%
χ^2									49.04%

The table reports the factor loadings for the eight portfolios and estimates of the premia for the market factor and the carry factor estimated via the GMM approach. The GMM results are estimated jointly as part of a single, overidentified estimation. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Error terms are adjusted according to Newey and West (1987) with the optimal number of lags chosen using the Bartlett kernel. p-values of χ^2 tests are reported in percentage points. Data are daily and include GC and special repos of term type TN for the period 2010–2017.

Table OA2.1.9: Factor analysis: GC

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8	GMM
a	−0.00	0.00	0.00	0.01*	0.01***	0.01***	0.02***	0.02***	
	(−0.70)	(0.82)	(0.80)	(1.74)	(3.80)	(9.31)	(8.91)	(10.60)	
β^{Market}	1.00***	1.02***	1.02***	1.02***	1.00***	0.99***	1.01***	1.02***	
	(118.91)	(225.15)	(139.68)	(128.09)	(122.09)	(145.65)	(172.46)	(225.35)	
β^{HML}	−0.50***	−0.35***	−0.26***	−0.13***	0.03*	0.21***	0.34***	0.53***	
	(−26.44)	(−25.15)	(−15.11)	(−9.34)	(1.74)	(15.38)	(19.52)	(33.40)	
λ^{Market}									0.03
									(0.77)
λ^{HML}									0.15***
									(14.96)
N									14,960
Time periods									1,870
adj. R^2									98.83%
χ^2									28.96%

The table reports the factor loadings for the eight portfolios and estimates of the premia for the market factor and the carry factor estimated via the GMM approach. The GMM results are estimated jointly as part of a single, overidentified estimation. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Error terms are adjusted according to Newey and West (1987) with the optimal number of lags chosen using the Bartlett kernel. p-values of χ^2 tests are reported in percentage points. Data are daily and include GC repos of term type TN for the period 2010–2017.

Table OA2.1.10: Factor analysis: Special collateral

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8	GMM
a	-0.02^{**}	-0.00	0.02^{***}	-0.01^{**}	-0.01^{**}	0.00	0.00	0.01^{**}	
	(-3.26)	(-1.49)	(9.73)	(-2.79)	(-2.10)	(0.36)	(0.40)	(2.17)	
β^{Market}	0.97^{***}	1.07^{***}	1.04^{***}	1.00^{***}	0.99^{***}	0.98^{***}	0.97^{***}	0.97^{***}	
	(96.43)	(108.28)	(144.60)	(104.26)	(140.01)	(179.82)	(124.75)	(127.62)	
β^{HML}	-0.81^{***}	-0.05^{***}	0.00	0.10^{***}	0.15^{***}	0.22^{***}	0.32^{***}	0.37^{***}	
	(-35.26)	(-5.68)	(0.02)	(10.72)	(15.90)	(28.84)	(38.48)	(36.97)	
λ^{Market}									-0.07^{*}
									(-1.66)
λ^{HML}									0.42^{***}
									(14.79)
N									14,960
Time periods									1,870
adj. R^2									98.39%
χ^2									34.54%

The table reports the factor loadings for the eight portfolios and estimates of the premia for the market factor and the carry factor estimated via the GMM approach. The GMM results are estimated jointly as part of a single, overidentified estimation. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Error terms are adjusted according to Newey and West (1987) with the optimal number of lags chosen using the Bartlett kernel. p-values of χ^2 tests are reported in percentage points. Data are daily and include special repos of term type SN for the period 2010–2017.

Table OA2.1.11: Factor analysis: Collateral traded on BrokerTec

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8	GMM
a	-0.02^{***}	-0.01^{*}	0.02^{***}	-0.01^{**}	-0.01^{**}	0.01^{**}	0.00	0.00	
	(-3.52)	(-1.87)	(8.25)	(-2.95)	(-2.63)	(2.89)	(0.09)	(1.15)	
β^{Market}	0.96^{***}	1.07^{***}	1.05^{***}	1.01^{***}	0.99^{***}	0.98^{***}	0.95^{***}	0.96^{***}	
	(91.75)	(96.28)	(160.86)	(114.13)	(111.07)	(105.60)	(103.77)	(121.49)	
β^{HML}	-0.80^{***}	-0.04^{***}	0.02^{*}	0.12^{***}	0.16^{***}	0.18^{***}	0.29^{***}	0.38^{***}	
	(-34.55)	(-3.87)	(1.88)	(11.63)	(13.27)	(14.68)	(26.35)	(32.01)	
λ^{Market}									-0.09^{**}
									(-2.14)
λ^{HML}									0.42^{***}
									(14.82)
N									14,960
Time periods									1,870
adj. R^2									98.16%
χ^2									15.93%

The table reports the factor loadings for the eight portfolios and estimates of the premia for the market factor and the carry factor estimated via the GMM approach. The GMM results are estimated jointly as part of a single, overidentified estimation. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Error terms are adjusted according to Newey and West (1987) with the optimal number of lags chosen using the Bartlett kernel. p-values of χ^2 tests are reported in percentage points. Data are daily and include GC and special repos of term type SN which have been traded on the BrokerTec platform for the period 2010–2017.

Fama & MacBeth (1973) methodology

In line with the "classical" approach introduced by Fama and MacBeth (1973), we follow the two-stage estimation procedure:

$$R_{n,t} = a_n + \beta_n^{Market} \cdot f_t^{Market} + \beta_n^{HML} \cdot f_t^{HML} + \epsilon_{n,t} \tag{2.7}$$

$$R_n = \beta_n^{Market} \cdot \lambda^{Market} + \beta_n^{HML} \cdot \lambda^{HML} + \zeta_n. \tag{2.8}$$

In the time-series regression 2.7, we determine the portfolios' betas, while in the cross-sectional regression 2.8, we determine the factor premia for the market and the carry. In the estimation, n refers to the respective portfolio $n \in [1, .., 8]$. Thus, β_n^{Market} denotes portfolio n's sensitivity to the market factor, β_n^{HML} denotes portfolio n's sensitivity to the carry factor, and λ^{Market} and λ^{HML} represent the respective factor premia. We do not include a constant in the cross-sectional regression since the market factor serves as a constant.

FMB estimation

Table OA2.1.12: Factor analysis: FMB

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Portf. 1	Portf. 2	Portf. 3	Portf. 4	Portf. 5	Portf. 6	Portf. 7	Portf. 8	FMB
a	−0.01	−0.01	0.01	0.02***	0.02***	0.01	0.01	0.01	
	(−0.85)	(−1.09)	(1.52)	(2.87)	(4.40)	(1.25)	(0.82)	(1.25)	
β^{Market}	0.98***	1.06***	1.03***	1.01***	1.00***	0.98***	0.97***	0.98***	
	(81.66)	(76.70)	(113.33)	(166.11)	(191.06)	(98.10)	(90.98)	(89.76)	
β^{HML}	−0.83***	−0.02	0.02	0.04	0.10***	0.20***	0.30***	0.36***	
	(−17.18)	(−0.72)	(0.49)	(1.61)	(6.54)	(9.82)	(10.48)	(9.71)	
λ^{Market}									−0.06
									(−1.00)
λ^{HML}									0.41***
									(12.10)
N	1,870	1,870	1,870	1,870	1,870	1,870	1,870	1,870	14,960
Time periods									1,870
adj. R^2	97.62%	99.03%	99.17%	99.15%	99.70%	99.58%	99.31%	99.01%	98.28%

The table reports the factor loadings for the eight portfolios estimated via the FMB time-series regression of each portfolio's return on a constant, the market factor, and the carry factor as well as estimates of the premia for the market factor and the carry factor obtained using the FMB approach. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Error terms are adjusted according to Newey and West (1987) with the optimal number of lags chosen using the Bartlett kernel. Data are daily and include GC and special repos of term type SN for the period 2010–2017.

OA2.2 Economic determinants of convenience yield

Theoretical framework

We propose a simple supply- and demand-framework which builds on Krishnamurthy (2002) as shown in Figure OA2.2.1a.

The x-axis displays the quantity of a bond pledged as collateral in the repo market ("repo quantity"), and the y-axis displays an asset's convenience ("convenience").[54] We consider two separate demand curves, one for truly safe assets and one for quasi-safe assets.[55] As investors value the higher convenience yield of truly safe assets, there is a higher demand for them, leading to a lower equilibrium rate of the repo carrying this higher convenience. The supply of collateral is perfectly elastic as long as an asset's convenience is zero which is the case if the repo rate is close to the interest rate benchmark but becomes upward slowing for positive convenience levels.

In our setting, the supply curve is given as

$$c(Q) = A + b^S \cdot X^S + d^S \cdot max[Q - Q^*, 0], \tag{2.9}$$

and the demand curve as

$$c(Q) = b^D \cdot X^D + b^R \cdot (\overline{Risk} - Risk^i) + b^L \cdot opportunitycost - d^D \cdot Q. \tag{2.10}$$

In the supply curve, the intercept is given by $A + b^S \cdot X^S$, which contains a parameter A and a shift in supply X^S. After a cut-off quantity Q^*, the supply curve increases in the quantity with a slope of d^S. The demand curve depends on the specific risk of the collateral asset i ($Risk^i$) relative to the overall risk ($\overline{Risk}$) and the opportunity cost. More specifically, the intercept increases (i) for bonds with below-average country risk ($\overline{Risk} - Risk^i$) and (ii) in the *opportunitycost*. The intercept also reacts to shifts in demand X^D. The demand curve falls in the quantity with a slope of d^D.

[54] In our setting, we consider general collateral and special repos and thus distinguish between specialness and convenience. In the spirit of Krishnamurthy (2002), the difference between the repo rate and the interest rate benchmark reflects the convenience premium, whereas specialness is defined as the difference between the GC and the special repo rate. In that sense, a GC repo can carry a convenience yield without being special. The y-axis in our setting, therefore, reflects the convenience yield of a collateral asset.

[55] The demand curves are downward sloping, i.e., there is a higher demand for lending against a given asset if it carries a lower convenience yield (and specialness) and higher repo rate.

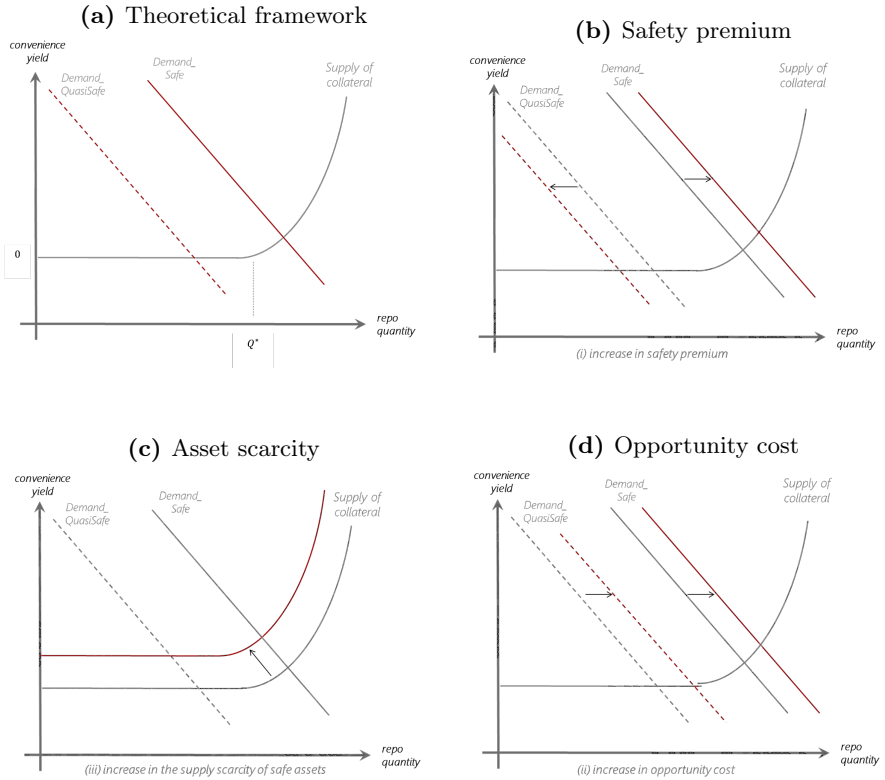


Figure OA2.2.1: Convenience yield framework

As outlined in the demand equation and illustrated in Figure OA2.2.1b, an increase in the perceived sovereign risk of quasi-safe asset i relative to the overall risk ($\overline{Risk}$) leads to a weaker demand for those quasi-safe assets and a higher demand for assets such as German Bunds that remain safe even in flight-to-safety episodes such as the European sovereign debt crisis. Thus, truly safe assets feature the highest demand and convenience yield.

Our framework accommodates changes in the liquidity premium due to changes in the supply of assets via a movement in the supply curve. For example, an increase in the relative scarcity of truly safe assets leads to a lower repo supply of those scarce assets for a given level in repo convenience (Figure OA2.2.1c). This is reflected in X^S in the supply curve.

In our graphical framework, an increase in the opportunity cost leads to an

increase in the demand for safe assets. Since the demand for quasi-safe assets is met at the inelastic part of the supply curve, only the convenience for truly safe assets increases (Figure OA2.2.1d).

Analysis for different control variables

Table OA2.2.1: Economic analysis with different control variables for risk and asset supply

	(1) Carry b/t	(2) Carry b/t	(3) Carry b/t	(4) Carry b/t	(5) Carry b/t	(6) Carry b/t
CDS						
Baseline	0.483***	0.455***	0.458***	0.517***		
	(5.75)	(5.34)	(5.40)	(5.85)		
Dynamic weights					−0.070	
					(−1.12)	
CDS banking sector						0.124***
						(3.57)
Asset supply						
Baseline					0.571***	0.430**
					(3.26)	(2.55)
Static weights	0.808*					
	(1.77)					
Debt/GDP		0.416		0.043		
		(1.22)		(0.12)		
Debt/GDP net ECB PSPP			0.393			
			(1.28)			
ECB PSPP				−0.817**		
				(−2.16)		
Opportunity cost	0.509***	0.464***	0.468***	0.539***	0.278***	0.229**
	(4.43)	(5.00)	(5.06)	(6.28)	(3.57)	(2.21)
N	30	30	30	30	30	30
adj. R^2	0.701	0.731	0.736	0.828	0.884	0.712
Arbitrage deviation	Yes	Yes	Yes	Yes	Yes	Yes
Lagged carry	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the results of the time-series regressions of our carry factor on a constant, different measures of the CDS spread ("CDS") and different asset supply measures ("Asset supply"), the EONIA rate ("Opportunity cost"), the absolute U.S. dollar Euro CIP deviations ("Arbitrage deviation"), and the lagged carry factor ("Lagged carry"). Measures of the CDS spread include the static weighted CDS price difference between portfolios 8 and 1 ("Baseline"), the dynamic weighted CDS price difference between portfolios 8 and 1 ("Dynamic weights"), and the five-year CDS spread of the European banking sector ("CDS banking sector"). Measures of Asset Supply include the dynamic weighted difference in the log of the ratio of short-term debt to GDP between portfolios 8 and 1 ("Baseline"), the static weighted difference in the log of the ratio of short-term debt to GDP between portfolios 8 and 1 ("Static weights"), the dynamic ratio with debt to GDP ("Debt/GDP") and debt net of ECB PSPP purchases to GDP ("Debt/GDP net ECB PSPP"), and including ECB PSPP purchases ("ECB PSPP"). ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Error terms are adjusted according to Cochrane and Orcutt (1949), following Wooldridge (2015). Data are quarterly and include GC and special repos of term type SN for the period 2010–2017.

Table OA2.2.2: Economic analysis with different control variables for opportunity cost and arbitrage deviations

	(1) Carry b/t	(2) Carry b/t	(3) Carry b/t	(4) Carry b/t	(5) Carry b/t	(6) Carry b/t
CDS	0.389***	0.428***	0.280***	0.498***	0.374***	0.402***
	(3.90)	(4.05)	(3.77)	(4.61)	(2.97)	(4.42)
Asset supply	0.290	0.270	0.455***	0.308*	0.385**	0.258
	(1.58)	(1.40)	(3.46)	(1.84)	(2.14)	(1.50)
Opportunity cost						
Baseline			0.497***	0.491***	0.423***	0.444**
			(10.08)	(4.24)	(4.24)	(6.05)
One-month Euribor	0.333***					
	(4.79)					
Average repo market rate		0.390***				
		(3.81)				
N	30	30	30	30	30	30
adj. R^2	0.696	0.635	0.912	0.680	0.697	0.764
Arbitrage deviation	Baseline	Baseline	TED	VIX	CISS	Balance sheet cost
Lagged carry	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the results of the time-series regressions of our carry factor on a constant, the static weighted CDS price difference between portfolios 8 and 1 ("CDS"), the dynamic weighted difference in the log of the ratio of short-term debt to GDP between portfolios 8 and 1 ("Asset supply"), different measures of ("Opportunity cost") and ("Arbitrage deviation"), and the lagged carry factor ("Lagged carry"). Measures of Opportunity Cost include the EONIA rate ("Baseline"), the one-month Euribor rate ("One-month Euribor"), and the average repo market rate ("Average repo market rate"). Measures of Arbitrage Deviations include the absolute U.S. dollar Euro CIP deviations ("Baseline"), the TED spread ("TED"), the VIX ("VIX"), the CISS ("CISS"), and the difference between the 10-year German government bond yield and the 10-year Euro OIS rate as a measure for the balance sheet cost of holding government bonds in line with He et al. (2022) ("Balance sheet cost"). ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Error terms are adjusted according to Cochrane and Orcutt (1949), following Wooldridge (2015). Data are quarterly and include GC and special repos of term type SN for the period 2010–2017.

Chapter 3

Money market disconnect

Benedikt Ballensiefen, Angelo Ranaldo, and Hannah Winterberg[1]

A repurchase agreement (repo) is a source of funding and collateral. We document that the money market is more segmented when the collateral motive prevails. Two crucial aspects of the central bank framework lead to this disconnect: banks' access to the central bank's deposit facility and assets' eligibility for quantitative easing (QE). We show that repo rates lent by banks with access to the deposit facility and secured by QE eligible assets are more collateral-driven and disconnected from funding-based money market rates. Our results are relevant for different monetary policies and have suggestive implications for the monetary policy pass-through.

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The money market is crucial for the efficient allocation of funding and financial securities as well as for preserving financial stability. Furthermore, "a deep and integrated money market is a precondition for an efficient monetary policy, since it ensures an even distribution of central bank liquidity and a homogeneous level of short-term interest rates (European Central Bank, 2011)." Given its essential role in the financial and economic system, it is important to understand frictions in the money market and *how* they lead to market segmentation which can create rate dispersion and be detrimental to market quality.

In this paper, we study money market segmentation and its underlying mechanism. A repurchase agreement (repo) is the main money market instrument; it is a secured short-term loan that serves a dual role in obtaining funding and collateral. We show that the money market becomes more segmented when the role of collateral in repos dominates the role of funding. We uncover two key aspects of the central bank framework that lead money market participants and securities to disconnect from funding-based money market segments. First, whether banks have access to the central bank's deposit facility; and second, whether the collateral asset is the target of the quantitative easing (QE) program. We demonstrate that the lending rates of banks with access to the central bank's deposit facility and secured by assets eligible for QE programs are more collateral-driven and therefore less connected to funding-based benchmark rates. Both effects lead to rate dispersion and add to one another, pointing towards a pervasive money market segmentation. Our results have implications for different monetary policies and provide suggestive evidence that money market segmentation weakens the monetary policy transmission.

The European repo market is the ideal laboratory to examine the dual role of repos and the resulting money market segmentation for several reasons. First, it is the largest repo market worldwide and the main source of short-term funding and collateral for euro area banks.[2] For our analysis, we employ a unique and highly representative transaction- and firm-level data set from

[2]The asset being used as collateral in a repo transaction can be a particular asset ("special repo") or any asset from a predefined basket of assets ("general collateral or GC repo"). In the U.S., a special repo is sometimes also referred to as a "specific" repo. The GC market is generally more funding-driven, while the special market is more collateral-driven. Still, even GC baskets differ in rates as some baskets are more funding-driven while others are more collateral-driven. Our data set covers both the GC and special repo market segments.

2010 to 2020. Second, the repo market infrastructure features central clearing and anonymous centralized order book platforms, ensuring homogeneous counterparty risk and collateral policy, no bargaining power, and an efficient price formation process. Third, euro repos are secured by government bonds issued by various euro area countries with different sovereign risks, scarcity, and liquidity. This heterogeneity of collateral bonds creates cross-sectional and time variation in repo rates and implies that some repos are more funding-driven while others are more collateral-driven;[3] hence, it provides the ideal laboratory to examine the dual nature of repos. And fourth, the euro repo market is affected by monetary policy as the ECB maintains a corridor system for the deposit facility (floor) rate (DFR) and the marginal lending facility (ceiling) rate. The key short-term interest rate benchmark in the euro area is the EONIA rate, an unsecured overnight interest rate. Since the EONIA serves as the operational target rate of the ECB (Cœuré, 2018), our results also have implications for monetary policy.

Conceptually, the idea of this paper is that the money market becomes more segmented when repos are predominantly collateral-driven. Empirically, a weaker correlation between secured and unsecured money market rates is a sign of this segmentation. To document this mechanism, we investigate two crucial aspects of the central bank's institutional framework that induce money market participants and securities to disconnect from funding-driven segments.

The first key aspect is that only some money market participants can access the ECB's deposit facility. Banks can either operate as *lenders* of cash in GC repos to invest liquidity safely (funding motive) or to obtain collateral (collateral motive). Storing funds at the deposit facility is the outside option for banks with access to it. An important development has been the drop in several GC repo rates *below* the DFR (henceforth GC $<$ DFR). In such an environment, access banks have an incentive to deposit liquidity with the central bank to the detriment of engaging in funding-based repo trades; at the same time, access banks continue to have the motive to trade for collateral purposes in the repo market. We, therefore, expect an endogenous selection of access banks into more collateral-driven repo segments that are less connected to funding-based money market rates in the GC $<$ DFR environment. At

[3]Empirical evidence about heterogeneity in convenience yields of collateral assets in the euro repo market is provided in Ballensiefen and Ranaldo (2022).

first, it seems surprising that secured lending rates of access banks are more disconnected from other money market benchmark rates. At the same time, our proposed mechanism is intuitive as the deposit facility is the outside lending option for those banks. In line with this mechanism, we document that access banks lend more in collateral-driven baskets when GC rates fall below the DFR. Banks without access to the deposit facility, by contrast, do not have the option to store liquidity at the deposit facility and therefore select themselves into more funding-driven repo segments which behave more like the unsecured market.

To test empirically whether banks with (without) access to the ECB's deposit facility lend at repo rates more (less) disconnected from the EONIA as the unsecured benchmark rate, especially in the GC $<$ DFR environment, we perform a comprehensive panel regression analysis. Our results clearly show that access banks respond less to changes in the EONIA. For instance, in the GC $<$ DFR environment, an increase in the EONIA rate by one percentage point translates into an increase in GC rates involving access banks of only four basis points (pointing to market segmentation) compared to 94 basis points for banks without access (pointing to high integration). In addition to the statistical significance, our findings are economically relevant, which corroborates the idea that access to the deposit facility is the first illustration of our mechanism that creates money market segmentation.

The second key aspect of the central bank framework relates to the eligibility criteria of the QE program, which specify that the ECB can purchase only a given set of assets. For this part, we focus on the "special" repo segment. QE eligible assets tend to be scarcer, and repo rates secured by those assets are more special (Arrata et al., 2020; Corradin and Maddaloni, 2020). Consequently, repos with QE eligible assets as collateral become predominantly driven by collateral demand disconnecting them from funding-based money market segments. In line with this idea, we document that the trading volume in the special market has increased since the start of QE, mainly driven by transactions collateralized with assets eligible for central bank purchases, which feature the highest collateral demand.

We perform a similar panel regression analysis to test whether repos secured by assets eligible (noneligible) for QE become more (less) disconnected from the EONIA rate. We also apply the initial QE implementation provisions

retrospectively to compare time trends between (hypothetically) eligible and noneligible assets, which creates a difference-in-difference estimation setting. We find that in the period after the introduction of QE, an increase in the EONIA rate by one percentage point is associated with a 50% lower sensitivity of eligible assets. In addition, we observe a similar behavior of (hypothetically) eligible and noneligible assets in the periods prior to QE and diverging patterns during QE, which suggests a causal impact of central bank asset purchases and resulting asset scarcity on money market segmentation.

We perform numerous robustness analyses which confirm our results. For example, we study the combined effect of the two disconnecting mechanisms, i.e., access to the central bank's deposit facility and QE eligibility, and find that they together induce an even more pronounced market segmentation. We also employ other money market benchmark rates such as the new €STR rate, secured funding rates, and derivative-based rates.

Our results have implications for different monetary policies. The introduction of the ECB's two-tier system for remunerating excess reserve holdings in 2019 is a natural experiment for our mechanism. It created an even stronger incentive for access banks to store funds at the deposit facility by exempting part of the excess reserve holdings held at the ECB from negative rates. We analyze the two-tier system's impact in a difference-in-difference estimation setting and find that the repo rates of access banks are more disconnected from the EONIA rate after the introduction of the tiering system. Due to the tiering exemptions, access banks have an additional incentive to store funds at the ECB's deposit facility and thus predominantly trade in collateral-driven parts of the repo market, which are less connected to funding-based money market rates. Widening deposit facility access to foreign banks as in Switzerland (Kraenzlin and Nellen, 2015) is a similar illustration of this mechanism. Amendments to the Capital Requirements Regulation (CRR), which (temporarily) exclude central bank reserves from the calculation of the leverage ratio, could also manifest money market segmentation as they encourage banks (with access) to store additional funds at the ECB's deposit facility. In addition, our work is informative for the recent discussion about new short-term benchmark rates as it underlines that measuring the price of cash becomes increasingly difficult in a collateral-driven repo market environment.

Our results also have *suggestive* implications for the monetary policy trans-

mission process. A consistent and uniform response of money market rates to the monetary policy stance is the first key step of an effective pass-through mechanism. By contrast, a *"wider dispersion in short-term money market rates"* could cause *"a reduction in the efficacy and transmission of monetary policy"* (Bank for International Settlements, 2017, p.32). This is why many central banks target a well-defined money market rate, and in the case of the Eurosystem, the operational target rate is the EONIA. It must be stressed that the variation in the EONIA rate is not only due to changes in the monetary policy stance as other factors such as risk premia and illiquidity determine it. However, it seems reasonable to assume that the ECB takes the EONIA rate into account when evaluating the transmission of its monetary policy as it captures more information about money market conditions than other key rates set by the ECB, such as the DFR.

We show that in a more collateral-driven environment, repo rates lent by access banks and whose collateral qualifies for the QE program deviate significantly more from the EONIA rate. Our findings suggest that the monetary policy transmission could be more difficult when the dispersion of money market rates is wider. To capture this, we compute a dispersion indicator of repo rates based on Duffie and Krishnamurthy (2016). We then show that interest rates relevant to the real economy, such as non-financial corporate borrowing and housing rates, respond less to changes in the EONIA as the ECB's operational target rate when the dispersion in money market rates is wider. Although not causal, the lower conditional correlation could be relevant for assessing the effectiveness of the monetary policy transmission on a continuous basis.

Our analysis mainly contributes to two strands of the literature. First, we add to the literature on short-term money markets. Our innovations are twofold: First, we show that the money market becomes more segmented when the repo market is predominately collateral-driven. Second, we identify two disconnecting mechanisms as the sources of this segmentation, i.e., access to a central bank's deposit facility and asset eligibility for QE. Arrata, Nguyen, Rahmouni-Rousseau, and Vari (2020) and Corradin and Maddaloni (2020) investigate the effects of QE purchases on the level of special repo rates.[4] Other

[4]Asset scarcity induced by QE is one illustration of the mechanism we study in this paper. Extending Arrata, Nguyen, Rahmouni-Rousseau, and Vari (2020) and Corradin and Maddaloni (2020), we study segmentation between the special repo market and other money market segments related to QE purchases as well as the QE impact on GC rates and document

papers analyze the unsecured money market; for instance, Kraenzlin and Nellen (2015) examine domestic and foreign banks' behavior in the Swiss franc unsecured money market, and Bech and Klee (2011) evaluate the impact of bargaining power in the segmented and unsecured U.S. money market.

Second, we add to the literature on monetary policy, the transmission process, and the central bank framework (e.g., Duffie and Krishnamurthy, 2016; Drechsler et al., 2017; Eisenschmidt et al., 2020). Our results about money market segmentation are relevant for different monetary policies. We also provide suggestive evidence that the monetary policy pass-through can be impeded by two key features of the central bank framework.[5]

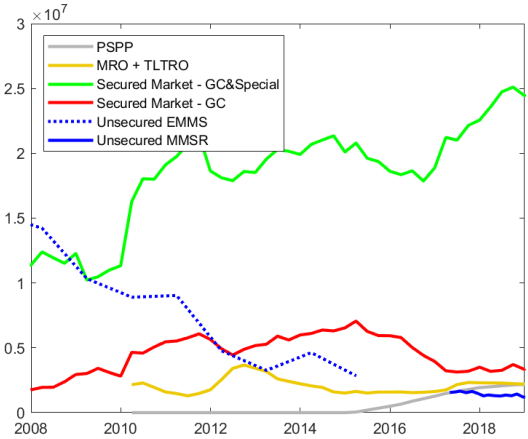
3.1 European money market

The focus of this paper is to provide new insights into money market segmentation, its underlying mechanism, and potential implications for monetary policy. We, therefore, start our work by providing an overview of the European money market structure, including the secured (repo) and unsecured money market segments. Figure 3.1 depicts the aggregate trading volumes in the repo and unsecured money market. The total cumulative PSPP purchases and volumes of the ECB's main refinancing operations (MRO) and targeted longer-term refinancing operations (TLTRO) are also shown as a reference.

Since the global financial crisis, trading in the European money market has moved towards the secured segment. With a size of more than EUR 9.0 trillion in outstanding contracts (International Capital Market Association, 2022), the

the underlying mechanism behind it. Roh (2022) points out that the ECB's decision to lend out bonds that it purchased also impacts asset scarcity. Related, the inactive lending of bonds by nonbanks adds to the scarcity of those assets (Maddaloni and Roh, 2021).

[5]The existing literature on the effectiveness of monetary policy has mostly focused on its pass-through in the context of specific events, such as announcements or policy changes. Duffie and Krishnamurthy (2016) analyze the effects of the introduction of the reverse repurchase facility and new Basel regulation on the monetary policy pass-through in the U.S. Drechsler et al. (2017) consider announced changes to the target corridor of the fed funds rate. Eisenschmidt et al. (2020) analyze the monetary policy transmission in the context of the over-the-counter (OTC) repo market and dealer market power. On a macro-wide level, Avouyi-Dovi et al. (2017) find a slowdown of the overall interest rates transmission mechanism, which Al-Eyd and Berkmen (2013) have associated with segmentation along country lines. Illes et al. (2019) study the cointegration between policy rates and banks' weighted cost of capital. Kalemli-Özcan (2019) analyzes the pass-through in the context of emerging markets. For a detailed literature review on interest rate pass-through, see Andries and Billon (2016) and Horvath et al. (2018).



The figure depicts the aggregate cumulative quarterly trading volumes in the secured and unsecured market segments, the total cumulative PSPP purchases, and volumes of the ECB's main refinancing operations (MRO) and targeted longer-term refinancing operations (TLTRO). The data for the secured market refers to our repo data set as described in Section 3.1.4. 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, we 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 million.

Figure 3.1: Different market turnovers

repo market now plays a crucial role in the efficient allocation of money and financial securities. To put the size of the repo market into perspective, trading volumes by far exceed volumes of cumulative purchases of the largest ECB QE program, the PSPP, or the ECB's main refinancing operations. While the repo market has become the main money market segment for banks, the unsecured money market is an important short-term interest rate benchmark. The EONIA rate is the one-day, unsecured interest rate at which banks lend to one another and represents the funding-based money market benchmark in the euro area. It is "the key ECB interest rate"(European Central Bank, 2011) and serves as the operational target rate for the ECB (Cœuré, 2018). Similar to other countries such as the U.S., the period studied involves a transition in the economy's benchmark interest rate. The ECB has chosen to replace the EONIA rate with the €STR rate, another unsecured rate, which highlights the ECB's renewed commitment to an unsecured target rate.[6]

3.1.1 Repo market

In the repo market, two counterparts exchange cash for collateral for a predefined period with a fixed repurchase obligation. The asset being used as collateral can be a particular asset ("special repo") or any asset from a predefined basket of assets ("general collateral or GC repo").[7] The lender in a repo transaction provides a short-term, typically one-day, loan (over-)collateralized by a sovereign bond and thus benefits from the ability to use the collateral for the time between the purchase and repurchase. Due to their collateralized nature, repos serve a dual role for funding and collateral. *Lenders* of cash in repos can either look for a safe investment that offers a market-based return or a way to source the asset serving as collateral which provides convenience. The GC market is generally more funding-driven, while the special repo market is

[6]The EONIA rate is determined as the weighted average of the interest rates on unsecured overnight lending transactions denominated in euros, as reported by a panel of contributing banks. In 2017, the ECB announced that the euro short-term rate (€STR) would replace the EONIA as the new short-term interest rate benchmark in the euro area. The €STR rate reflects the wholesale euro unsecured overnight borrowing costs of banks located in the euro area. It thus covers the borrowing cost of a larger set of banks compared to the EONIA. We consider both rates in our analysis and show that our results are valid for both unsecured benchmarks.

[7]The lender accepts a lower interest rate in a special repo than in a GC repo since a particular asset is specified as collateral; GC repo rates provide the upper bound for special repo rates.

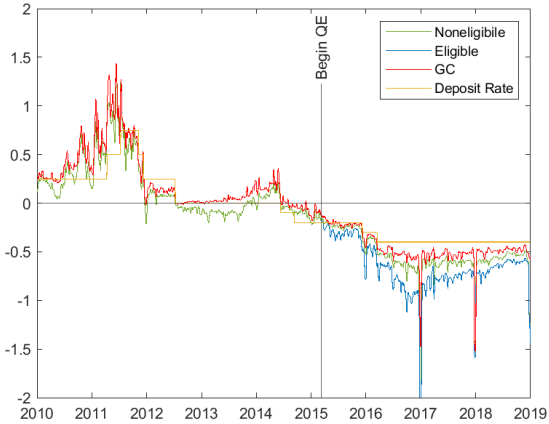
more collateral-driven.

The European repo market infrastructure is particularly well suited to analyzing money market segmentation as it eliminates many confounding factors. The core segment is the interbank market, in which banks trade anonymously via centralized platforms supporting liquidity and a transparent price discovery process. We focus on trades operated through central counterparties (CCP), which constitute the majority of trades in the euro interbank repo market.[8] CCPs interpose themselves between each lender and borrower, eliminating concerns regarding individual counterparty risk. The CCP acts as a clearinghouse and applies the same collateral and (credit) risk policies to all CCP members. Our setting, therefore, avoids frictions such as bargaining power, counterparty credit risk, and heterogeneous haircuts. The euro area repo market also features a large variety of repos, both in the GC and special segments. The richness of this cross-sectional dispersion across GC and special repo rates allows us to examine the dual role of repos as funding and collateral markets since some repos are more funding-driven while others are more collateral-driven.[9]

Figure 3.2 shows the repo rate development for the average GC rate and for the average special repo rates for QE eligible and noneligible assets (illustratively for Germany) relative to the development of the ECB's DFR. Two developments are important: First, GC rates have fallen *below* the ECB's rate on the deposit facility at the height of the European sovereign debt crisis in 2012 and during the recent period of unconventional monetary policy. This is an important regime change for our analysis that we will refer to as the GC $<$ DFR environment. It speaks to the importance of access to central bank facilities as it indicates that storing funds at the deposit facility is an attractive alternative for those banks with access to it. It also points to the idea that repo lenders increasingly trade for *collateral* purposes, even in the GC segment, since they are willing to accept a lower remuneration for lending cash in the repo market instead of depositing it at the central bank. Second, during the QE period, repo rates secured by assets eligible for QE have fallen below those for

[8] CCP-based repos account for more than two-thirds of the total turnover (European Central Bank, 2018). The bilateral OTC repo segment is very small and does not allow for a clear differentiation between general and special collateral repos.

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



The figure shows the development of the average volume-weighted GC rate and special repo rates for QE eligible and noneligible assets (illustratively for Germany) relative to the development of the ECB's deposit facility rate.

Figure 3.2: Repo rate development

noneligible assets (e.g., Arrata et al., 2020 and Corradin and Maddaloni, 2020), thus highlighting the role of asset scarcity induced by QE. Market participants are willing to accept a lower interest rate to lend cash against QE eligible than noneligible assets, which points towards *collateral* demand for those QE eligible assets.[10]

Those two observations provide the motivation for our analysis as they suggest that banks with and without access to the central bank's deposit facility and repos secured by assets eligible or not for QE purchases behave differently in the money market.

3.1.2 ECB access

The first key aspect that we investigate is that only a given set of money market participants are banks with access to the central bank's refinancing

[10]The spread between eligible and noneligible rates has been present since the introduction of QE and peaked at the end of 2017 when the ECB's Securities Lending Programme was introduced (Brand et al., 2019). For the period prior to QE, we can apply the initial implementation provisions retrospectively to classify assets into *(hypothetically)* eligible and noneligible. The corresponding figure is presented in the online appendix; it confirms that the dispersion in levels has increased since the inception of the QE program.

operations and deposit facility.[11] In the euro area, the ECB operates two standing facilities that allow banks to deposit or access liquidity overnight: The deposit facility allows for overnight deposits, while the marginal lending facility provides overnight central bank liquidity. However, access to the ECB's facilities is limited to eligible counterparties, most importantly to banks subject to the Eurosystem's minimum reserve requirements. The minimum reserve system applies to banks and credit institutions established in the euro area. Whether a bank is formed in or outside the euro area is unrelated to monetary policy and the repo market and is thus a source of exogenous variation. We exploit the restriction that only euro area banks can access the deposit facility to classify counterparties in a repo transaction into *access* and *nonaccess* banks.

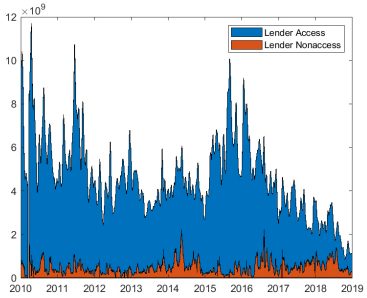
For this part, we focus on the *lending-side* in GC repos. Banks in the GC repo market can either operate as lenders of cash (i) to have a short-term, safe investment that offers a market-based rate of return (funding motive) or (ii) to source a high-quality collateral (collateral motive). Storing funds at the deposit facility is the outside option for banks with access to it.[12] The segmentation between access and nonaccess banks comes from the fact that access banks can safely invest liquidity in the repo market or place it at the deposit facility. In contrast, nonaccess banks can only rely on the former.[13] This mechanism

[11] The importance of access to central bank's facilities has been stressed in the literature. The deposit rate as the rate of remuneration for reserves is a general and important feature of financial intermediaries' decision problems that is incorporated into macro-financial models (Cúrdia and Woodford, 2011; Bech and Monnet, 2016; Williamson, 2019). In these models, a single deposit rate applies uniformly to all market participants and serves as the outside option for those banks. Segmentation induced by different access levels to central bank facilities is also supported empirically. For instance, Bech and Klee (2011) argue that the level of the effective federal funds rate was pushed downward by government agencies that could not receive interest on reserves. The analysis in Bech and Klee (2011) is confined to the unsecured market, while we look at segmentation across different secured and unsecured money market segments. In addition, Bech and Klee (2011) attribute their effect to bargaining power, this friction that does not play a role in a centrally-cleared setting like ours. Kraenzlin and Nellen (2015) find that banks without access to central bank facilities pay more interest in the unsecured money market to borrow liquidity.

[12] Banks could also invest in government bonds directly as opposed to investing liquidity in the repo market or – when having access – placing funds at the deposit facility. However, direct government bond investments have several drawbacks, such as higher transaction costs and not providing the same low-risk and liquid store of value as repos (Bank for International Settlements, 2017).

[13] The regulatory framework plays a negligible role in our analysis for at least three reasons: First, access and nonaccess banks in our sample are similarly regulated. Second, the new Basel regulation considers all assets under inspection to be of the highest quality (Level 1 assets) from the perspective of the Liquidity Coverage Ratio (LCR) (Bank for International Settlements, 2017). Furthermore, all maturities under inspection are shorter than the thirty-

(a) General collateral trading volumes



(b) Deposit facility volume and spread between GC rate and DFR

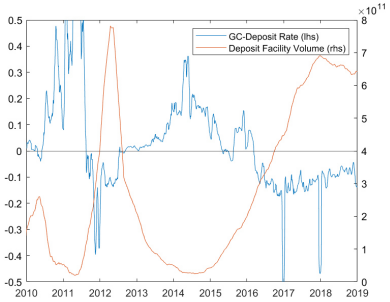


Figure 3.3a depicts the total trading volume in the German GC market for trades involving a lender with and without access to the ECB facilities. Figure 3.3b depicts the spread between the German GC rate and the ECB's rate on the deposit facility and the total volume deposited at the ECB deposit facility.

Figure 3.3: Repo market and deposit facility volumes

can also be shown graphically. Figure 3.3a depicts the development of the GC trading volume for access and nonaccess lenders (illustratively for Germany).[14] We observe a drop in GC trading volume in the two periods during which GC rates fell below the rate on the deposit facility (i.e., in 2012 and since 2015), we observe a drop in GC trading volume. This drop is accompanied by an increase in the volume of funds deposited at the ECB's deposit facility (see Figure 3.3b). For example, since 2015, we have observed a drop in GC trading volume to about a third of its original size. This reduction was mainly driven by banks that had access to the ECB's deposit facility. To our knowledge, this is a new stylized fact suggesting a first form of segmentation between access and nonaccess banks induced by the central bank framework. Access banks increasingly deposit funds at the deposit facility in the GC $<$ DFR environment,

day LCR cut-off time. Third, the Basel III leverage ratio does not impact the lender in a repo transaction since reverse repos do not enter the Basel III leverage ratio calculation (Ranaldo et al., 2021). The effect of segmentation between access and nonaccess banks is therefore not driven by the leverage ratio regulation. The introduction of the leverage ratio led to window dressing effects on repo rates, but those were mainly caused by the borrowing side. We provide several robustness checks in which we exclude those trading days.

[14] We present corresponding volume breakdowns by the borrowing side in the online appendix. However, we focus on the lending side throughout our paper. This allows us to examine market segmentation arising from access banks being able to lend liquidity in the repo market or deposit it at the central bank.

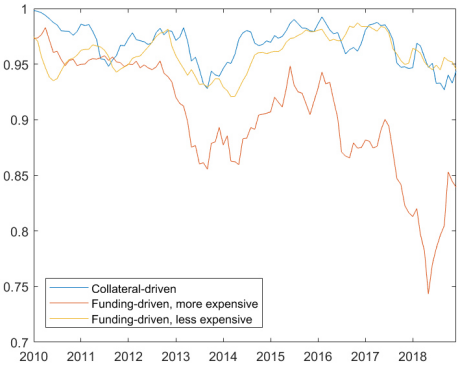
while nonaccess banks continue to lend in the GC market to obtain a (safe) deposit of liquidity.

In the euro area repo market, various GC repo baskets are traded, each with a different GC rate. Separate GC baskets exist for different euro area countries (e.g., German or Italian GC baskets) and for different government bonds types (e.g., German notes or long-term German bonds). Those GC rates differ and are naturally dispersed. Some of the GC baskets are more collateral-driven (trading at a lower rate), while others are more funding-driven (trading at a higher rate). Figure 3.4 shows in this context the share of access banks' trading in (i) German government bond baskets (blue line, "collateral-driven"), (ii) baskets of core euro area countries (red line, "funding-driven, more expensive"), and (iii) baskets of peripheral euro area countries including the GC pooling baskets (yellow line, "funding-driven, less expensive").[15] GC baskets in (i) are more collateral-driven as they ensure that the lender is receiving a high-quality asset such as a German Bund as collateral. In contrast, GC baskets in (ii) and (iii) are more funding-driven as they include, for example, the two GC pooling baskets.[16]

In the recent environment where several GC rates dropped below the ECB's DFR, access banks continued to have a collateral motive for lending in the repo market and remained active in collateral-driven baskets. At the same time, they moved out of more expensive, funding-driven baskets due to their outside option of storing funds at the deposit facility. The idea here is that access banks select themselves into more collateral-driven segments of the repo market in the GC $<$ DFR environment, which are less connected to funding-based money market segments. This mechanism is interesting, if not surprising since one would expect the secured lending rates of euro area banks to be more connected to other euro area money market rates. Still, the proposed mechanism is intuitive as the DFR is the attractive outside lending option to funding-based repo trades for access banks. This explains why access banks remained active in funding-driven baskets yielding higher rates than the DFR

[15]The Eurex GC pooling baskets are the main funding baskets in the euro area. They allow for highly-rated assets (i.e., investment-grade bonds), including assets issued by regional governments or "Pfandbrief" instruments of credit institutions, to be delivered.

[16]We present alternative classifications into collateral-driven and funding-driven trades in the online appendix. The results for all specifications are consistent. The share of nonaccess banks is defined as 100% minus the access banks' share.



The figure depicts the volume-weighted trading share of access banks in different types of GC baskets. The share is depicted for three subgroups: trades against German government bond baskets ("collateral-driven"), trades involving GC baskets of core euro area countries ("funding-driven, more expensive"), and trades involving collateral baskets of peripheral euro area countries, including the GC pooling baskets ("funding-driven, less expensive").

Figure 3.4: Trading share of access banks

(those of peripheral euro area countries) while they moved out of funding-driven baskets trading at lower rates close to or below the DFR (those of core euro area countries).[17] We provide a theoretical discussion of this mechanism in the online appendix.

3.1.3 Asset eligibility

The second key aspect we consider is the eligibility criteria of collateral assets for central bank QE purchases.[18] The ECB announced in 2015 its intention

[17] As some repo rates have been lower than the deposit rate for an extended period, the question arises whether an arbitrage opportunity for access banks exists by borrowing in the repo market and storing the borrowed funds at the deposit facility. This direct comparison of the repo rate and the deposit rate abstracts, however, from the value of the collateral as it assumes that central bank reserves are equivalent to repo loans. As Figure 3.4 shows, access banks still trade in the repo market in the GC $<$ DFR environment to obtain collateral. In fact, access banks are willing to accept a lower repo rate than the DFR to obtain the collateral, which they would forgo by delivering the collateral in a repo trade. Prior research shows that (repo) arbitrage activity exists but is insufficient to close these "gaps" (Ranaldo et al., 2019).

[18] The interplay of central bank asset purchases, financial intermediation, and collateral has been featured prominently in the theoretical literature. Gertler and Karadi (2013) show that

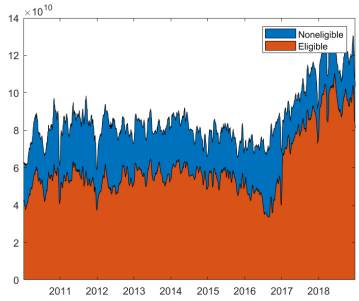
to conduct large-scale asset purchases. Since the beginning of these programs, cumulative net purchases amounted to more than 2.5 trillion euro. The Public Sector Purchase Program is the largest of the programs implemented in the Eurosystem; it focuses on purchasing government bonds. The sheer size of these purchases has contributed to scarcity effects for government bonds, which are an important category of safe assets and serve as collateral in repo transactions. QE programs, in general, aim to influence longer-term rates in an environment where short-term rates are at the zero lower bound (by affecting term premia, see Eser et al., 2019). An impact of QE-induced asset scarcity on short-term rates is thus an unintended side effect that can increase rate dispersion and lead to market segmentation. The effect of asset purchases on bond scarcity comes on top of tighter regulation of financial institutions under the new Basel framework (e.g., the introduction of the leverage ratio rules). The ECB has therefore constituted implementation provisions to limit market impacts and distortions. These provisions specify the assets the ECB can purchase (via local central banks). The implementation provisions for asset purchases, therefore, provide a source of exogenous variation as to which securities meet the respective criteria.

In our analysis, we exploit the implementation provisions to classify collateral in a repo transaction into *eligible* and *noneligible* depending on the provisions that were valid at a specific point in time.[19] We further apply the

if limits to arbitrage exist in the banking sector, central bank purchases of securities cause yields to fall. Araújo et al. (2015) stress that the direction of the impact of asset purchases depends on the way collateral constraints are affected. Piquard and Salakhova (2019) highlight how monetary policy affects unsecured and secured markets differently once the central bank purchases marketable collateral. Their mechanism is motivated by an increase in the opportunity cost of pledging collateral. Divergent QE effects on financial markets are also supported empirically. For instance, Arrata, Nguyen, Rahmouni-Rousseau, and Vari (2020) and Corradin and Maddaloni (2020) show that asset purchases lowered special repo rates, an effect that they relate to asset scarcity. Roh (2022) points out that the ECB's decision not to lend out bonds that it purchased also increased their scarcity. Related, nonbanks' reluctance to lend bonds adds to the scarcity of those assets (Maddaloni and Roh, 2021). Focusing on the bond market, Schlepper, Riordan, Hofer, and Schrimpf (2017) show that QE increased prices and lowered liquidity in purchased German bonds. Koijen, Koulischer, Nguyen, and Yogo (2017) show that in response to the ECB's purchasing programs, foreign investors sold most of their QE eligible bond holdings to domestic investors, pointing to a strong home bias in eligible securities. This shift was also documented in aggregate data by Avdjiev et al. (2019).

[19] Under the umbrella of the PSPP, the ECB started in 2015 to buy nominal and inflation-linked government bonds and securities issued by recognized agencies, regional and local governments, international organizations, and multilateral development banks located in the euro area. Overall, around 90% of the purchases correspond to government bonds. The

(a) Special collateral trading volume



(b) Spread between (hypothetically) eligible and noneligible assets

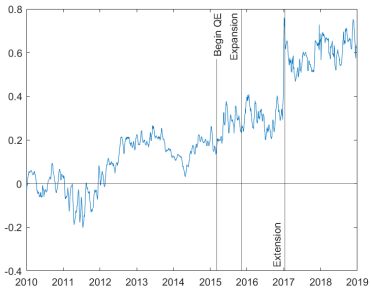


Figure 3.5a depicts the total trading volume in the special collateral market for trades involving eligible and noneligible collateral. Figure 3.5b depicts the spread between the average repo rate on noneligible and eligible securities (average rate for noneligible collateral minus average rate for eligible collateral).

Figure 3.5: Special collateral repo market

initial implementation provisions retrospectively to compare time trends between *(hypothetically) eligible* and *noneligible* assets, which creates a difference-in-difference estimation setting. Observing similar reactions of both types of assets before QE would imply common trends and allow us to interpret the QE impact as causal.

For this part of the analysis, we focus on the special repo segment that specifies a specific asset as collateral. The idea is that assets eligible for QE tend to be scarcer, and repos secured by those assets become predominantly driven by collateral demand disconnecting them from funding-based money market segments. Figure 3.5a shows in this context the development of the trading volume in the special repo market for eligible and noneligible bonds, while Figure 3.5b depicts the spread between the average repo rate on noneligible and eligible securities. A second, new stylized fact emerges as we observe an increase in special collateral trading volume since the start of QE. This increase is pre-

implementation 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 bond, (ii) a yield restriction that states that the yield of a bond needs to be above the ECB's deposit facility rate, and (iii) it only allows for the purchase of bonds denominated in euro. Over time, the ECB has adjusted and modified the initial implementation provisions. For example, the yield restriction ceased at the end of 2017.

dominantly driven by QE eligible assets. Since the start of QE, we also observe that repo rates for QE eligible assets have fallen below those of noneligible assets in line with Arrata et al. (2020) and Corradin and Maddaloni (2020). The spread between noneligible and eligible assets was always positive during the QE period and has increased further after the expansion and extension of the program. This is in line with our idea that QE eligible assets become scarcer due to central bank asset purchases; the demand to source those assets in the repo market has therefore increased, leading to a higher repo specialness. Naturally, one expects collateral types that are scarcer to be more collateral-driven and thus less connected to funding-based money market segments. Again, we provide a theoretical discussion of this mechanism in the online appendix.

3.1.4 Data

For our analysis, we employ high-frequency data for the European repo market for the period from 2010 to 2020. Our data includes all electronically traded repo transactions in euro on the three main trading platforms (i.e., BrokerTec, Eurex, and MTS) and covers more than 70% of the entire repo market universe. For each transaction, we observe the trade date, the term, the trade volume, the rate, the collateral identified by a unique ISIN (for special repos) or basket (for GC repos), the lender, the borrower, the aggressor type and the trading platform. We focus on the term types overnight (ON), tomorrow-next (TN), and spot-next (SN), with the purchase date being today, tomorrow, and the day after tomorrow, respectively, and the repurchase date one day thereafter.[20]

We exclude a very small fraction of repo contracts and trading days to ensure the robustness and general validity of our results. First, we exclude holidays as well as year-end trading days. We further provide robustness checks excluding all quarter-end and end of ECB maintenance period trading days, as well as the corresponding weeks.[21] Second, we exclude special repos secured by corporate securities. Third, we exclude repos with floating rates, repos with open term type, bilaterally pre-arranged repos, and repos that are not cleared via a CCP.

[20] These term types make up 97% of the entire repo market trading volume. Trading in the GC market predominantly takes place in the ON and TN market segments. In contrast, trading in the special repo market segment predominantly takes place in the TN and SN market segments. We account for this in the empirical part.

[21] On quarter- and year-end days as well as on the end of ECB maintenance period days, window dressing impacts repo rates (Ranaldo, Schaffner, and Vasios, 2021).

Finally, we exclude repos that are traded infrequently.[22] We also perform our analyses for three different groups of countries: (i) Germany, (ii) core European countries, and (iii) all European countries.[23]

To identify banks, we follow the approach of Ranaldo et al. (2019) and Di Filippo et al. (2022) based on supervisory data. We then classify banks into access and nonaccess institutions depending on whether they need to fulfill the reserve requirements of the Eurosystem and have access to the deposit facility.[24] Our data contains repo trades involving 98 different banks, of which 85 are access banks and 13 are nonaccess banks.[25] We observe information on both the lending and borrowing bank for trades featuring 59% of the entire trading volume; among those trades, 22% are associated with a nonaccess bank. The upper part of Table 3.1 provides a comparison of the two groups. We see that the characteristics of access and nonaccess banks are similar. For instance, at the end of our sample period, access banks had, on average, assets worth 290.6 euro billion compared to 241.2 euro billion for nonaccess banks; the leverage ratios were about 17 for both types of banks. Interestingly, in the GC $<$ DFR environment, the average repo rate of trades involving access lenders is -0.22% compared to -0.29% for nonaccess lenders. This points to the idea that access lenders move away from funding-driven baskets trading below the DFR and substitute their investments with DFR deposits that yield a higher remuneration.

Moreover, we classify assets as eligible and noneligible for QE according to the PSPP's implementation provisions. We also apply the initial implementation provisions retrospectively to compare hypothetically eligible and noneligible assets. Our data set contains special repo trades involving more than

[22] To be included in our analysis, a repo needs to be traded at least 100 times. In addition, between the issuance and maturity date of the collateral, a repo needs to be traded at least once every two weeks 95% of the time. Our results are robust to different specifications.

[23] Core European countries include Austria, Belgium, Finland, France, Germany, and the Netherlands, and all European countries include, in addition, the EU, Ireland, Italy, Portugal, and Spain.

[24] Banks operating in the repo market are, for example, Deutsche Bank AG and Nordea Bank Danmark A/S. The former is a euro area bank with access to the deposit facility, while the latter is a foreign bank without access. For our classification, we assume that local subsidiaries of global banking institutions operate independently in the short run. Thus, euro area subsidiaries of foreign banking groups have access to the deposit facility while foreign subsidiaries of euro area banking groups do not have access to the deposit facility.

[25] The number of nonaccess banks is constant throughout our sample, thereby mitigating endogeneity concerns of nonaccess banks switching locations to access the deposit facility.

Table 3.1: Breakdown of the repo data

	Access banks	Nonaccess banks
General collateral euro area repos		
Trade size (mn)	206.0	133.7
Repo rate (GC > DFR)	0.16%	0.13%
Repo rate (GC < DFR)	−0.22%	−0.29%
Interquartile range	0.51%	0.66%
# Baskets traded in per month	4.0	3.7
Total assets (bn)	290.6	241.2
Leverage ratio	16.7	17.2

	QE eligible assets	QE noneligible assets
Special collateral euro area repos		
Trade size (mn)	22.3	21.6
Repo rate (pre-QE)	0.16%	0.26%
Repo rate (post-QE)	−0.58%	−0.13%
Interquartile range	0.60%	0.74%
Bond issue size (bn)	37.8	36.7
Bond tenor (years)	12.6	6.4
Bond coupon rate	3.2%	3.1%

The table shows the breakdown of the repo data denominated in euro. For the classification between access and nonaccess banks, we focus on the lending side in GC repos; for the classification between eligible and noneligible assets, we focus on special repos. For all repo trades, we show the average daily trade size (in euro million), the daily volume-weighted average repo rate for periods when the average GC rate is above/below the DFR (for periods prior to and after the introduction of the QE program), and the daily interquartile range defined as the difference between the 25th and 75th percentile repo rate. For access and nonaccess banks, we further show the average number of different GC baskets each bank is trading in during a month, the average total asset size (in euro billion), and the leverage ratio at the end of our sample period. For eligible and noneligible assets, we show each bond's issue size (in euro billion), tenor (in years), and coupon rate (if bonds are fixed-rate).

2,000 collateral assets (ISINs). Seventy-six percent of our sample involves repo trades collateralized by (hypothetically) eligible assets, 24% collateralized by noneligible assets. The lower part of Table 3.1 compares characteristics between eligible and noneligible collateral assets. We observe that repo rates for QE eligible assets have fallen below those of noneligible assets since the start of QE. The average tenor is longer for eligible assets as this is one of the implementation criteria. Other bond characteristics such as repo trade size, bond issue size, and bond coupon rate are comparable between the two groups. Since we only consider government bonds as collateral, all assets are broadly accepted as collateral and are treated in the same way for regulatory purposes.

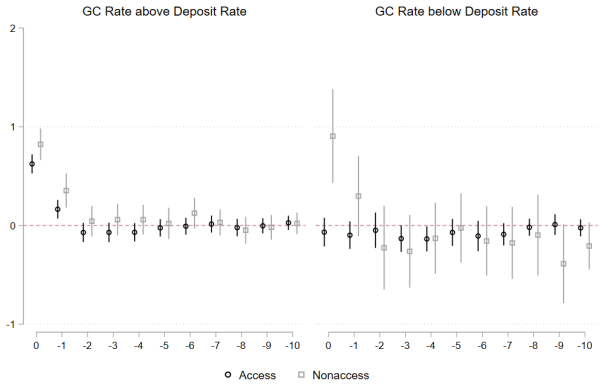
3.2 Empirical results

The idea of this paper is that a weaker correlation between money market rates is a sign of segmentation that emerges when the role of collateral in repos becomes dominant over the role of funding. To document this mechanism, we begin by analyzing the correlation between secured repo rates and the unsecured money market benchmark rate (EONIA) before broadening our view to other money market segments.

3.2.1 Access/nonaccess banks

We first want to understand whether the access restrictions to the central bank's deposit facility lead to money market segmentation. Access banks always have the option to store funds at the deposit facility, which is particularly attractive in the GC $<$ DFR environment; during those periods, we expect access banks to trade in the repo market predominantly for collateral purposes. Therefore, our first testing hypothesis is that lending rates of access banks are more collateral-driven and thus less connected to the funding-based EONIA rate, particularly when repo rates fall below the DFR.

We provide a first graphical intuition of this mechanism in Figure 3.6 which illustrates the lower sensitivity of access banks to changes in the EONIA rate in the form of impulse response functions. We compute impulse response functions for trades involving access and nonaccess banks separately for periods during which the average GC rate is above the deposit rate (left panel) and below the deposit rate (right panel). The coefficients are derived from a time series



The figure depicts the impulse response function of repo rates to changes in the money market benchmark rate for trades involving access and nonaccess banks in the period when the average GC rate is above (left panel) and below the rate on the deposit facility (right panel). The coefficients are derived from a time series regression of current repo rate changes on the concurrent and the preceding ten EONIA rate changes controlling for basket-month-term fixed effects. The regression includes heteroscedasticity-robust standard errors. Data include GC repo transactions for Germany for the term types ON and TN for the period 2010–2018.

Figure 3.6: Impulse response for trades involving access/nonaccess banks

regression of current repo rate changes on the concurrent and the preceding ten EONIA rate changes. The left panel highlights that access and nonaccess banks react similarly during periods when the GC rate is above the deposit rate, with the point estimate for access banks being slightly smaller. Even if the deposit facility provides a smaller remuneration than a repo trade, the liquidity storage at the deposit facility is convenient for banks with access to it, thus explaining the overall lower sensitivity of access banks. However, once the GC rate drops below the DFR, the sensitivity of access banks is completely muted as they predominately trade for collateral purposes. By contrast, banks without the outside option of storing funds at the deposit facility are still active in funding-based repo market segments keeping them more connected to changes in the EONIA rate. The graphical results point towards money market segmentation associated with access banks reacting less to changes in funding-based money market rates and a resulting rate dispersion between access and nonaccess banks, particularly when GC rates fall below the DFR.

We formalize the graphical intuition in a set of panel regressions. Our main regression equations read as follows:

$$\begin{aligned}
\Delta r^{GC}_{t,i,l} &= \beta_1 \cdot \Delta MMRate_t + \beta_2 \cdot D^{Dep}_{t,n} + \beta_3 \cdot \Delta MMRate_t \cdot D^{Dep}_{t,n} \\
&\quad + \beta_4 \cdot \Delta r^{GC}_{t-1,i,l} + \epsilon_t \qquad (3.1)\\
\Delta r^{GC}_{t,i,l} &= \beta_1 \cdot \Delta MMRate_t + \beta_2 \cdot D^{Access}_{t,l} + \beta_3 \cdot \Delta MMRate_t \cdot D^{Access}_{t,l} \\
&\quad + \beta_4 \cdot \Delta r^{GC}_{t-1,i,l} + \epsilon_t \qquad (3.2)\\
\Delta r^{GC}_{t,i,l} &= \beta_1 \cdot \Delta MMRate_t + \beta_2 \cdot D^{Dep}_{t,n} + \beta_3 \cdot D^{Access}_{t,l} + \beta_4 \cdot \Delta MMRate_t \cdot D^{Dep}_{t,n} \\
&\quad + \beta_5 \cdot \Delta MMRate_t \cdot D^{Access}_{t,l} + \beta_6 \cdot \Delta MMRate_t \cdot D^{Dep}_{t,n} \cdot D^{Access}_{t,l} \\
&\quad + \beta_7 \cdot \Delta r^{GC}_{t-1,i,l} + \epsilon_t, \qquad (3.3)
\end{aligned}$$

where $\Delta r^{GC}_{t,i,l}$ denotes the log-change in GC repo rates of basket i and lender type (access / nonaccess) l at time t and $\Delta MMRate_t$ denotes the log-change in the EONIA rate which we refer to as the money market benchmark rate. Moreover, we employ two dummy variables: $D^{Dep}_{t,n}$, which is equal to one if country n's average GC rate is below the deposit facility rate, and $D^{Access}_{t,l}$, which is equal to one if lender l has access to the deposit facility.[26] We add basket-month-term fixed effects and employ heteroscedasticity-robust standard

[26]The denominations are: $\Delta r^{GC}_{t,i,l}$ is the log change in the volume-weighted average daily repo rate per basket and lender type in percentage points. Correspondingly, $\Delta MMRate_t$ refers to the log change in the EONIA rate denoted in percentage points.

errors. Since trading in the GC repo market is concentrated in the ON and TN term types, we show our main results as a pooled regression of both term types in Table 3.2. We report our results for Germany in columns (1)–(3), core European countries in columns (4)–(6), and all European countries in columns (7)–(9).

As a first step, we consider repo transactions collateralized by German government bonds. Since German collateral is considered safe and liquid, this limits any concerns about cross-country differences in sovereign risk and liquidity impacting our results. Column (1) relates changes in GC rates to changes in the money market benchmark rate, depending on whether the GC rate is above or below the DFR. The results highlight that GC rates react strongly: A one-percentage-point increase in the EONIA rate is accompanied by an increase in GC rates of about 54 basis points. The effect is smaller at 36 basis points when the GC rate is below the DFR. This confirms our intuition that GC repo trades have a strong funding motive, which, however, becomes less important in the GC $<$ DFR environment.

In column (2), we analyze the different reactions of access and nonaccess banks. GC rates lent by banks with access to the deposit facility react less strongly. For example, an increase in the funding-based benchmark rate by one percentage point relates to an increase in GC rates involving access banks of 45 basis points compared to 72 basis points for nonaccess banks.

Considering our main regression in column (3), which includes both dummy variables, we observe a combined effect: GC rates involving lenders with access tend to react less; their reaction is particularly weak when GC rates are below the DFR. The effect of changes in the money market benchmark rate on GC rates is 68 basis points for nonaccess banks as compared to 50 basis points for access banks for periods when GC rates are above the deposit rate. Once GC rates are below the DFR, the effect increases to 94 basis points for nonaccess banks while it decreases to 4 basis points for access banks. This indicates that lenders with access to the deposit facility do not react to changes in the funding-based money market segment in the GC $<$ DFR environment as their trades are predominantly collateral-driven, while lenders without access are very sensitive to it.

Columns (4)–(9) expand our analysis by looking at larger samples of core European countries and all European countries. Overall, the results remain

Table 3.2: ECB access

	Germany			Core			All		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.539***	0.717***	0.675***	0.473***	0.683***	0.646***	0.426***	0.589***	0.563***
	(15.699)	(10.745)	(8.781)	(23.146)	(16.875)	(14.515)	(24.823)	(16.778)	(15.341)
D^{Dep}	−0.046**		−0.047**	−0.031***		−0.031***	0.003		0.002
	(−2.265)		(−2.338)	(−2.851)		(−2.917)	(0.304)		(0.287)
$\Delta MMRate \cdot D^{Dep}$	−0.176**		0.265**	−0.061		0.312***	−0.013		0.399***
	(−2.216)		(2.082)	(−1.141)		(3.952)	(−0.257)		(5.370)
D^{Access}		−0.001	−0.000		−0.005	−0.004		−0.003	−0.003
		(−0.071)	(−0.035)		(−0.819)	(−0.720)		(−0.746)	(−0.669)
$\Delta MMRate \cdot D^{Access}$		−0.264***	−0.177**		−0.284***	−0.224***		−0.223***	−0.187***
		(−3.549)	(−2.100)		(−6.242)	(−4.520)		(−5.687)	(−4.548)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$			−0.719***			−0.574***			−0.616***
			(−4.970)			(−5.860)			(−6.607)
N	10,007	10,007	10,007	35,102	35,102	35,102	58,216	58,216	58,216
R^2	0.210	0.213	0.220	0.180	0.185	0.187	0.174	0.177	0.179
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, 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 heteroscedasticity-robust standard errors. Data include GC repo transactions for Germany, core European countries, and all European countries pooled across the term types ON and TN for the period 2010–2018.

statistically and economically consistent. This indicates that the impact of having access to central bank facilities is not only present in the German "safe haven" market but across European countries as well.

We perform several additional robustness checks, which confirm our main results. First, we ensure that the results are consistent for each term type and regional classification. Second, we show that the results are robust for different standard error and fixed effect specifications. Third, we repeat our analysis in a sample without quarter-end and end of ECB maintenance period days and weeks. Our results are robust to removing those days characterized by higher idiosyncratic rate movements and spikes. And finally, we replicate our results for the sub-period until 2016 to account for the lower volatility and trading volume in the EONIA rate in recent years. We report all results in the online appendix.

To gain additional insight into our mechanism and the role of the DFR reflecting the opportunity cost of engaging in a repo trade for funding purposes, we extend our analysis by looking at the distance between GC rates and the DFR. Our idea is that the sensitivity of access banks to changes in the funding-based money market rate is weaker for periods when the opportunity cost of engaging in a repo trade for funding purposes is higher. More precisely, we expect that the lower GC rates are relative to the DFR, the more access banks will be active in collateral-based repo market segments, which are more disconnected from funding-based money market segments.

Table 3.3 reports the regression results, which focus on the distance of repo rates to the DFR. We show two regression specifications: (i) by employing a new, continuous variable, "DFR Distance," which measures the difference between the DFR and the GC rate;[27] and (ii) by employing three buckets with $DFR1$ indicating periods when the GC rate is 25-50 basis points above the DFR, $DFR2$ indicating periods when the GC rate is 0-25 basis points above the DFR, and $DFR3$ indicating periods when the GC rate is below the DFR. For all regressions, we replace our previous D^{Dep} dummy with the newly introduced DFR Distance variable or the respective DFR Distance buckets, interacted with the change in the EONIA rate $\Delta MMRate_t$. We report our results for Germany in columns (1) and (2), core European countries in columns (3) and (4), and all European countries in columns (5) and (6).

[27] Positive values of the DFR Distance variable indicate that GC rates are below the DFR.

Table 3.3: ECB access: Distance to deposit facility rate

	Germany		Core		All	
	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t
$\Delta MMRate$	0.716^{***}	0.716^{***}	0.684^{***}	0.684^{***}	0.589^{***}	0.589^{***}
	(10.706)	(10.726)	(16.862)	(16.875)	(16.782)	(16.795)
D^{Access}	-0.005	-0.004	-0.007	-0.007	-0.006	-0.006
	(-0.424)	(-0.350)	(-1.254)	(-1.282)	(-1.280)	(-1.348)
$\Delta MMRate \cdot D^{Access}$	-0.386^{***}	0.108	-0.411^{***}	0.149^{**}	-0.334^{***}	0.172^{***}
	(-4.772)	(1.183)	(-8.421)	(2.575)	(-8.083)	(3.210)
$\Delta MMRate \cdot D^{Access} \cdot DFRDistance$	-0.719^{***}		-0.783^{***}		-0.608^{***}	
	(-5.718)		(-9.091)		(-8.245)	
$\Delta MMRate \cdot D^{Access} \cdot D^{DFR1}$		-0.235^{**}		-0.137^{**}		-0.244^{***}
		(-2.235)		(-1.992)		(-3.207)
$\Delta MMRate \cdot D^{Access} \cdot D^{DFR2}$		-0.375^{***}		-0.483^{***}		-0.443^{***}
		(-4.831)		(-9.861)		(-9.692)
$\Delta MMRate \cdot D^{Access} \cdot D^{DFR3}$		-0.785^{***}		-0.683^{***}		-0.612^{***}
		(-8.907)		(-10.004)		(-9.205)
N	10,007	10,007	35,102	35,102	58,216	58,216
R^2	0.218	0.221	0.190	0.192	0.180	0.181
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation, focusing on the distance of repo rates to the deposit facility rate. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Access} equals one if a lending bank has access to the deposit facility. $DFRDistance$ refers to the difference between the DFR and a country's average GC rate. D^{DFR1} indicates periods when the GC rate is between 25-50 basis points above the DFR, D^{DFR2} indicates periods when the GC rate is between 0-25 basis points above the DFR, and D^{DFR3} indicates periods when the GC rate is below the DFR. ***, **, 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 heteroscedasticity-robust standard errors. Data include GC repo transactions for Germany, core European countries, and all European countries pooled across the term types ON and TN for the period 2010–2018.

Our results highlight that the distance of GC rates to the DFR significantly impacts access banks. Column (1) shows that the sensitivity of access banks to changes in the money market benchmark rate decreases in the difference between the DFR and the GC rate. For example, if the difference between the DFR and the GC rate increases by ten basis points (i.e., GC rates drop by ten basis points relative to the DFR), the sensitivity of access banks to changes in the EONIA rate reduces by seven basis points. Column (2) confirms that access banks are already less reactive to EONIA rate changes when GC rates get closer to the DFR. This effect is intensified once GC rates drop below the DFR. Both results confirm that access banks select themselves into more collateral-driven repo market segments when the opportunity cost of engaging in funding-based repo trades is higher, which leads to a disconnect of their repo lending rates from funding-based money market rates.

3.2.2 Introduction of the ECB tiering as a natural experiment

The introduction of the ECB's two-tier system for remunerating excess reserve holdings ("tiering") in 2019 is a natural experiment to illustrate our mechanism. The two-tier system allows each access bank to store excess reserves at the ECB without paying the negative deposit rate that would generally apply to them.[28] The introduction of the tiering implies that the deposit facility becomes an even more attractive option for access banks to store liquidity, particularly for those access banks that still have unused allowances. Fuster et al. (2021) find that an increase in exemption allowances in Switzerland induced banks to deposit more funds at the deposit facility and restrict their lending activities. In the context of our mechanism, access banks have an additional incentive to store funds at the ECB's deposit facility due to the tiering exemptions. Consequently, we expect access banks to move out of funding-based repo market segments after the tiering exemptions were introduced. At the same time, we expect access banks to continue trading in collateral-driven parts of the repo market, which are less connected to funding-based money market rates, thereby exacerbating money market segmentation.

To isolate the impact of the tiering system, we adapt our empirical analysis for the period around the introduction of the two-tier system covering the

[28] For holdings above the allowance, the deposit facility rate continues to apply.

Table 3.4: ECB access: Introduction of ECB tiering system

	Germany	Core	All
	(1)	(2)	(3)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON/TN	ON/TN	ON/TN
	b/t	b/t	b/t
$\Delta MMRate$	0.887***	0.752***	0.774***
	(17.552)	(13.238)	(17.169)
$D^{Tiering}$	−0.017*	−0.022***	−0.043***
	(−1.961)	(−3.406)	(−4.550)
$\Delta MMRate \cdot D^{Tiering}$	0.086	−0.034	−0.001
	(0.629)	(−0.268)	(−0.004)
D^{Access}	0.002	−0.003	0.000
	(0.344)	(−1.023)	(0.053)
$\Delta MMRate \cdot D^{Access}$	−0.076	0.048	0.035
	(−0.672)	(0.544)	(0.509)
$\Delta MMRate \cdot D^{Access} \cdot D^{Tiering}$	−0.350	−0.566**	−0.758**
	(−1.181)	(−2.451)	(−2.294)
N	516	1,657	2,811
R^2	0.470	0.357	0.334
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes

The table reports the regression results examining the impact of the ECB's introduction of the tiering program on money market segmentation. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the money market rate. $D^{Tiering}$ equals one during the period the tiering was in place beginning on October 30th, 2019. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. All regressions include basket, month, and term fixed effects and heteroscedasticity-robust standard errors. Data include GC repo transactions for Germany, core European countries, and all European countries pooled across the term types ON and TN for the period of the two ECB maintenance periods preceding the ECB Tiering introduction as well as the two ECB maintenance periods thereafter (i.e., August 2019 to January 2020).

two ECB maintenance periods before and after the introduction.[29] For this, we introduce the dummy variable $D^{Tiering}$, which is equal to one after the introduction of the tiering system on October 30th, 2019. For this analysis, We then replace our previous D^{Dep} dummy for this analysis with the newly introduced $D^{Tiering}$ dummy.

The results in Table 3.4 confirm that access banks are less responsive to EONIA rate changes after the introduction of the tiering. This effect is significant for core and all European countries in line with the idea that banks in those peripheral countries have benefited most from the introduction of the

[29]The tiering is an out-of-sample analysis; hence it does not impact our main results.

tiering and thus became less reactive to changes in funding-based money market rates. The two-tier system strongly impacts banks that still have room in their allowance, which is more common in peripheral countries, for example, in Italy (Cœuré, 2018). Due to the home bias observed among European financial institutions (Koijen et al., 2017), the segmentation becomes particularly noticeable in GC baskets associated with those peripheral countries.

3.2.3 Eligible/noneligible assets

The eligibility criteria of the QE program are a second illustration of our mechanism leading to money market segmentation. Eligible collateral is scarce and in high demand; repos secured by those scarce assets are more collateral-driven and thus less connected to funding-based money market segments. Therefore, our second testing hypothesis is that repo rates secured by QE eligible assets are more disconnected from other money market rates, such as the EONIA rate. Similar to the previous analysis, a lower correlation implies a stronger segmentation between the secured and unsecured money market segments. Our main panel regression equations read as follows:

$$\begin{aligned}\Delta r^{Special}_{t,i,l} &= \beta_1 \cdot \Delta MMRate_t + \beta_2 \cdot D^{QE}_t + \beta_3 \cdot \Delta MMRate_t \cdot D^{QE}_t \\ &\quad + \beta_4 \cdot \Delta r^{Special}_{t-1,i,l} + \epsilon_t \end{aligned} \tag{3.4}$$

$$\begin{aligned}\Delta r^{Special}_{t,i,l} &= \beta_1 \cdot \Delta MMRate_t + \beta_2 \cdot D^{Eligible}_{t,i} + \beta_3 \cdot \Delta MMRate_t \cdot D^{Eligible}_{t,i} \\ &\quad + \beta_4 \cdot \Delta MMRate_t \cdot D^{QE}_t \cdot D^{Eligible}_{t,i} + \beta_5 \cdot \Delta r^{Special}_{t-1,i,l} + \epsilon_t \end{aligned} \tag{3.5}$$

$$\begin{aligned}\Delta r^{Special}_{t,i,l} &= \beta_1 \cdot \Delta MMRate_t + \beta_2 \cdot D^{QE}_t + \beta_3 \cdot D^{Eligible}_{t,i} + \beta_4 \cdot \Delta MMRate_t \cdot D^{QE}_t \\ &\quad + \beta_5 \cdot \Delta MMRate_t \cdot D^{Eligible}_{t,i} + \beta_6 \cdot \Delta MMRate_t \cdot D^{QE}_t \cdot D^{Eligible}_{t,i} \\ &\quad + \beta_7 \cdot \Delta r^{Special}_{t-1,i,l} + \epsilon_t, \end{aligned} \tag{3.6}$$

where $\Delta r^{Special}_{t,i,l}$ denotes the log-change in special repo rates and $\Delta MMRate_t$ denotes the log-change in the EONIA rate. Moreover, we employ two dummy variables: $D^{Eligible}_{t,i}$, which is equal to one if *security* i is (hypothetically) eligible for purchase under the PSPP, and D^{QE}_t, which is equal to one after the introduction of the PSPP in March 2015. Additionally, we add ISIN-month-term fixed effects and heteroscedasticity-robust standard errors.[30] Trading in the special repo market is concentrated in the TN and SN term types; we,

[30]The fixed effects capture all bond-specific properties that are constant within a month, for example, the issue size or the on-the-run status.

therefore, show our main results as a pooled regression of both term types in Table 3.5. We report our results for Germany in columns (1)–(3), core European countries in columns (4)–(6), and all European countries in columns (7)–(9).

Column (1) relates changes in special repo rates to changes in the money market benchmark rate in the period prior to and after the introduction of the QE program. An increase in the unsecured benchmark rate by one percentage point translates into an increase of around 11 basis points in special repo rates in the period prior to QE. During the current QE period, the effect has been muted. Although well expected based on our idea, a new stylized fact emerges as special repo rates are more collateral-driven and thus react less strongly to changes in the EONIA rate than more funding-driven GC rates. Still, a special repo trade also involves a funding motive and reacts to changes in funding conditions.

In column (2), we consider the impact of market segmentation along the lines of assets' eligibility for QE in a difference-in-difference setting. The dummy variable $D_{t,i}^{Eligible}$ measures whether the underlying collateral asset fulfills the eligibility criteria since the start of the program and whether it had (hypothetically) fulfilled the criteria in the prior periods. In order to be able to interpret the effect of asset eligibility as causal, we need to verify that the common trend assumption holds. This assumption holds if eligible and noneligible assets behave similarly in the period prior to QE. We, therefore, apply the initial implementation provisions retrospectively. We observe that trades involving hypothetically eligible assets do not exhibit significantly different changes in repo rates prior to QE; eligible and noneligible collateral assets also respond similarly to changes in the benchmark rate during that period. In the pre-QE period, the common trend assumption therefore holds. However, since the start of QE, repo trades involving eligible assets have a 17-basis-points lower sensitivity to changes in the EONIA rate than noneligible assets. This speaks to an effect caused by central bank bond purchases.

Our main regression in column (3) captures both effects. The impact of changes in the money market benchmark rate on special repo rates is almost muted during QE, which is, in particular, driven by trades involving QE eligible assets. In the period after the QE introduction, an increase in the benchmark rate by one percentage point implies an increase in the rates of noneligible

Table 3.5: Asset eligibility

	Germany			Core			All		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.106***	0.098***	0.109***	0.105***	0.095***	0.103***	0.099***	0.094***	0.101***
	(19.746)	(13.001)	(13.196)	(31.250)	(17.688)	(17.850)	(30.217)	(18.379)	(18.370)
D^{QE}	−0.016		−0.016	−0.008		−0.008	−0.020**		−0.020**
	(−1.448)		(−1.420)	(−1.176)		(−1.157)	(−2.001)		(−1.996)
$\Delta MMRate \cdot D^{QE}$	−0.150***		−0.120***	−0.126***		−0.106***	−0.108***		−0.091***
	(−15.860)		(−8.160)	(−19.822)		(−9.820)	(−17.347)		(−8.349)
$D^{Eligible}$		0.004	0.004		0.003	0.003		0.001	0.001
		(0.443)	(0.428)		(0.580)	(0.578)		(0.236)	(0.214)
$\Delta MMRate \cdot D^{Eligible}$		0.006	−0.005		0.011	0.002		0.004	−0.004
		(0.537)	(−0.462)		(1.622)	(0.299)		(0.594)	(−0.556)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$		−0.172***	−0.052***		−0.136***	−0.030**		−0.116***	−0.026*
		(−14.030)	(−2.736)		(−17.421)	(−2.211)		(−15.232)	(−1.936)
N	301,766	301,766	301,766	706,015	706,015	706,015	943,926	943,926	943,926
R^2	0.116	0.116	0.116	0.113	0.113	0.113	0.117	0.117	0.117
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing programs on money market segmentation. The dependent variable is the change in the special rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) 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 ISIN-month-term fixed effects and heteroscedasticity-robust standard errors. Data include special repo transactions for Germany, core European countries, and all European countries pooled across the term types TN and SN for the period 2010–2018.

assets by five basis points more relative to QE eligible assets. While the overall size of this effect seems small, it represents a 50% reduction relative to the overall sensitivity of special repo rates to changes in the unsecured money market segment. It highlights that assets become even more collateral-driven and therefore disconnect from funding-based money market movements when they are targeted by QE.

Columns (4)–(9) extend our analysis to core European countries and all European countries and confirm our results.

Similar to the previous analyses, we perform several additional robustness checks. First, we repeat our analysis for each term type and regional classification; second, for different standard error and fixed effect specifications; third, in a sample without quarter-end and end of ECB maintenance period trading days and weeks; and finally, for a shorter sub-period until 2016. Overall, the results remain statistically and economically consistent.[31]

To further manifest the economic determinants of our mechanism, we extend our analysis by looking at asset scarcity associated with QE in more detail. Our idea is that asset scarcity is stronger for those assets which have been QE eligible for a longer period. Presumably, repos secured by scarcer assets are even more collateral-driven and thus less connected to funding-based money market segments.

Table 3.6 reports the regression results focusing on the number of days an asset is eligible for QE purchase. We show two regression specifications: (i) by employing a new variable "time since eligibility" (TSE) which captures the number of days an asset has been eligible for purchase under the PSPP;[32] and (ii) by employing three TSE buckets with TSE^1_{Bucket} for assets that have been QE eligible for up to 200 trading days, TSE^2_{Bucket} for assets that have been eligible for up to 400 days, and TSE^3_{Bucket} for assets that have been eligible for more than 400 days. For all regressions, we replace our previous $D^{Eligible}_{t,i}$ dummy with the newly introduced TSE variable or the respective TSE buckets, interacted with the change in the EONIA rate $\Delta MMRate_t$.

Column (1) relates changes in special repo rates to changes in the money market benchmark rate under consideration of the continuous TSE variable.

[31] All robustness checks are reported in the online appendix.

[32] TSE is a continuous variable which increases by one if asset i on day t was eligible for QE purchases. If an asset was eligible in the past but is not at the moment, the TSE variable keeps its value.

Table 3.6: Asset eligibility: Time since eligibility

	Germany		Core		All	
	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t
$\Delta MMRate$	0.106***	0.106***	0.105***	0.105***	0.099***	0.099***
	(19.745)	(19.745)	(31.250)	(31.250)	(30.217)	(30.217)
D^{QE}	−0.015	−0.016	−0.008	−0.008	−0.020*	−0.020**
	(−1.365)	(−1.409)	(−1.091)	(−1.146)	(−1.951)	(−1.987)
$\Delta MMRate \cdot D^{QE}$	−0.093***	−0.120***	−0.080***	−0.104***	−0.070***	−0.082***
	(−9.025)	(−8.483)	(−11.334)	(−9.789)	(−10.101)	(−7.532)
$\Delta MMRate \cdot TSE$	−0.001***		−0.001***		−0.001***	
	(−9.655)		(−9.894)		(−10.604)	
$\Delta MMRate*$						
TSE^1_{Bucket}		−0.008		−0.010		−0.022*
		(−0.467)		(−0.817)		(−1.776)
TSE^2_{Bucket}		−0.279***		−0.087**		−0.037
		(−5.995)		(−2.515)		(−1.376)
TSE^3_{Bucket}		−0.465***		−0.455***		−0.377***
		(−6.458)		(−9.473)		(−11.092)
N	301,766	301,766	706,015	706,015	943,926	943,926
R^2	0.116	0.116	0.113	0.113	0.117	0.117
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation under particular consideration of the number of days an asset is eligible for QE purchase. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. TSE refers to the time since eligibility (i.e., the cumulative time an asset is eligible for purchase under the PSPP). We split the TSE variable into three buckets: TSE^1_{Bucket} for assets that have (cumulatively) been eligible for up to 200 days, TSE^2_{Bucket} for assets that have been eligible for up to 400 days, and TSE^3_{Bucket} for assets that have been eligible for more than 400 days. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. All regressions include ISIN-month-term fixed effects and heteroscedasticity-robust standard errors. Data include special repo transactions for Germany, core European countries, and all European countries pooled across the term types TN and SN for the period 2010–2018.

We observe that the connection of repo rates to the EONIA rate is weaker for those assets that have been eligible for purchase for a longer period. A one-percentage-point change in the benchmark rate translates into a 0.1 basis point lower sensitivity in special repo rates for each day an asset is eligible for purchase. To put this number into perspective: Assets that are 100 days eligible for purchase have a ten basis points lower sensitivity. Column (2) shows that the lower sensitivity of eligible assets is particularly driven by those assets which have been eligible for the longest period. For example, assets that have been eligible for less than 200 trading days do not show a significantly different sensitivity to changes in the EONIA rate. However, assets that have been eligible for up to 400 days have a 28-basis-points lower sensitivity. For assets that have been eligible for more than 400 days, the effect increases to 47-basis-points. The results are consistent for core European countries and all European countries, as shown in columns (3)–(6).

Our results speak to the role of asset scarcity as repos secured by assets that have been eligible for purchase by the ECB for a longer period become more collateral-driven, and their rates are less connected to the funding-based money market segment.

3.2.4 Joint effects

We now analyze the joint impact of banks' access to central bank deposits and collateral assets' eligibility for QE programs on money market segmentation.

In the GC market, certain baskets contain a higher share of collateral assets (out of the list of assets eligible to be delivered as collateral into a basket) that are eligible for QE purchases. Thus, trading in these baskets increases the likelihood of sourcing assets that have become scarcer due to QE. This implies that baskets with a higher share of QE eligible assets might be more collateral-driven, and, as a result, lenders might accept lower rates on those baskets, which would be an additional source of rate dispersion leading to money market segmentation.

To analyze this idea, we compute the share of securities eligible for QE within the pool of collateral assets potentially deliverable into a GC basket as an indicator for the likelihood of obtaining a QE eligible asset as collateral in a GC transaction. Our data features a cross-section of 46 GC baskets for

Table 3.7: Joint effects of both forms of market segmentation

	Germany			Core			All		
	(1a)	(1b)	(2)	(3a)	(3b)	(4)	(5a)	(5b)	(6)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{Special}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{Special}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{Special}$
	ON/TN	ON/TN	TN/SN	ON/TN	ON/TN	TN/SN	ON/TN	ON/TN	TN/SN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.475***	0.594***	0.158***	0.582***	0.604***	0.153***	0.612***	0.654***	0.159***
	(5.030)	(5.998)	(12.932)	(10.815)	(10.541)	(17.592)	(12.817)	(12.609)	(18.622)
D^{Dep}	−0.067**	−0.066**	0.019***	−0.037***	−0.038***	0.006**	−0.024**	−0.024**	0.008***
	(−2.456)	(−2.396)	(3.611)	(−2.720)	(−2.772)	(2.049)	(−1.997)	(−2.025)	(2.709)
$\Delta MMRate \cdot D^{Dep}$	0.361***	0.284*	0.027	0.394***	0.349***	0.115***	0.358***	0.312***	0.116***
	(2.692)	(1.946)	(0.969)	(4.099)	(3.628)	(5.035)	(3.891)	(3.300)	(5.169)
D^{Access}	−0.004	−0.003	−0.005***	−0.006	−0.006	−0.005***	−0.005	−0.004	−0.005***
	(−0.265)	(−0.201)	(−2.673)	(−1.002)	(−0.949)	(−4.207)	(−0.846)	(−0.756)	(−4.517)
$\Delta MMRate \cdot D^{Access}$	−0.181**	−0.182*	−0.061***	−0.264***	−0.268***	−0.062***	−0.316***	−0.315***	−0.072***
	(−2.015)	(−1.836)	(−5.132)	(−4.726)	(−4.840)	(−7.841)	(−6.318)	(−6.312)	(−9.181)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$	−0.606***	-0.626***	−0.191***	−0.466***	−0.486***	−0.245***	−0.413***	−0.431***	−0.239***
	(−3.775)	(−3.586)	(−6.483)	(−4.260)	(−4.347)	(−10.253)	(−3.909)	(−3.927)	(−9.984)
D^{QE}	−0.113	−0.117	−0.013	−0.047	−0.053	−0.007	−0.056	−0.062	−0.011
	(−1.489)	(−1.495)	(−1.218)	(−1.336)	(−1.494)	(−0.979)	(−1.069)	(−1.185)	(−1.301)
$D^{Eligible}$	−0.017	−0.008	0.003	−0.010**	0.010*	0.004	−0.010**	0.007	0.004
	(−1.509)	(−0.683)	(0.374)	(−2.048)	(1.900)	(0.655)	(−2.183)	(1.592)	(0.611)
$\Delta MMRate \cdot D^{Eligible}$	0.252***	0.056	−0.006	0.138***	0.084*	0.006	0.099**	0.010	0.005
	(3.338)	(0.609)	(−0.531)	(3.199)	(1.943)	(0.849)	(2.510)	(0.250)	(0.684)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$	−0.315***	−0.024	−0.097***	−0.432***	−0.298***	−0.105***	−0.349***	−0.215***	−0.109***
	(−2.872)	(−0.159)	(−6.258)	(−6.809)	(−5.044)	(−10.268)	(−5.437)	(−3.486)	(−11.589)
N	6,802	6,802	301,525	30,314	30,314	628,424	37,453	37,453	758,182
R^2	0.262	0.257	0.116	0.239	0.237	0.113	0.233	0.232	0.116
$\Delta repo$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the joint impact of bank access and QE asset eligibility on money market segmentation. The dependent variable is the change in the GC rate $\Delta repo^{GC}$ respectively the change in the special rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one in the GC segment in columns 1a/3a/5a if basket i at point t has a higher share of QE eligible securities than the median basket for that country. In columns 1b/3b/5b, $D^{Eligible}$ equals one if the bond with the highest special repo rate out of all bonds eligible to be delivered in basket i at point t is QE eligible. In the special segment, $D^{Eligible}$ equals one if a security is (hypothetically) eligible for purchase under the PSPP. Note that the term $\Delta PolRate * D^{QE}$ was not included because it overlaps with $\Delta PolRate * D^{Dep}$ which complicates the identification and interpretation of the two coefficients. Including $\Delta PolRate \cdot D^{QE}$ instead of $\Delta PolRate \cdot D^{Dep}$ leads to consistent results. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. All regressions include basket-/ISIN-month-term fixed effects and heteroscedasticity-robust standard errors. Data include GC and special repo transactions for Germany, core European countries, and all European countries pooled across the term types ON, TN, and SN for the period 2010–2018.

which we compute, at each point in time, the volume-weighted share of the securities that can be used as collateral that are also (hypothetically) eligible for central bank asset purchases.[33] Using a similar panel regression set-up, we analyze whether baskets with a higher share of QE eligible securities react less strongly to changes in the EONIA rate, even after accounting for banks' access to the ECB's deposit facility as the first form of market segmentation. For the regression, we introduce the dummy variable $D_{t,i}^{Eligible}$ for the GC market. $D_{t,i}^{Eligible}$ is equal to one if basket i at time t has a (hypothetical) QE eligibility share higher than the median eligibility share across all baskets of that country at time t.

Table 3.7 reports our results for Germany in column (1a), core European countries in column (3a), and all European countries in column (5a). In addition to confirming our previous results, we find in column (1a) that trades involving baskets with high and low eligibility shares respond differently to changes in the funding-based money market benchmark rate, even after controlling for banks' access to the deposit facility. Since the start of QE, repo trades involving baskets with a higher share of QE eligible securities are less sensitive to changes in the EONIA rate. This points to the idea that GC baskets with a higher share of QE eligible assets become more collateral-driven and thus respond less to changes in funding-based money market rates, consistent with the effect for QE eligible assets in the special repo segment. Comparing the economic magnitude, access to central bank facilities remains the more pronounced effect.

In a GC repo, certain assets may be more likely to be delivered as collateral than others (Ballensiefen, 2022). In particular, it is possible to identify, at each point in time, the bond with the highest special repo rate out of all bonds eligible to be delivered in a basket. Based on this, we employ this bond's QE eligibility as an alternative to capture the effect of asset scarcity on GC repos. The results, which are reported for Germany in column (1b), core European countries in column (3b), and all European countries in column (5b), confirm

[33] Consider, for example, the Eurex GC Basket "German Bond GC." All bonds issued by the German sovereign with a fixed or zero-coupon and a minimum issue size of 100 euro million can be used as collateral for this basket. For each trading day and basket, we compile a list of all bonds that meet these basket-specific criteria and evaluate whether these securities are (hypothetically) eligible for QE purchases. The sample is slightly smaller compared to the previous analysis for the GC market due to data availability.

our previous results.

We now turn to the joint effects on special repos. To do this, we account for the lenders' access to the central bank's deposit facility in addition to the collateral assets' eligibility for QE.[34] The results are shown for Germany in column (2), core European countries in column (4), and all European countries in column (6). Column (2) confirms that both forms of market segmentation are also present in the special repo market. A one-percentage-point change in the money market benchmark rate translates into a 19-basis-points lower sensitivity of access banks relative to nonaccess banks in the GC < DFR environment and a 10-basis-points lower sensitivity of QE eligible collateral assets relative to noneligible assets during the recent period of unconventional monetary policy.

Columns (3)–(6) expand our analysis by looking at larger samples. Again, the results remain statistically and economically consistent.

Overall, two new findings arise from our analysis of the joint effects: First, the QE implementation has increased money market segmentation in the GC segment suggesting a pervasive effect of asset scarcity coming from QE on the entire repo market. Second, the segmentation through special repos also depends on the access to central bank operations. To our knowledge, we are the first to document the QE impact on GC repos and the impact of access to central bank facilities on special repo rates. Both forms of segmentation lead repos to become more collateral-driven and thus less connected to funding-based money market segments.

3.2.5 Other money market segments

To underline the robustness of our results and show that segmentation is also present across other money market segments, we experiment with alternative rates to capture funding-based money market conditions. We employ the short-term interest rate benchmark (EONIA) as (i) our baseline rate. In 2017, the ECB announced that the euro short-term rate (€STR) would replace the EONIA as the new short-term benchmark in the euro area. Historical €STR rates date back to March 13th, 2017. We, therefore, consider an EONIA-€STR combination with the €STR rate replacing the EONIA rate after its publication as a (ii) second rate. As a (iii) third unsecured reference

[34] In this setting, $D_{t,i}^{Eligible}$ is specified as in our main regressions and equals one if *security* i is (hypothetically) eligible for purchase under the PSPP.

Table 3.8: ECB access: Different money market rates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	EONIA	€STR	euro LIBOR	zero OIS	zero EURIBOR	OIS 1W	GC Pooling
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.675***	0.675***	0.481***	0.298***	0.152***	0.402***	0.754***
	(8.781)	(8.781)	(9.252)	(5.751)	(4.765)	(5.358)	(15.465)
D^{Dep}	−0.047**	−0.047**	−0.050**	−0.043**	−0.049**	−0.045**	−0.041**
	(−2.338)	(−2.341)	(−2.497)	(−2.021)	(−2.088)	(−2.139)	(−2.109)
$\Delta MMRate \cdot D^{Dep}$	0.265**	0.284**	0.355***	0.338***	0.186**	0.296**	0.244**
	(2.082)	(2.218)	(3.996)	(3.482)	(2.236)	(2.571)	(2.052)
D^{Access}	−0.000	0.000	0.004	0.005	0.001	0.002	−0.001
	(−0.035)	(0.004)	(0.335)	(0.466)	(0.080)	(0.193)	(−0.141)
$\Delta MMRate \cdot D^{Access}$	−0.177**	−0.177**	−0.115*	−0.194***	−0.067*	−0.184**	−0.152**
	(−2.100)	(−2.100)	(−1.708)	(−3.510)	(−1.937)	(−2.157)	(−2.567)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$	−0.719***	−0.721***	−0.679***	−0.416***	−0.251***	−0.282*	−0.666***
	(−4.970)	(−4.955)	(−5.731)	(−4.040)	(−2.904)	(−1.777)	(−4.235)
N	10,007	10,007	9,958	9,848	9,615	9,938	9,988
R^2	0.220	0.220	0.188	0.131	0.129	0.156	0.308
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation for different money market rates. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in different money market rates. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, 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 heteroscedasticity-robust standard errors. Data include German GC repo transactions pooled across the term types ON and TN for the period 2010–2018.

Table 3.9: Asset eligibility: Different money market rates

	(1) EONIA	(2) €STR	(3) euro LIBOR	(4) zero OIS	(5) zero EURIBOR	(6) OIS 1W	(7) GC Pooling
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t
$\Delta MMRate$	0.109***	0.109***	0.104***	0.050***	0.046***	0.110***	0.201***
	(13.196)	(13.196)	(11.539)	(9.063)	(9.272)	(13.665)	(19.083)
D^{QE}	−0.016	−0.016	−0.039***	−0.028**	−0.030**	−0.039***	−0.014
	(−1.420)	(−1.407)	(−3.102)	(−2.327)	(−2.451)	(−3.466)	(−1.274)
$\Delta MMRate \cdot D^{QE}$	−0.120***	−0.115***	−0.109***	−0.022***	−0.019***	−0.050***	0.453***
	(−8.160)	(−7.874)	(−9.379)	(−3.136)	(−2.937)	(−3.203)	(9.917)
$D^{Eligible}$	0.004	0.004	0.003	0.003	0.002	0.002	0.005
	(0.428)	(0.424)	(0.304)	(0.317)	(0.247)	(0.223)	(0.562)
$\Delta MMRate \cdot D^{Eligible}$	−0.005	−0.005	0.000	0.014*	0.002	−0.018*	−0.008
	(−0.462)	(−0.462)	(0.005)	(1.960)	(0.393)	(−1.777)	(−0.555)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$	−0.052***	−0.044**	−0.023	−0.031***	−0.017**	−0.022	−0.311***
	(−2.736)	(−2.287)	(−1.491)	(−3.321)	(−2.045)	(−0.998)	(−5.435)
N	301,766	301,766	300,047	295,606	289,216	299,622	301,192
R^2	0.116	0.116	0.117	0.116	0.116	0.114	0.123
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation for different money market rates. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in different money market rates. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) 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 ISIN-month-term fixed effects and heteroscedasticity-robust standard errors. Data include German special repo transactions pooled across the term types TN and SN for the period 2010–2018.

rate, we consider the overnight euro LIBOR rate. We also consider a set of derivatives-based, forward-looking overnight interest rates. We employ (iv) the overnight point of the Overnight Index Swap (OIS)–implied zero curve, which uses one-month, three-month, and six-month OIS derivatives, as well as (v) the overnight point of the EURIBOR-implied zero curve, which uses one-month, three-month, and six-month EURIBOR derivatives. We also consider (vi) the one-week OIS rate.[35] Finally, we employ the (vii) rate on the GC Pooling basket, the primary GC repo funding basket featuring a large trading volume and no counterparty credit risk due to central clearing. Any segmentation emerging from the dominant role of repo collateral (as opposed to funding) should also be present relative to funding-based repo rates.

Table 3.8 shows that our results on banks' access to the deposit facility are statistically and economically consistent across all specifications.[36] All

[35]Since we observe daily closing prices for the derivatives-based measures from Thomson Reuters/Refinitiv Eikon, we relate changes in those derivatives-based money market rates over two days to daily rate changes in repo rates.

[36]We present the results for German repo transactions for illustrative purposes. The results for core and all European countries are presented in the online appendix.

regressions arrive at the same conclusion that access banks are less sensitive to changes in funding-based money market rates in the GC < DFR environment, reinforcing our idea that access banks lean towards more collateral-driven repo trades during those periods. Our results on QE eligibility are reported in Table 3.9 and are also fully consistent. QE eligible securities are less sensitive to changes in funding-based money market rates since the ECB's QE program was introduced. This lower sensitivity has not been present in prior periods and thus reinforces our idea that asset scarcity leads repos to become more collateral-driven.

Across both specifications, repo rates are more sensitive to changes in unsecured overnight rates than derivative-based, implied overnight rates. This is intuitive since the funding conditions in the unsecured segment influence repo transactions. In line with this intuition, the explanatory power of our panel regressions is largest for changes in unsecured overnight rates, which confirms our approach of employing the EONIA rate across our baseline specifications. Our results also hold if we employ the ECB GC Pooling basket rate as our funding-based repo benchmark rate. This supports the interpretation that the two disconnecting mechanisms, i.e., DFR access and QE asset eligibility, are sources of money market segmentation also *within* the secured market.

3.3 Implications for monetary policy

Our results are relevant for the interpretation of different monetary policies. One example is the introduction of the tiering system, which we analyze in this paper. Due to the tiering exemptions, access banks have an additional incentive to store funds at the deposit facility and thus predominantly trade in collateral-driven parts of the repo market, which are less connected to funding-based money market rates. The observed effects are not a failure of the tiering policy, which had the goal of supporting "the transmission of monetary policy through banks to firms and households by lowering banks' costs caused by negative interest rates" (Bank of Finland, 2019). At the same time, it is important to understand those patterns in money markets, which help evaluate the overall effects of such policies. For example, the excessive usage of the deposit facility by access banks raises concerns about discouraging interbank trading, which inhibits price determination (Keister et al., 2008). Widening the access to the

deposit facility to include foreign banks, such as in Switzerland (Kraenzlin and Nellen, 2015), is a similar illustration of this mechanism. Amendments to the Capital Requirements Regulation (CRR), which (temporarily) exclude central bank reserves from the calculation of the leverage ratio, could also manifest money market segmentation as they encourage banks (with access) to store additional funds at the ECB's deposit facility.

Focusing on QE, the notion that unconventional policies "safeguard the transmission of our monetary policy," as pointed out by ECB President Christine Lagarde (European Central Bank, 2020), should also consider that those programs can create rate dispersion, thereby leading to unintended consequences such as segmentation across different money market segments. Our results are also informative for the recent discussion about new short-term benchmark rates as they underline that measuring the price of cash becomes increasingly difficult in a collateral-driven repo market environment. Consequently, the ECB chose an unsecured rate as their new benchmark.

Our results also have *suggestive* implications for the monetary policy transmission process. The "monetary policy transmission pipeline" involves three distinct steps: (i) the central bank's monetary policy actions pass through into the money market, (ii) the conditions in the money market impact debt and equity markets, and (iii) monetary policy changes then propagate into the real sector.[37] Focusing on the first step, "in an idealized money market, any change in the main monetary policy rate should pass through perfectly to all money market rates" (Corradin et al., 2020, p.13). Our empirical analysis of money market segmentation, by contrast, indicates a dispersion in short-term rates, which would suggest less control of the monetary policy transmission for central banks and pass-through inefficiencies.[38]

We employ the EONIA rate as the main short-term interest rate benchmark

[37]We thank our discussant Olivier Wang for suggesting this metaphor. While the main focus of this paper is on the money market, other recent papers such as Wang (2020) consider the longer-run impacts of an inhibited monetary policy transmission, such as the impact on inflation.

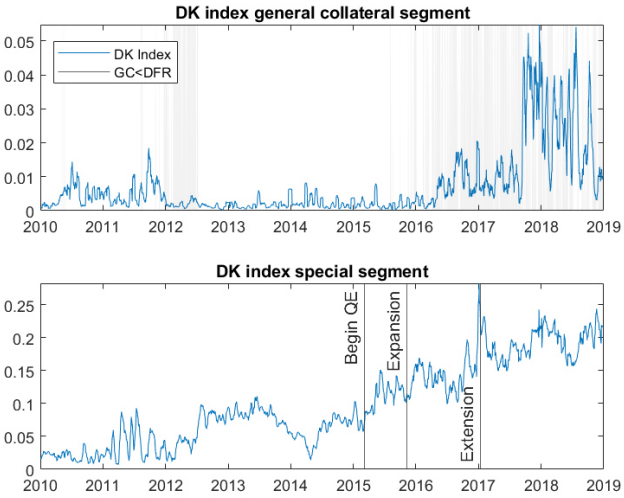
[38]The repo market is important for the transmission of monetary policy for two other reasons: First, repo market frictions not only impact the funding conditions of banks, but also the borrowing conditions faced by other financial institutions and governments, as has been shown for the U.S. Treasury market by He et al. (2022). Given that governments are the largest debt issuers, this is another avenue through which the repo market affects monetary policy transmission. Second, the repo market in the euro area plays an important role in the redistribution of reserves (Bank for International Settlements, 2017, p.16).

in our analysis. In addition to being an important money market rate, the EONIA rate is "the key ECB interest rate"(European Central Bank, 2011) used as its operational target (Cœuré, 2018). For this reason, our results have implications for monetary policy.[39] The ECB directly sets the rates on the deposit and marginal lending facility, which define the corridor for the EONIA rate.[40] The two rates, however, do not lend themselves to a pass-through analysis since the ECB sets them in infrequent and discrete jumps. The EONIA rate, by contrast, evolves continuously and is informative to central banks (and market participants) about time-varying money market conditions and unconventional monetary policy effects. It must be stressed that variations in the EONIA rate are not only due to changes in the monetary policy stance as other factors, such as risk premia and illiquidity, determine it. However, it is reasonable to assume that the ECB takes the EONIA rate into account when evaluating the transmission of its monetary policy.

One prime indicator of pass-through inefficiency in money markets has been proposed by Duffie and Krishnamurthy (2016, p.36): a volume-weighted absolute dispersion index. Inspired by this, we present dispersion measures for the GC and special repo market segments in Figure 3.7, which we refer to as "DK index." We observe that the dispersion in the GC segment increases in the GC $<$ DFR environment (as indicated by the grey shaded area). Similarly, we observe an increase in the dispersion in the special segment since the introduction of QE that has further increased with extensions and expansions of the QE program. Both indices point towards rate dispersion and thus a potential

[39] Several other aspects render the EONIA rate important to ECB monetary policy framework. First, the EONIA comovement with other interest rates has been shown in, for example, Hristov et al. (2014) and Altavilla et al. (2020). Second, the EONIA is a standard choice on interest rate pass-through in the literature (see, e.g., Hristov, Hülsewig, and Wollmershäuser, 2014, Altavilla, Canova, and Ciccarelli, 2020, as well as Ciccarelli, Maddaloni, and Peydró, 2015; all three papers employ the EONIA rate as the ECB's policy instrument. And third, an unsecured money market rate, such as the EONIA or the U.S. federal funds rate, is commonly considered the main policy rule to fulfill the central bank's mandate, which is well reflected in the widely used Taylor rule (Taylor, 1999).

[40] Within the corridor, the ECB steers the short-run liquidity conditions with its open market operations by providing liquidity for a period of one week or three months. Although these transactions are secured, open market operations are distinct from regular repo transactions in three ways. First, since October 2008, open market operations have been conducted via fixed-rate full-allotment or benchmark allotment auctions, which are executed at the same rate for all participants. Second, these auctions occur on a weekly to monthly basis and thus do not provide for a viable alternative to obtain day-to-day short-term funding. And third, the maturities of one week or three months are longer-term than typical overnight repo transactions.



The figure depicts two DK dispersion indices defined as the volume-weighted average of the absolute deviation of repo rates from the volume-weighted mean repo rate in the spirit of Duffie and Krishnamurthy (2016, p.36). For the first DK index in the special market, we differentiate between rates on repos secured by QE eligible and noneligible collateral. For the GC segment, we consider rates of trades involving access and nonaccess lenders.

Figure 3.7: Repo market dispersion

(a) Eurozone government bond rates **(b)** German real sector lending rates

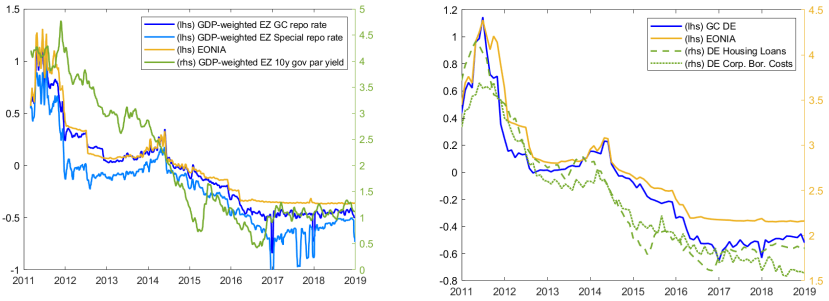


Figure 3.8a depicts the GDP-weighted average government bond yield within the Eurozone, and the GDP-weighted mean GC and Special repo rates. Figure 3.8b depicts the co-movement of the mean German GC rate with two real sector lending rates, one depicting the borrowing costs for private homeowners and one for non-financial corporations in Germany. Both lending rates stem from the ECB's MFI Interest Rate Statistics (MIR). The mean GC rate refers to the volume-weighted mean observed in our dataset. For reference, we also include the EONIA rate in both graphs.

Figure 3.8: Interest rate co-movements

weakening in the monetary policy transmission associated with the two disconnecting mechanisms we analyze, i.e., access to central bank facilities and QE eligibility. What has emerged from our analysis and may be relevant to a deeper understanding of monetary policy transmission is that access to central bank facilities and QE eligibility lead repo trades to become more collateral-driven.

To highlight the importance of the repo market for the monetary policy transmission into the real sector, Figure 3.8a shows the co-movement of GC and special repo rates with a GDP-weighted average Eurozone government bond yield; Figure 3.8b illustrates that repo rates correlate with credit conditions faced by corporate borrowers and private households (illustratively for Germany). The graphical intuition points toward the repo rate playing an important role in the transmission of monetary policy into borrowing cost and bank lending rates. This raises the question of how the dispersion in money market rates that arises when the role of collateral in repos becomes dominant over the role of funding impacts the second and third steps of the monetary policy pass-through pipeline.

To empirically analyze this idea, we examine the pass-through of changes

in the EONIA rate into lending rates faced by corporate borrowers and private households depending on the conditions in the repo market. The dependent variable is the change of a given lending rate Δr^L, for which we consider borrowing costs of non-financial firms and loans to households for house purchases. $\Delta MMRate_t$ denotes the change in the EONIA rate. $D^{DK_{GC}}$ equals one if the dispersion measure for the GC market is above its median; $D^{DK_{Special}}$ equals one if the dispersion measure for the special market is above its median; and dummy $D^{DK_{Repo}}$ equals one if at least one of the two (GC and special) repo market dispersion measures is one.

Table 3.10 reports the results of our panel regressions. Column (1) relates changes in non-financial corporate borrowing rates to changes in the money market benchmark rate, depending on the dispersion in GC and special repo rates; column (2) considers our repo market dispersion dummy. The results highlight that lending rates react strongly to changes in money market funding conditions: A one-percentage-point increase in the EONIA rate is accompanied by an increase in corporate borrowing rates of about 50 basis points. The effect is, however, almost muted when the dispersion in repo rates is high. The regressions in columns (3) and (4) confirm our results for residential housing rates.[41]

Both results provide suggestive support for Duffie and Krishnamurthy (2016) who highlight that a dispersion across money market interest rates is a primary indicator of the inefficiency of the monetary policy pass-through. Although the monetary policy transmission into the real economy involves additional steps that deserve a detailed analysis beyond short-term rates, our results speak to the importance of the repo market for the monetary policy transmission. Since the repo market is the predominant source of short-term funding, it determines bank funding conditions and ultimately seems to impact the transmission of monetary policy into the real sector. Our results suggest that the money market is more segmented in a collateral-dominant environment and that the consequent rate dispersion is associated with a reduced responsiveness of real-sector lending rates to changes in the EONIA rate, which serves as the operational target for monetary policy.

[41] In all regressions, we account for country-year fixed effects. We also show in the online appendix that our results remain statistically and economically consistent if we consider other money market rates and shorten the sample period to the end of 2016.

Table 3.10: Repo dispersion and the pass-through to lending rates

	(1)	(2)	(3)	(4)
	Non-fin. corporate Δr^L b/t	Non-fin. corporate Δr^L b/t	New housing Δr^L b/t	New housing Δr^L b/t
$\Delta MMRate$	0.506***	0.501***	0.787**	0.792**
	(3.431)	(3.327)	(2.804)	(2.778)
$\Delta MMRate \cdot D^{DK_{GC}}$	−0.522***		−0.690**	
	(−3.254)		(−2.326)	
$\Delta MMRate \cdot D^{DK_{Special}}$	−0.445		−0.570***	
	(−1.653)		(−3.318)	
$\Delta MMRate \cdot D^{DK_{Repo}}$		−0.526**		−0.723**
		(−3.072)		(−2.286)
N	1,101	1,101	1,017	1,017
R^2	0.126	0.125	0.174	0.173

The table reports the regression results examining the pass-through of changes in the EONIA rate into lending rates faced by corporate borrowers and private households. The dependent variable is the change of a given lending rate Δr^L. Non-financial corporate borrowing rates refer to the annualized borrowing costs of non-financial firms for new loans. New housing rates refer to bank interest rates on new loans to households for house purchases with an initial rate fixation period of between one and five years. Both lending rates are available from the ECB's monetary financial institutions (MFI) interest rate statistics. $\Delta MMRate$ denotes the change in the EONIA rate. $D^{DK_{GC}}$ equals one if the dispersion measure for the GC market is above its median. $D^{DK_{Special}}$ equals one if the dispersion measure for the Special market is above its median. $D^{DK_{Repo}}$ equals one if any of the GC and special repo market dispersion measures is above its median. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. All regressions include country-year fixed effects and standard errors accounting for clustering at the year level. Data are at a monthly frequency for all European countries for the period 2010–2020.

3.4 Conclusion

"(T)he repo market has a number of unique characteristics related to the motivation for entering into a trade" (European Central Bank, 2022). Our analysis has shown that the money market becomes more segmented when the motivation to obtain collateral rather than cash is prevalent. We uncover two important sources of money market segmentation: whether the money market participant is a bank that has access to the central bank's deposit facility and whether the collateral asset is the target of the QE program. We demonstrate that the lending rates of banks with access to the central bank's deposit facility and repo rates secured by assets eligible for QE programs are more collateral-driven and thus disconnected from funding-based benchmark rates.

Since the main funding-based benchmark rate EONIA is also the operational target for the ECB's monetary policy, our findings suggest that money market segmentation weakens the transmission of monetary policy. Furthermore, our results underline that measuring the price of cash becomes increasingly difficult in a collateral-driven repo market environment. It is therefore important to consider the mechanism brought to light in this study when evaluating different monetary policies, which is also relevant for other regions such as the U.S. market.

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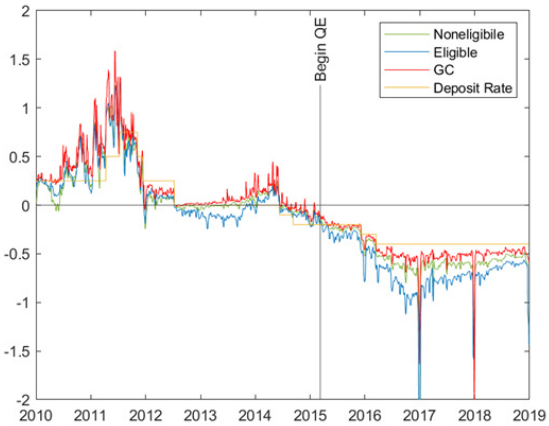
Online appendix

OA3.1 European money market

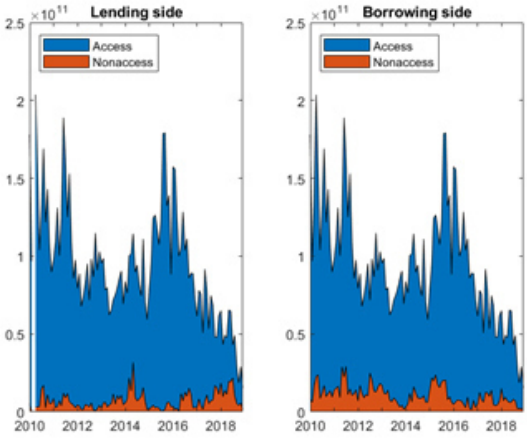
Repo rate development



The figure shows the development of the average volume-weighted GC rate and special repo rates for QE eligible and noneligible assets (illustratively for Germany) relative to the development of the ECB's deposit facility rate. For the period prior to the introduction of the QE program, we apply the initial implementation provisions of the PSPP retrospectively to classify assets into *(hypothetically)* eligible and noneligible.

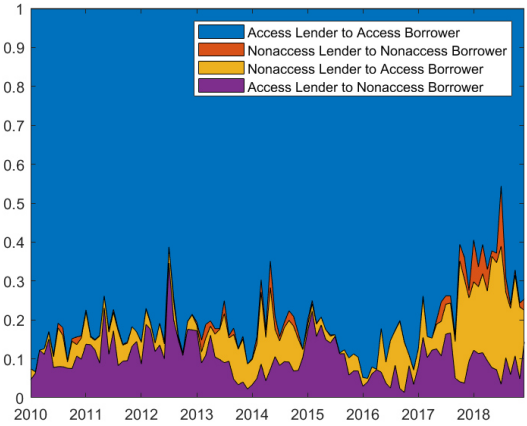
Figure OA3.1.1: Repo rate development

Trading volume of access and nonaccess banks



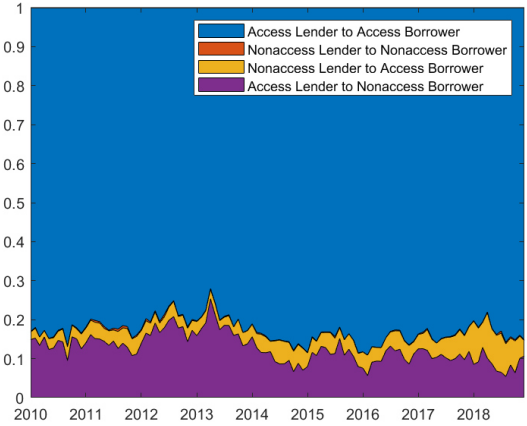
The figure depicts the total trading volume in the German GC market. The left panel breaks down the trading volume for trades involving a lender with and without access to the ECB facilities; the right panel breaks down the trading volume for trades involving a borrower with and without access to the ECB facilities.

Figure OA3.1.2: Lending- and borrowing-side in general collateral trading volumes



The figure depicts the trading shares in the German GC repo market, broken down by the access status of the trading counterparty.

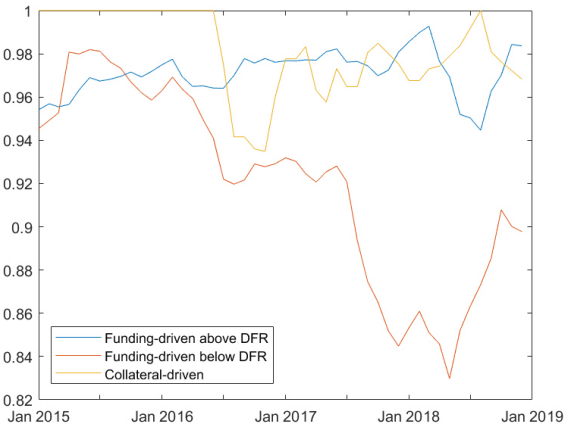
Figure OA3.1.3: Trading shares in the GC repo market



The figure depicts the trading shares in the German special repo market, broken down by the access status of the trading counterparty.

Figure OA3.1.4: Trading shares in the special repo market

Trading share of access banks



The figure depicts the volume-weighted share of access banks in total trading volume during the most recent period in which GC rates hovered below the deposit facility rate. The share is depicted in three subgroups: (i) trades against collateral baskets trading above the DFR, (ii) trades involving cheaper collateral baskets just trading below the DFR, (iii) and trades involving costly collateral baskets trading far below the DFR (by at least 20 basis points).

Figure OA3.1.5: Trading share of access banks in the GC<DFR environment, alternative classification

Theoretical mechanisms at work

Building on the framework proposed in Duffie (1996), we illustrate how the two features of the central bank framework affect the decision problem of banks operating in the GC and special repo market in a supply and demand diagram. While Duffie (1996) focuses on the special market, we extend his framework to GC repos.

Figure OA3.1.6 depicts the supply and demand diagram in the *GC* market: the x-axis shows the GC rate, and the y-axis the quantity (per institution). The borrower in the GC market is searching for funding; the supply curve, therefore, has a negative slope (i.e., the lower the repo rate, the larger the supply of collateral to be temporarily sold to borrow funds).[42] On the demand side, we present two distinct demand curves: one for access banks and one for nonaccess banks. This is needed since the decision problem of those two types of banks is different; one can deposit funds at the deposit facility while the other cannot.

The demand of nonaccess banks for investing liquidity is inelastic.[43] Access banks can always access the deposit facility. This option becomes more attractive when the GC rate falls below the rate on the deposit facility, leading to a lower demand by access banks. We illustrate this change in the demand via a kink in the demand curve. In line with the kinked demand curve, we show that access banks move out of funding-driven baskets once they are trading at a rate below the DFR. However, the demand of access banks to deposit liquidity in the repo market does not immediately vanish due to the benefits of obtaining collateral over holding cash, for example, to pledge it in margin accounts.[44] The idea is that access banks still operate in the repo market for collateral

[42]In the traditional model of Duffie (1996), the supply curve is upward-sloping since the x-axis shows the "specialness" instead of the GC rate (i.e., reverse direction).

[43]While we do not explicitly model the behavior of nonaccess banks, this is suggested for several reasons: First, banks without central bank access face the decision problem of investing in the secured or unsecured money market. Repos are mostly secured by government bonds, which are safe assets per se, carrying convenience yields in the form of safety and liquidity benefits. The benefits from obtaining collateral (Piquard and Salakhova, 2019) therefore create a net demand for safe assets (Infante, 2020), which is particularly inelastic when QE programs render them scarce. Second, financial regulation incentivizes, directly and indirectly, banks to hold secured deposits (Ranaldo et al., 2021).

[44]The current spread deducted from benchmark rates at Eurex on cash denominated in euro pledged in margin accounts is, for example, 20 basis points, thus rendering cash collateral less attractive (https://www.eurex.com/ec-en/services/collateral-management/cash-collateral/interest-rates-on-cash-collateral).

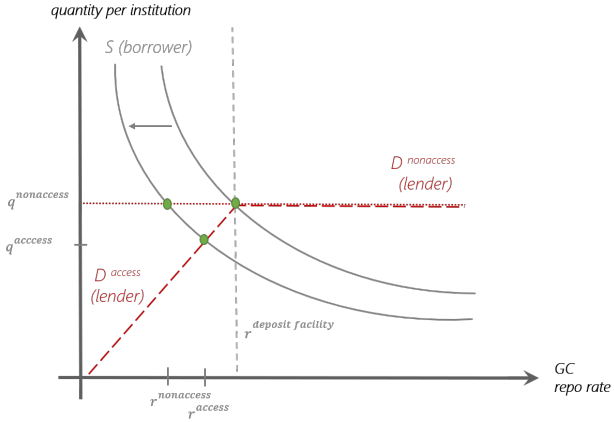


Figure OA3.1.6: Impact of supply shock in the GC repo market

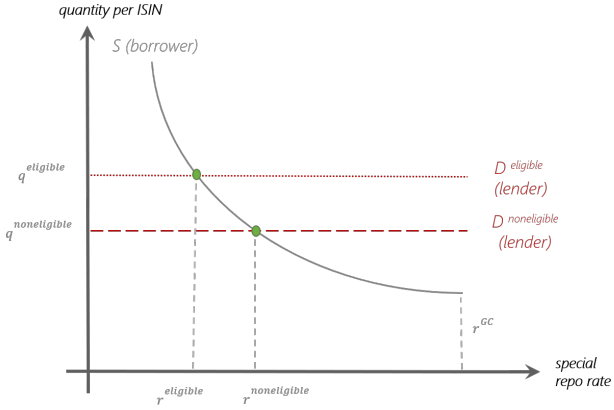


Figure OA3.1.7: Impact of demand shock in the special repo market

purposes but not for investing liquidity, i.e., they select themselves into more collateral-driven segments of the repo market.

Since the start of QE, excess liquidity in the euro area has strongly risen. This is graphically illustrated in a negative supply shock: fewer banks need to borrow liquidity in the repo market. As a result of this negative supply shock, GC rates can fall below the rate on the deposit facility. This leads access banks to deposit an increasing share of their liquidity at the deposit facility; thus, the size of the GC market and the trading share of access banks in the GC market declines. Furthermore, as access banks predominantly trade for collateral purposes in the GC $<$ DFR environment, they select themselves into collateral-driven GC baskets, which are less connected to funding-based money market rates.

Figure OA3.1.7 depicts the supply and demand diagram in the *special* market: the x-axis now shows the special rate, and the y-axis the quantity (per bond). In the special market, the trading behavior is characterized by the collateral leg of the repo transaction: Following Duffie (1996), some security holders are only willing to lend (supply) those securities at a premium (i.e., at a repo rate below the GC rate). This translates into a negatively sloped supply curve. The demand in the form of short-sellers is completely inelastic. Asset purchases of QE eligible securities have led to asset scarcity and additional demand for eligible assets (Bank for International Settlements, 2017, p.16). This is graphically illustrated in two demand curves, one at a higher level (for QE eligible assets) and one at a lower level (for noneligible assets). Two effects emerge from this positive demand shock for eligible assets: First, the size of the special market increases with an increasing share of trading in QE eligible (collateral) assets. Second, repo rates diverge as rates for QE eligible assets fall below those for noneligible assets (i.e., eligible assets are more "special"). The idea here is that due to asset scarcity, repos secured by QE eligible assets become predominantly collateral-driven, and rates on those repos become less connected to other funding-based money market segments.

OA3.2 Robustness results for ECB access

Results by term type and regional classification

Table OA3.2.1: ECB access: Germany

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON	TN	ON/TN	ON	TN	ON/TN	ON	TN	ON/TN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.742***	0.456***	0.539***	0.646***	0.760***	0.717***	0.601***	0.719***	0.675***
	(10.018)	(11.475)	(15.699)	(6.547)	(8.970)	(10.745)	(5.285)	(7.428)	(8.781)
D^{Dep}	−0.042	−0.045*	−0.046**				−0.043	−0.047**	−0.047**
	(−1.102)	(−1.890)	(−2.265)				(−1.136)	(−1.986)	(−2.338)
$\Delta MMRate \cdot D^{Dep}$	−0.130	−0.210**	−0.176**				0.238	0.287	0.265**
	(−0.891)	(−2.228)	(−2.216)				(1.477)	(1.614)	(2.082)
D^{Access}				−0.003	0.001	−0.001	−0.001	0.001	−0.000
				(−0.143)	(0.067)	(−0.071)	(−0.080)	(0.074)	(−0.035)
$\Delta MMRate \cdot D^{Access}$				0.114	−0.424***	−0.264***	0.194	−0.337***	−0.177**
				(0.912)	(−4.685)	(−3.549)	(1.387)	(−3.274)	(−2.100)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$							−0.625**	−0.760***	−0.719***
							(−2.461)	(−4.036)	(−4.970)
N	2,830	7,177	10,007	2,830	7,177	10,007	2,830	7,177	10,007
R^2	0.332	0.161	0.210	0.332	0.172	0.213	0.336	0.179	0.220
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, 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 heteroscedasticity-robust standard errors. Data include German GC repo transactions separate for each and pooled across the term types ON and TN for the period 2010–2018.

Table OA3.2.2: ECB access: Core countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON	TN	ON/TN	ON	TN	ON/TN	ON	TN	ON/TN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.681***	0.376***	0.473***	0.810***	0.624***	0.683***	0.801***	0.577***	0.646***
	(15.916)	(16.046)	(23.146)	(13.089)	(11.957)	(16.875)	(11.233)	(10.266)	(14.515)
D^{Dep}	−0.018	−0.037***	−0.031***				−0.017	−0.038***	−0.031***
	(−1.042)	(−2.641)	(−2.851)				(−1.005)	(−2.777)	(−2.917)
$\Delta MMRate \cdot D^{Dep}$	−0.252***	0.029	−0.061				0.053	0.455***	0.312***
	(−2.986)	(0.420)	(−1.141)				(0.523)	(4.149)	(3.952)
D^{Access}				−0.002	−0.006	−0.005	−0.002	−0.005	−0.004
				(−0.232)	(−0.801)	(−0.819)	(−0.221)	(−0.671)	(−0.720)
$\Delta MMRate \cdot D^{Access}$				−0.201***	−0.324***	−0.284***	−0.156*	−0.263***	−0.224***
				(−2.692)	(−5.644)	(−6.242)	(−1.843)	(−4.270)	(−4.520)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$							−0.536***	−0.609***	−0.574***
							(−3.917)	(−4.614)	(−5.860)
N	12,227	22,875	35,102	12,227	22,875	35,102	12,227	22,875	35,102
R^2	0.253	0.143	0.180	0.254	0.150	0.185	0.257	0.153	0.187
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, 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 heteroscedasticity-robust standard errors. Data include GC repo transactions for core European countries separate for each and pooled across the term types ON and TN for the period 2010–2018.

Table OA3.2.3: ECB access: All countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON	TN	ON/TN	ON	TN	ON/TN	ON	TN	ON/TN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.661***	0.305***	0.426***	0.708***	0.520***	0.589***	0.696***	0.487***	0.563***
	(19.603)	(15.604)	(24.823)	(10.665)	(12.866)	(16.778)	(9.865)	(11.631)	(15.341)
D^{Dep}	0.036***	−0.020*	0.003				0.037***	−0.021*	0.002
	(2.889)	(−1.726)	(0.304)				(2.958)	(−1.825)	(0.287)
$\Delta MMRate \cdot D^{Dep}$	−0.243**	0.108	−0.013				0.175*	0.543***	0.399***
	(−3.031)	(1.614)	(−0.257)				(1.720)	(5.325)	(5.370)
D^{Access}				−0.002	−0.004	−0.003	−0.002	−0.004	−0.003
				(−0.303)	(−0.713)	(−0.746)	(−0.289)	(−0.602)	(−0.669)
$\Delta MMRate \cdot D^{Access}$				−0.085	−0.279***	−0.223***	−0.049	−0.242***	−0.187***
				(−1.152)	(−6.199)	(−5.687)	(−0.635)	(−5.193)	(−4.548)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$							−0.686***	−0.612***	−0.616***
							(−5.141)	(−4.945)	(−6.607)
N	21,910	36,306	58,216	21,910	36,306	58,216	21,910	36,306	58,216
R^2	0.249	0.140	0.174	0.249	0.145	0.177	0.251	0.146	0.179
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, 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 heteroscedasticity-robust standard errors. Data include GC repo transactions for all European countries separate for each and pooled across the term types ON and TN for the period 2010–2018.

Results for clustered standard errors

Table OA3.2.4: ECB access: Germany, core countries, and all countries

	Germany			Core			All		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	
	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t
$\Delta MMRate$	0.539*	0.717*	0.675*	0.473*	0.683**	0.646**	0.426*	0.589**	0.563**
	(7.367)	(10.556)	(9.705)	(6.469)	(16.968)	(17.556)	(6.540)	(18.598)	(18.642)
D^{Dep}	−0.046		−0.047	−0.031		−0.031	0.002		0.002
	(−4.367)		(−4.723)	(−3.209)		(−2.657)	(0.152)		(0.120)
$\Delta MMRate \cdot D^{Dep}$	−0.176		0.265	−0.061		0.312*	−0.013		0.399
	(−0.631)		(3.538)	(−0.278)		(7.430)	(−0.059)		(5.919)
D^{Access}		−0.001	−0.000		−0.005	−0.004		−0.003	−0.003
		(−0.126)	(−0.061)		(−2.574)	(−1.723)		(−2.730)	(−2.013)
$\Delta MMRate \cdot D^{Access}$		−0.264**	−0.177*		−0.284***	−0.224**		−0.223	−0.187
		(−15.995)	(−12.534)		(−74.534)	(−21.855)		(−6.137)	(−5.473)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$			−0.719*			−0.574**			−0.615**
			(−11.802)			(−31.998)			(−18.568)
N	10,007	10,007	10,007	35,102	35,102	35,102	58,216	58,216	58,216
R^2	0.210	0.213	0.220	0.180	0.185	0.187	0.174	0.177	0.179
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation using clustered standard errors. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, 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 basket and access level. Data include GC repo transactions for Germany, core European countries, and all European countries pooled across the term types ON and TN for the period 2010–2018.

Results for different fixed effect specifications

Table OA3.2.5: ECB access: Germany, different fixed effect specifications

	(1)	(2)	(3)	(4)	(5)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN
	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.675***	0.684***	0.712***	0.725***	0.725***
	(8.781)	(9.300)	(9.197)	(8.733)	(8.709)
D^{Dep}	−0.047**	−0.047**	−0.027**	−0.032***	−0.021*
	(−2.338)	(−2.274)	(−2.068)	(−3.606)	(−1.795)
$\Delta MMRate \cdot D^{Dep}$	0.265**	0.269**	0.279**	0.313**	0.293**
	(2.082)	(2.350)	(2.225)	(2.358)	(2.228)
D^{Access}	−0.000	−0.002	0.003	0.002	0.003
	(−0.035)	(−0.146)	(0.265)	(0.155)	(0.338)
$\Delta MMRate \cdot D^{Access}$	−0.177**	−0.149*	−0.130	−0.138	−0.139
	(−2.100)	(−1.766)	(−1.456)	(−1.461)	(−1.468)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$	−0.719***	−0.686***	−0.665***	−0.591***	−0.583***
	(−4.970)	(−4.821)	(−4.400)	(−3.616)	(−3.608)
FE	Basket× Month× Term	Basket× Month	Basket× Year	Basket	Year
N	10,007	10,104	10,170	10,173	10,173
R^2	0.220	0.239	0.227	0.220	0.223
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. The regressions include different fixed effect specifications and heteroscedasticity-robust standard errors. Data include German GC repo transactions pooled across the term types ON and TN for the period 2010–2018.

Table OA3.2.6: ECB access: Core countries, different fixed effect specifications

	(1)	(2)	(3)	(4)	(5)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN
	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.646***	0.677***	0.714***	0.721***	0.719***
	(14.515)	(15.318)	(15.312)	(15.029)	(15.011)
D^{Dep}	−0.031***	−0.027**	−0.018***	−0.018***	−0.015**
	(−2.917)	(−2.408)	(−2.555)	(−4.011)	(−2.200)
$\Delta MMRate \cdot D^{Dep}$	0.312***	0.288***	0.293***	0.327***	0.308***
	(3.952)	(3.845)	(3.615)	(3.902)	(3.720)
D^{Access}	−0.004	−0.004	−0.002	−0.002	−0.001
	(−0.720)	(−0.638)	(−0.301)	(−0.448)	(−0.124)
$\Delta MMRate \cdot D^{Access}$	−0.224***	−0.235***	−0.231***	−0.231***	−0.230***
	(−4.520)	(−4.702)	(−4.392)	(−4.284)	(−4.248)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$	−0.574***	−0.507***	−0.481***	−0.436***	−0.427***
	(−5.860)	(−5.367)	(−4.828)	(−4.168)	(−4.111)
FE	Basket× Month× Term	Basket× Month	Basket× Year	Basket	Year
N	35,102	35,396	35,643	35,650	35,650
R^2	0.187	0.198	0.192	0.188	0.190
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. The regressions include different fixed effect specifications and heteroscedasticity-robust standard errors. Data include GC repo transactions for core European countries pooled across the term types ON and TN for the period 2010–2018.

Table OA3.2.7: ECB access: All countries, different fixed effect specifications

	(1)	(2)	(3)	(4)	(5)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN
	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.563***	0.587***	0.621***	0.628***	0.627***
	(15.341)	(16.203)	(16.884)	(16.810)	(16.780)
D^{Dep}	0.002	0.005	−0.001	−0.011***	−0.002
	(0.249)	(0.608)	(−0.227)	(−2.720)	(−0.466)
$\Delta MMRate \cdot D^{Dep}$	0.399***	0.382***	0.390***	0.425***	0.411***
	(5.366)	(5.447)	(5.155)	(5.426)	(5.302)
D^{Access}	−0.003	−0.003	−0.003	−0.004	−0.003
	(−0.667)	(−0.771)	(−0.689)	(−0.939)	(−0.848)
$\Delta MMRate \cdot D^{Access}$	−0.187***	−0.192***	−0.195***	−0.187***	−0.185***
	(−4.548)	(−4.712)	(−4.674)	(−4.399)	(−4.356)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$	−0.615***	−0.540***	−0.500***	−0.463***	−0.450***
	(−6.604)	(−6.061)	(−5.271)	(−4.669)	(−4.574)
FE	Basket× Month× Term	Basket× Month	Basket× Year	Basket	Year
N	58,216	58,659	59,015	59,028	59,028
R^2	0.179	0.191	0.188	0.186	0.188
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. The regressions include different fixed effect specifications and heteroscedasticity-robust standard errors. Data include GC repo transactions for all European countries pooled across the term types ON and TN for the period 2010–2018.

Table OA3.2.8: ECB access: Germany

	w/o quarter-end days			w/o end of ECB maintenance period			w/o weeks of quarter-end and end of ECB maintenance period		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t
$\Delta MMRate$	0.544***	0.716***	0.671***	0.551***	0.730***	0.702***	0.603***	0.805***	0.771***
	(15.580)	(10.460)	(8.484)	(14.850)	(10.235)	(8.501)	(12.151)	(9.444)	(7.822)
D^{Dep}	−0.051**		−0.050***	−0.031		−0.037*	−0.011		−0.009
	(−2.565)		(−2.590)	(−1.455)		(−1.728)	(−0.833)		(−0.722)
$\Delta MMRate \cdot D^{Dep}$	−0.174**		0.286**	−0.125		0.194	−0.062		0.207
	(−2.161)		(2.218)	(−1.551)		(1.585)	(−0.592)		(1.371)
D^{Access}		0.004	0.005		−0.005	−0.005		0.005	0.004
		(0.394)	(0.462)		(−0.461)	(−0.456)		(0.416)	(0.377)
$\Delta MMRate \cdot D^{Access}$		−0.259***	−0.167*		−0.255***	−0.196**		−0.294***	−0.232**
		(−3.418)	(−1.935)		(−3.226)	(−2.182)		(−2.990)	(−2.079)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$			−0.760***			−0.574***			−0.511***
			(−5.231)			(−3.971)			(−2.689)
N	9,898	9,898	9,898	9,557	9,557	9,557	7,426	7,426	7,426
R^2	0.207	0.210	0.217	0.202	0.205	0.209	0.220	0.227	0.229
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation when dropping additional periods from the sample. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Regressions (1)–(6) include basket-month-term fixed effects; regressions (7)–(9) include basket-year-term fixed effects; all regressions include heteroscedasticity-robust standard errors. Data include German GC repo transactions pooled across the term types ON and TN for the period 2010–2018. The results for w/o quarter-end days remove quarter-end trading days, the results for w/o end of ECB maintenance period remove the last trading days of the end of the ECB maintenance period, and the results for w/o weeks of quarter-end and end of ECB maintenance period remove the entire trading weeks surrounding quarter ends and end of ECB maintenance periods.

Table OA3.2.9: ECB access: Core countries

	w/o quarter-end days			w/o end of ECB maintenance period			w/o weeks of quarter-end and end of ECB maintenance period		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.492***	0.712***	0.673***	0.484***	0.701***	0.667***	0.537***	0.807***	0.767***
	(24.048)	(18.272)	(15.638)	(21.819)	(16.267)	(14.006)	(19.391)	(15.386)	(12.928)
D^{Dep}	−0.029***		−0.029***	−0.028**		−0.029***	0.004		0.005
	(−2.648)		(−2.707)	(−2.568)		(−2.724)	(0.535)		(0.686)
$\Delta MMRate \cdot D^{Dep}$	−0.051		0.310***	−0.034		0.278***	−0.016		0.265***
	(−0.937)		(3.992)	(−0.622)		(3.500)	(−0.248)		(2.611)
D^{Access}		−0.002	−0.002		−0.007	−0.007		0.002	0.002
		(−0.414)	(−0.297)		(−1.248)	(−1.147)		(0.326)	(0.324)
$\Delta MMRate \cdot D^{Access}$		−0.296***	−0.236***		−0.291***	−0.239***		−0.356***	−0.297***
		(−6.737)	(−4.898)		(−6.014)	(−4.508)		(−6.011)	(−4.475)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$			−0.564***			−0.507***			−0.473***
			(−5.786)			(−5.046)			(−3.850)
N	34,730	34,730	34,730	33,592	33,592	33,592	26,218	26,218	26,218
R^2	0.179	0.184	0.187	0.179	0.184	0.185	0.186	0.193	0.195
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation when dropping additional periods from the sample. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Regressions (1)–(6) include basket-month-term fixed effects; regressions (7)–(9) include basket-year-term fixed effects; all regressions include heteroscedasticity-robust standard errors. Data include GC repo transactions for core European countries pooled across the term types ON and TN for the period 2010–2018. The results for w/o quarter-end days remove quarter-end trading days, the results for w/o end of ECB maintenance period remove the last trading days of the end of the ECB maintenance period, and the results for w/o weeks of quarter-end and end of ECB maintenance period remove the entire trading weeks surrounding quarter ends and end of ECB maintenance periods.

Table OA3.2.10: ECB access: All countries

	w/o quarter-end days			w/o end of ECB maintenance period			w/o weeks of quarter-end and end of ECB maintenance period		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t
$\Delta MMRate$	0.445***	0.617***	0.590***	0.429***	0.600***	0.576***	0.473***	0.697***	0.667***
	(26.428)	(17.798)	(16.235)	(23.128)	(15.833)	(14.489)	(20.464)	(14.520)	(13.084)
D^{Dep}	0.003		0.003	0.006		0.005	0.014**		0.015**
	(0.331)		(0.320)	(0.758)		(0.652)	(2.102)		(2.265)
$\Delta MMRate \cdot D^{Dep}$	−0.003		0.397***	0.023		0.375***	0.060		0.366***
	(−0.057)		(5.386)	(0.436)		(5.017)	(0.960)		(3.784)
D^{Access}		−0.003	−0.002		−0.005	−0.005		−0.000	−0.000
		(−0.641)	(−0.539)		(−1.119)	(−1.022)		(−0.053)	(−0.018)
$\Delta MMRate \cdot D^{Access}$		−0.235***	−0.198***		−0.232***	−0.200***		−0.298***	−0.262***
		(−6.092)	(−4.882)		(−5.489)	(−4.510)		(−5.575)	(−4.612)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$			−0.605***			−0.547***			−0.481***
			(−6.501)			(−5.740)			(−4.100)
N	57,605	57,605	57,605	55,753	55,753	55,753	43,392	43,392	43,392
R^2	0.170	0.174	0.175	0.173	0.176	0.177	0.179	0.184	0.185
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation when dropping additional periods from the sample. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Regressions (1)–(6) include basket-month-term fixed effects; regressions (7)–(9) include basket-year-term fixed effects; all regressions include heteroscedasticity-robust standard errors. Data include GC repo transactions for all European countries pooled across the term types ON and TN for the period 2010–2018. The results for w/o quarter-end days remove quarter-end trading days, the results for w/o end of ECB maintenance period remove the last trading days of the end of the ECB maintenance period, and the results for w/o weeks of quarter-end and end of ECB maintenance period remove the entire trading weeks surrounding quarter ends and end of ECB maintenance periods.

Results for shorter time period

Table OA3.2.11: ECB access: Germany, core countries, and all countries

	Germany			Core			All		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	
	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.539***	0.719***	0.675***	0.473***	0.688***	0.646***	0.424***	0.590***	0.562***
	(15.706)	(10.754)	(8.786)	(23.113)	(16.889)	(14.486)	(24.638)	(16.685)	(15.228)
D^{Dep}	−0.047**		−0.047**	−0.034***		−0.035***	−0.035***		−0.036***
	(−2.269)		(−2.344)	(−3.086)		(−3.161)	(−3.656)		(−3.750)
$\Delta MMRate \cdot D^{Dep}$	−0.158*		0.288**	−0.039		0.360***	0.017		0.455***
	(−1.940)		(2.233)	(−0.707)		(4.523)	(0.313)		(6.068)
D^{Access}		−0.001	−0.001		−0.007	−0.006		−0.004	−0.004
		(−0.113)	(−0.079)		(−0.911)	(−0.809)		(−0.771)	(−0.654)
$\Delta MMRate \cdot D^{Access}$		−0.264***	−0.178**		−0.287***	−0.225***		−0.226***	−0.188***
		(−3.545)	(−2.106)		(−6.286)	(−4.517)		(−5.708)	(−4.554)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$			−0.731***			−0.630***			−0.669***
			(−4.969)			(−6.565)			(−7.344)
N	7,934	7,934	7,934	25,967	25,967	25,967	44,180	44,180	44,180
R^2	0.212	0.215	0.221	0.178	0.183	0.186	0.171	0.175	0.177
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, 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 heteroscedasticity-robust standard errors. Data include GC repo transactions for Germany, core European countries, and all European countries pooled across the term types ON and TN for the period 2010–2016.

Results for different money market rates

Table OA3.2.12: ECB access: Core countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	EONIA	€STR	euro LIBOR	zero OIS	zero EURIBOR	OIS 1W	GC Pooling
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t	ON/TN b/t
$\Delta MMRate$	0.646***	0.646***	0.443***	0.273***	0.115***	0.376***	0.724***
	(14.515)	(14.517)	(8.992)	(8.719)	(6.846)	(6.787)	(24.695)
D^{Dep}	−0.031***	−0.031***	−0.029***	−0.034***	−0.036***	−0.032***	−0.032***
	(−2.917)	(−2.903)	(−2.721)	(−3.045)	(−3.218)	(−2.928)	(−3.102)
$\Delta MMRate \cdot D^{Dep}$	0.312***	0.341***	0.376***	0.230***	0.199***	0.291***	0.292***
	(3.952)	(4.356)	(5.333)	(3.897)	(4.542)	(3.799)	(3.796)
D^{Access}	−0.004	−0.003	−0.004	−0.001	−0.005	−0.005	−0.006
	(−0.720)	(−0.570)	(−0.759)	(−0.253)	(−0.909)	(−0.783)	(−1.124)
$\Delta MMRate \cdot D^{Access}$	−0.224***	−0.225***	−0.122**	−0.200***	−0.059***	−0.177***	−0.180***
	(−4.520)	(−4.521)	(−2.103)	(−6.098)	(−3.182)	(−3.066)	(−5.004)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$	−0.574***	−0.574***	−0.428***	−0.240***	−0.224***	−0.256***	−0.410***
	(−5.860)	(−5.870)	(−4.760)	(−3.876)	(−4.774)	(−2.897)	(−3.713)
N	35,102	35,102	34,969	34,589	34,016	34,834	35,053
R^2	0.187	0.188	0.169	0.126	0.117	0.144	0.262
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation for different money market rates. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in different money market rates. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, 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 heteroscedasticity-robust standard errors. Data include GC repo transactions for core European countries pooled across the term types ON and TN for the period 2010–2018.

Table OA3.2.13: ECB access: All countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	EONIA	€STR	euro LIBOR	zero OIS	zero EURIBOR	OIS 1W	GC Pooling
	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$	$\Delta repo^{GC}$
	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN	ON/TN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.563***	0.563***	0.381***	0.214***	0.112***	0.263***	0.657***
	(15.341)	(15.353)	(10.740)	(9.602)	(10.070)	(6.758)	(25.349)
D^{Dep}	0.002	0.001	0.003	0.000	-0.000	0.000	0.002
	(0.287)	(0.156)	(0.370)	(0.010)	(-0.028)	(0.022)	(0.202)
$\Delta MMRate \cdot D^{Dep}$	0.399***	0.432***	0.451***	0.303***	0.202***	0.414***	0.369***
	(5.370)	(5.862)	(7.451)	(5.517)	(5.014)	(6.428)	(5.074)
D^{Access}	−0.003	−0.002	−0.003	−0.001	−0.003	−0.002	−0.005
	(−0.669)	(−0.514)	(−0.602)	(−0.154)	(−0.602)	(−0.487)	(−1.174)
$\Delta MMRate \cdot D^{Access}$	−0.187***	−0.187***	−0.113***	−0.148***	−0.053***	−0.137***	−0.146***
	(−4.548)	(−4.549)	(−2.719)	(−6.160)	(−4.254)	(−3.200)	(−4.792)
$\Delta MMRate \cdot D^{Access} \cdot D^{Dep}$	−0.616***	−0.609***	−0.434***	−0.302***	−0.228***	−0.273***	−0.438***
	(−6.607)	(−6.559)	(−5.554)	(−5.226)	(−5.275)	(−3.459)	(−4.190)
N	58,216	58,216	57,897	57,304	56,277	57,791	58,115
R^2	0.179	0.179	0.161	0.132	0.131	0.137	0.243
$\Delta repo^{GC}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of access to the ECB's deposit facility on money market segmentation for different money market rates. The dependent variable is the change in the GC rate $\Delta repo^{GC}$. $\Delta MMRate$ denotes the change in different money market rates. D^{Dep} equals one if a country's average GC rate is below the deposit facility rate. D^{Access} equals one if a lending bank has access to the deposit facility. ***, **, 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 heteroscedasticity-robust standard errors. Data include GC repo transactions for all European countries pooled across the term types ON and TN for the period 2010–2018.

OA3.3 Robustness results for asset eligibility

Results by term type and regional classification

Table OA3.3.1: Collateral eligibility: Germany

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN	SN	TN/SN	TN	SN	TN/SN	TN	SN	TN/SN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.190***	0.060***	0.106***	0.171***	0.059***	0.098***	0.186***	0.067***	0.109***
	(17.269)	(11.098)	(19.746)	(11.689)	(7.031)	(13.001)	(11.598)	(7.347)	(13.196)
D^{QE}	−0.022	−0.009	−0.016				−0.022	−0.009	−0.016
	(−0.996)	(−0.821)	(−1.448)				(−0.995)	(−0.784)	(−1.420)
$\Delta MMRate \cdot D^{QE}$	−0.206***	−0.118***	−0.150***				−0.165***	−0.095***	−0.120***
	(−10.786)	(−12.873)	(−15.860)				(−5.586)	(−6.514)	(−8.160)
$D^{Eligible}$				−0.001	0.005	0.004	−0.001	0.005	0.004
				(−0.043)	(0.544)	(0.443)	(−0.051)	(0.538)	(0.428)
$\Delta MMRate \cdot D^{Eligible}$				0.023	−0.002	0.006	0.008	−0.010	−0.005
				(1.097)	(−0.177)	(0.537)	(0.356)	(−0.882)	(−0.462)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$				−0.235***	−0.137***	−0.172***	−0.070*	−0.042**	−0.052***
				(−9.456)	(−11.521)	(−14.030)	(−1.820)	(−2.259)	(−2.736)
N	106,166	195,600	301,766	106,166	195,600	301,766	106,166	195,600	301,766
R^2	0.159	0.076	0.116	0.159	0.076	0.116	0.159	0.076	0.116
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) 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 ISIN-month-term fixed effects and heteroscedasticity-robust standard errors. Data include German special repo transactions separate for each and pooled across the term types TN and SN for the period 2010–2018.

Table OA3.3.2: Collateral eligibility: Core countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN b/t	SN b/t	TN/SN b/t	TN b/t	SN b/t	TN/SN b/t	TN b/t	SN b/t	TN/SN b/t
$\Delta MMRate$	0.184***	0.063***	0.105***	0.147***	0.063***	0.095***	0.157***	0.071***	0.103***
	(26.371)	(18.190)	(31.250)	(14.896)	(10.422)	(17.688)	(14.723)	(10.797)	(17.850)
D^{QE}	−0.010	−0.006	−0.008				−0.010	−0.005	−0.008
	(−0.719)	(−0.770)	(−1.176)				(−0.722)	(−0.727)	(−1.157)
$\Delta MMRate \cdot D^{QE}$	−0.160***	−0.110***	−0.126***				−0.125***	−0.095***	−0.106***
	(−12.396)	(−17.736)	(−19.822)				(−5.938)	(−8.441)	(−9.820)
$D^{Eligible}$				−0.006	0.008	0.003	−0.006	0.008	0.003
				(−0.565)	(1.169)	(0.580)	(−0.569)	(1.172)	(0.578)
$\Delta MMRate \cdot D^{Eligible}$				0.055***	−0.004	0.011	0.044***	−0.011	0.002
				(4.091)	(−0.500)	(1.622)	(3.169)	(−1.482)	(0.299)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$				−0.182***	−0.118***	−0.136***	−0.058**	−0.023*	−0.030**
				(−11.130)	(−16.094)	(−17.421)	(−2.165)	(−1.690)	(−2.211)
N	238,311	467,704	706,015	238,311	467,704	706,015	238,311	467,704	706,015
R^2	0.146	0.085	0.113	0.146	0.085	0.113	0.146	0.085	0.113
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) 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 ISIN-month-term fixed effects and heteroscedasticity-robust standard errors. Data include special repo transactions for core European countries separate for each and pooled across the term types TN and SN for the period 2010–2018.

Table OA3.3.3: Collateral eligibility: All countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN	SN	TN/SN	TN	SN	TN/SN	TN	SN	TN/SN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.173***	0.061***	0.099***	0.145***	0.062***	0.094***	0.153***	0.070***	0.101***
	(26.285)	(17.255)	(30.217)	(15.778)	(10.487)	(18.379)	(15.385)	(10.862)	(18.370)
D^{QE}	−0.032	−0.012	−0.020**				−0.032	−0.012	−0.020**
	(−1.402)	(−1.383)	(−2.001)				(−1.409)	(−1.355)	(−1.996)
$\Delta MMRate \cdot D^{QE}$	−0.127***	−0.105***	−0.108***				−0.094***	−0.090***	−0.091***
	(−10.349)	(−16.370)	(−17.347)				(−4.613)	(−7.700)	(−8.349)
$D^{Eligible}$				−0.013	0.008	0.001	−0.013	0.008	0.001
				(−1.256)	(1.328)	(0.236)	(−1.280)	(1.323)	(0.214)
$\Delta MMRate \cdot D^{Eligible}$				0.041***	−0.004	0.004	0.033**	−0.012	−0.004
				(3.277)	(−0.598)	(0.594)	(2.524)	(−1.551)	(−0.556)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$				−0.145***	−0.112***	−0.116***	−0.051**	−0.022	−0.026*
				(−9.459)	(−14.638)	(−15.232)	(−1.986)	(−1.570)	(−1.936)
N	323,488	620,438	943,926	323,488	620,438	943,926	323,488	620,438	943,926
R^2	0.150	0.090	0.117	0.150	0.090	0.117	0.150	0.091	0.117
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) 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 ISIN-month-term fixed effects and heteroscedasticity-robust standard errors. Data include special repo transactions for all European countries separate for each and pooled across the term types TN and SN for the period 2010–2018.

Results for clustered standard errors

Table OA3.3.4: Collateral eligibility: Germany, core countries, and all countries

	Germany			Core			All		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t
$\Delta MMRate$	0.106**	0.098**	0.109**	0.105***	0.095***	0.103***	0.099**	0.094***	0.101***
	(34.655)	(37.041)	(38.232)	(120.664)	(78.946)	(88.152)	(48.406)	(122.590)	(103.312)
D^{QE}	−0.016		−0.016	−0.008		−0.008	−0.020		−0.020
	(−0.820)		(−0.823)	(−0.705)		(−0.692)	(−0.742)		(−0.740)
$\Delta MMRate \cdot D^{QE}$	−0.150		−0.120**	−0.126*		−0.106**	−0.108*		−0.091**
	(−5.753)		(−23.555)	(−9.290)		(−35.762)	(−9.468)		(−50.415)
$D^{Eligible}$		0.004	0.004		0.003	0.003		0.001	0.001
		(0.388)	(0.388)		(0.669)	(0.663)		(0.262)	(0.237)
$\Delta MMRate \cdot D^{Eligible}$		0.006	−0.005		0.011*	0.002		0.004	−0.004
		(2.173)	(−1.241)		(7.898)	(1.164)		(3.513)	(−2.011)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$		−0.172***	−0.052*		−0.136***	−0.030*		−0.116***	−0.026**
		(−124.249)	(−7.961)		(−169.593)	(−9.881)		(−129.110)	(−22.176)
N	301,766	301,766	301,766	706,015	706,015	706,015	943,926	943,926	943,926
R^2	0.116	0.116	0.116	0.113	0.113	0.113	0.117	0.117	0.117
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation using clustered standard errors. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) 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 ISIN-month-term fixed effects and standard errors clustered at the ISIN and eligibility level. Data include special repo transactions for Germany, core European countries, and all European countries pooled across the term types TN and SN for the period 2010–2018.

Results for different fixed effect specifications

Table OA3.3.5: Collateral eligibility: Germany, different fixed effect specifications

	(1)	(2)	(3)	(4)	(5)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN
	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.109***	0.111***	0.117***	0.118***	0.118***
	(13.196)	(13.216)	(13.670)	(13.773)	(13.820)
D^{QE}	−0.016	−0.016	0.047***	0.013***	0.047***
	(−1.420)	(−1.414)	(9.011)	(5.899)	(9.399)
$\Delta MMRate \cdot D^{QE}$	−0.120***	−0.121***	−0.129***	−0.129***	−0.131***
	(−8.160)	(−8.175)	(−8.599)	(−8.559)	(−8.719)
$D^{Eligible}$	0.004	0.004	−0.010**	−0.002	−0.000
	(0.428)	(0.496)	(−2.336)	(−0.819)	(−0.020)
$\Delta MMRate \cdot D^{Eligible}$	−0.005	−0.006	−0.002	−0.003	−0.004
	(−0.462)	(−0.510)	(−0.216)	(−0.297)	(−0.344)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$	−0.052***	−0.053***	−0.053***	−0.051***	−0.052***
	(−2.736)	(−2.738)	(−2.712)	(−2.598)	(−2.644)
FE	ISIN× Month× Term	ISIN× Month	ISIN× Year	ISIN	Year
N	301,766	302,017	302,054	302,055	302,055
R^2	0.116	0.119	0.116	0.116	0.117
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) eligible for purchase under the PSPP. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. The regressions include different fixed effect specifications and heteroscedasticity-robust standard errors. Data include German special repo transactions pooled across the term types TN and SN for the period 2010–2018.

Table OA3.3.6: Collateral eligibility: Core countries, different fixed effect specifications

	(1)	(2)	(3)	(4)	(5)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN
	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.103***	0.106***	0.114***	0.115***	0.115***
	(17.850)	(18.234)	(19.629)	(19.751)	(19.784)
D^{QE}	−0.008	−0.008	0.045***	0.010***	0.045***
	(−1.157)	(−1.147)	(12.983)	(7.363)	(13.505)
$\Delta MMRate \cdot D^{QE}$	−0.106***	−0.109***	−0.121***	−0.121***	−0.123***
	(−9.820)	(−10.036)	(−11.024)	(−10.991)	(−11.200)
$D^{Eligible}$	0.003	0.003	−0.007***	−0.002	0.001
	(0.578)	(0.581)	(−2.655)	(−1.423)	(0.543)
$\Delta MMRate \cdot D^{Eligible}$	0.002	0.003	0.006	0.005	0.005
	(0.299)	(0.405)	(0.863)	(0.769)	(0.727)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$	−0.030**	−0.029**	−0.028**	−0.026*	−0.026*
	(−2.211)	(−2.186)	(−2.070)	(−1.864)	(−1.947)
FE	ISIN× Month× Term	ISIN× Month	ISIN× Year	ISIN	Year
N	706,015	706,589	706,634	706,637	706,637
R^2	0.113	0.117	0.113	0.113	0.114
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) eligible for purchase under the PSPP. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. The regressions include different fixed effect specifications and heteroscedasticity-robust standard errors. Data include special repo transactions for core European countries pooled across the term types TN and SN for the period 2010–2018.

Table OA3.3.7: Collateral eligibility: All countries, different fixed effect specifications

	(1)	(2)	(3)	(4)	(5)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN
	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.101***	0.105***	0.113***	0.114***	0.114***
	(18.370)	(18.837)	(20.428)	(20.566)	(20.594)
D^{QE}	−0.020**	−0.020**	0.037***	0.011***	0.039***
	(−1.996)	(−1.996)	(10.076)	(8.178)	(11.083)
$\Delta MMRate \cdot D^{QE}$	−0.091***	−0.093***	−0.105***	−0.106***	−0.107***
	(−8.349)	(−8.586)	(−9.690)	(−9.702)	(−9.882)
$D^{Eligible}$	0.001	0.002	−0.008***	−0.001	0.001
	(0.214)	(0.293)	(−3.115)	(−0.841)	(0.526)
$\Delta MMRate \cdot D^{Eligible}$	−0.004	−0.002	0.001	0.001	0.000
	(−0.556)	(−0.361)	(0.190)	(0.109)	(0.070)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$	−0.026*	−0.026**	−0.028**	−0.026*	−0.027**
	(−1.936)	(−1.981)	(−2.131)	(−1.903)	(−1.992)
FE	ISIN× Month× Term	ISIN× Month	ISIN× Year	ISIN	Year
N	943,926	944,843	944,909	944,913	944,913
R^2	0.117	0.121	0.117	0.117	0.117
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) eligible for purchase under the PSPP. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. The regressions include different fixed effect specifications and heteroscedasticity-robust standard errors. Data include special repo transactions for all European countries pooled across the term types TN and SN for the period 2010–2018.

Results without quarter ends and end of ECB maintenance periods

Table OA3.3.8: Collateral eligibility: Germany

	w/o quarter-end days			w/o end of ECB maintenance period			w/o weeks of quarter-end and end of ECB maintenance period		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t
$\Delta MMRate$	0.118***	0.111***	0.123***	0.120***	0.107***	0.120***	0.111***	0.126***	0.142***
	(21.365)	(14.189)	(14.386)	(20.436)	(13.080)	(13.328)	(14.880)	(12.206)	(12.419)
D^{QE}	−0.016		−0.015	−0.012		−0.012	−0.000		0.048***
	(−1.413)		(−1.390)	(−1.140)		(−1.134)	(−0.040)		(7.992)
$\Delta MMRate \cdot D^{QE}$	−0.171***		−0.136***	−0.167***		−0.139***	−0.153***		−0.169***
	(−17.209)		(−8.846)	(−17.466)		(−9.519)	(−13.432)		(−9.788)
$D^{Eligible}$		0.003	0.002		−0.000	−0.000		−0.011**	−0.009**
		(0.374)	(0.298)		(−0.011)	(−0.018)		(−2.525)	(−2.011)
$\Delta MMRate \cdot D^{Eligible}$		0.004	−0.008		0.013	0.000		0.003	−0.014
		(0.363)	(−0.700)		(1.184)	(0.011)		(0.222)	(−0.920)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$		−0.197***	−0.061***		−0.188***	−0.049**		−0.193***	−0.026
		(−15.224)	(−3.042)		(−14.791)	(−2.558)		(−12.207)	(−1.124)
N	298,122	298,122	298,122	288,634	288,634	288,634	221,393	221,757	221,757
R^2	0.116	0.116	0.116	0.117	0.116	0.117	0.119	0.109	0.109
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation when dropping additional periods from the sample. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) eligible for purchase under the PSPP. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Regressions (1)–(6) include ISIN-month-term fixed effects; regressions (7)–(9) include ISIN-year-term fixed effects; all regressions include heteroscedasticity-robust standard errors. Data include German special repo transactions pooled across the term types TN and SN for the period 2010–2018. The results for w/o quarter-end days remove quarter-end trading days, the results for w/o end of ECB maintenance period remove the last trading days of the end of the ECB maintenance period, and the results for w/o weeks of quarter-end and end of ECB maintenance period remove the entire trading weeks surrounding quarter ends and end of ECB maintenance periods.

Table OA3.3.9: Collateral eligibility: Core countries

	w/o quarter-end days			w/o end of ECB maintenance period			w/o weeks of quarter-end and end of ECB maintenance period		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t
$\Delta MMRate$	0.119***	0.106***	0.116***	0.117***	0.100***	0.110***	0.141***	0.120***	0.133***
	(34.445)	(19.128)	(19.382)	(31.701)	(17.381)	(17.568)	(30.421)	(16.797)	(16.978)
D^{QE}	−0.008		−0.008	−0.004		−0.004	0.044***		0.043***
	(−1.101)		(−1.090)	(−0.592)		(−0.579)	(11.038)		(10.831)
$\Delta MMRate \cdot D^{QE}$	−0.147***		−0.127***	−0.138***		−0.116***	−0.165***		−0.147***
	(−22.098)		(−11.170)	(−21.298)		(−10.608)	(−20.744)		(−11.036)
$D^{Eligible}$		0.002	0.002		0.002	0.002		−0.009***	−0.007**
		(0.340)	(0.264)		(0.286)	(0.290)		(−3.103)	(−2.225)
$\Delta MMRate \cdot D^{Eligible}$		0.015**	0.004		0.021***	0.011		0.025***	0.011
		(2.096)	(0.567)		(2.860)	(1.365)		(2.741)	(1.145)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$		−0.157***	−0.031**		−0.150***	−0.034**		−0.172***	−0.028*
		(−19.243)	(−2.188)		(−18.627)	(−2.531)		(−17.278)	(−1.673)
N	697,050	697,050	697,050	676,066	676,066	676,066	517,390	517,390	517,390
R^2	0.114	0.113	0.114	0.115	0.115	0.115	0.111	0.110	0.111
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation when dropping additional periods from the sample. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) eligible for purchase under the PSPP. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Regressions (1)–(6) include ISIN-month-term fixed effects; regressions (7)–(9) include ISIN-year-term fixed effects; all regressions include heteroscedasticity-robust standard errors. Data include special repo transactions for core European countries pooled across the term types TN and SN for the period 2010–2018. The results for w/o quarter-end days remove quarter-end trading days, the results for w/o end of ECB maintenance period remove the last trading days of the end of the ECB maintenance period, and the results for w/o weeks of quarter-end and end of ECB maintenance period remove the entire trading weeks surrounding quarter ends and end of ECB maintenance periods.

Table OA3.3.10: Collateral eligibility: All countries

	w/o quarter-end days			w/o end of ECB maintenance period			w/o weeks of quarter-end and end of ECB maintenance period		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t
$\Delta MMRate$	0.114***	0.105***	0.114***	0.109***	0.098***	0.107***	0.141***	0.121***	0.133***
	(33.704)	(19.721)	(19.799)	(30.461)	(17.926)	(17.932)	(30.695)	(17.856)	(17.806)
D^{QE}	−0.019*		−0.019*	−0.017*		−0.017	0.034***		0.033***
	(−1.936)		(−1.936)	(−1.646)		(−1.643)	(7.893)		(7.746)
$\Delta MMRate \cdot D^{QE}$	−0.125***		−0.108***	−0.119***		−0.098***	−0.150***		−0.123***
	(−19.323)		(−9.577)	(−18.493)		(−8.869)	(−19.445)		(−9.420)
$D^{Eligible}$		−0.001	−0.001		−0.000	−0.000		−0.008***	−0.006**
		(−0.096)	(−0.181)		(−0.033)	(−0.051)		(−2.895)	(−2.256)
$\Delta MMRate \cdot D^{Eligible}$		0.010	0.001		0.012*	0.003		0.024***	0.012
		(1.509)	(0.144)		(1.744)	(0.451)		(2.679)	(1.263)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$		−0.133***	−0.024*		−0.128***	−0.030**		−0.160***	−0.038**
		(−16.812)	(−1.763)		(−16.251)	(−2.245)		(−16.806)	(−2.350)
N	932,157	932,157	932,157	904,704	904,704	904,704	696,209	696,209	696,209
R^2	0.117	0.117	0.117	0.119	0.119	0.119	0.115	0.115	0.115
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation when dropping additional periods from the sample. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) eligible for purchase under the PSPP. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. Regressions (1)–(6) include ISIN-month-term fixed effects; regressions (7)–(9) include ISIN-year-term fixed effects; all regressions include heteroscedasticity-robust standard errors. Data include special repo transactions for all European countries pooled across the term types TN and SN for the period 2010–2018. The results for w/o quarter-end days remove quarter-end trading days, the results for w/o end of ECB maintenance period remove the last trading days of the end of the ECB maintenance period, and the results for w/o weeks of quarter-end and end of ECB maintenance period remove the entire trading weeks surrounding quarter ends and end of ECB maintenance periods.

Results for shorter time period

Table OA3.3.11: Collateral eligibility: Germany, core countries, and all countries

	Germany			Core			All		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t	TN/SN b/t
$\Delta MMRate$	0.106***	0.099***	0.109***	0.105***	0.095***	0.103***	0.099***	0.095***	0.101***
	(19.671)	(13.020)	(13.144)	(31.157)	(17.810)	(17.780)	(30.157)	(18.492)	(18.310)
D^{QE}	−0.016		−0.015	−0.008		−0.008	−0.019*		−0.019*
	(−1.415)		(−1.353)	(−1.128)		(−1.096)	(−1.921)		(−1.908)
$\Delta MMRate \cdot D^{QE}$	−0.137***		−0.113***	−0.111***		−0.093***	−0.096***		−0.079***
	(−14.406)		(−7.702)	(−17.365)		(−8.603)	(−15.130)		(−7.245)
$D^{Eligible}$		0.009	0.010		0.006	0.006		0.004	0.004
		(1.055)	(1.060)		(0.999)	(1.021)		(0.705)	(0.702)
$\Delta MMRate \cdot D^{Eligible}$		0.005	−0.005		0.010	0.002		0.003	−0.004
		(0.481)	(−0.448)		(1.468)	(0.328)		(0.425)	(−0.554)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$		−0.155***	−0.042**		−0.120***	-0.027**		−0.104***	−0.025*
		(−12.555)	(−2.176)		(−15.287)	(−2.012)		(−13.344)	(−1.859)
N	225,533	225,533	225,533	519,447	519,447	519,447	655,830	655,830	655,830
R^2	0.111	0.111	0.111	0.109	0.109	0.109	0.112	0.112	0.112
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in the EONIA rate. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) 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 ISIN-month-term fixed effects and heteroscedasticity-robust standard errors. Data include special repo transactions for Germany, core European countries, and all European countries pooled across the term types TN and SN for the period 2010–2016.

Results for different money market rates

Table OA3.3.12: Collateral eligibility: Core countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	EONIA	€STR	euro LIBOR	zero OIS	zero EURIBOR	OIS 1W	GC Pooling
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.103***	0.103***	0.099***	0.053***	0.040***	0.082***	0.181***
	(17.850)	(17.850)	(15.247)	(13.103)	(11.831)	(14.484)	(24.958)
D^{QE}	−0.008	−0.008	−0.032***	−0.023***	−0.026***	−0.033***	−0.009
	(−1.157)	(−1.138)	(−3.988)	(−2.898)	(−3.241)	(−4.686)	(−1.293)
$\Delta MMRate \cdot D^{QE}$	−0.106***	−0.097***	−0.094***	−0.035***	−0.022***	−0.006	0.548***
	(−9.820)	(−8.998)	(−10.418)	(−6.744)	(−4.857)	(−0.452)	(13.230)
$D^{Eligible}$	0.003	0.003	0.003	0.003	0.001	0.002	0.004
	(0.578)	(0.570)	(0.609)	(0.464)	(0.233)	(0.283)	(0.696)
$\Delta MMRate \cdot D^{Eligible}$	0.002	0.002	0.017**	0.004	0.001	0.031***	0.031***
	(0.299)	(0.299)	(2.120)	(0.907)	(0.315)	(4.415)	(3.330)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$	−0.030**	−0.028**	−0.028**	−0.009	−0.006	−0.032**	−0.269***
	(−2.211)	(−2.129)	(−2.525)	(−1.449)	(−0.971)	(−1.980)	(−5.607)
N	706,015	706,015	702,242	692,064	679,279	701,160	704,655
R^2	0.113	0.113	0.115	0.113	0.113	0.112	0.123
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation for different money market rates. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in different money market rates. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) 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 ISIN-month-term fixed effects and heteroscedasticity-robust standard errors. Data include special repo transactions for core European countries pooled across the term types TN and SN for the period 2010–2018.

Table OA3.3.13: Collateral eligibility: All countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	EONIA	€STR	euro LIBOR	zero OIS	zero EURIBOR	OIS 1W	GC Pooling
	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$	$\Delta repo^{Special}$
	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN	TN/SN
	b/t	b/t	b/t	b/t	b/t	b/t	b/t
$\Delta MMRate$	0.101***	0.101***	0.092***	0.053***	0.039***	0.072***	0.164***
	(18.370)	(18.370)	(15.646)	(13.810)	(12.482)	(13.615)	(24.179)
D^{QE}	−0.020**	−0.020**	−0.046***	−0.038***	−0.040***	−0.044***	−0.021**
	(−1.996)	(−1.985)	(−3.938)	(−3.294)	(−3.496)	(−4.563)	(−2.132)
$\Delta MMRate \cdot D^{QE}$	−0.091***	−0.083***	−0.086***	−0.030***	−0.018***	0.024*	0.474***
	(−8.349)	(−7.669)	(−9.500)	(−5.894)	(−3.748)	(1.881)	(14.305)
$D^{Eligible}$	0.001	0.001	0.001	−0.000	−0.002	−0.001	0.001
	(0.214)	(0.208)	(0.245)	(−0.019)	(−0.300)	(−0.096)	(0.235)
$\Delta MMRate \cdot D^{Eligible}$	−0.004	−0.004	0.006	−0.003	−0.002	0.041***	0.030***
	(−0.556)	(−0.556)	(0.883)	(−0.655)	(−0.541)	(6.176)	(3.552)
$\Delta MMRate \cdot D^{Eligible} \cdot D^{QE}$	−0.026*	−0.024*	−0.005	−0.001	−0.002	−0.018	−0.202***
	(−1.936)	(−1.787)	(−0.395)	(−0.090)	(−0.347)	(−1.179)	(−5.300)
N	943,926	943,926	938,971	926,436	910,906	937,675	942,145
R^2	0.117	0.117	0.119	0.117	0.118	0.117	0.125
$\Delta repo^{Special}$ lagged	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table reports the regression results examining the impact of asset eligibility for quantitative easing on money market segmentation for different money market rates. The dependent variable is the change in the special repo rate $\Delta repo^{Special}$. $\Delta MMRate$ denotes the change in different money market rates. D^{QE} equals one during the PSPP. $D^{Eligible}$ equals one if a security is (hypothetically) 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 ISIN-month-term fixed effects and heteroscedasticity-robust standard errors. Data include special repo transactions for all European countries pooled across the term types TN and SN for the period 2010–2018.

OA3.4 Robustness results for dispersion and lending rates

Results for shorter time period

Table OA3.4.1: Repo dispersion and the pass-through to lending rates: Shorter time period

	(1)	(2)	(3)	(4)
	Non-fin. corporate Δr^L b/t	Non-fin. corporate Δr^L b/t	New housing Δr^L b/t	New housing Δr^L b/t
$\Delta MMRate$	0.502**	0.500**	0.789**	0.792**
	(3.282)	(3.235)	(2.721)	(2.705)
$\Delta MMRate \cdot D^{DK_{GC}}$	−0.513**		−0.695*	
	(−3.078)		(−2.237)	
$\Delta MMRate \cdot D^{DK_{Special}}$	−0.298		−0.641**	
	(−0.716)		(−2.922)	
$\Delta MMRate \cdot D^{DK_{Repo}}$		−0.506**		−0.707*
		(−2.992)		(−2.209)
N	757	757	680	680
R^2	0.157	0.156	0.205	0.204

The table reports the regression results examining the pass-through of changes in the EONIA rate into lending rates faced by corporate borrowers and private households. The dependent variable is the change of a given lending rate Δr^L. Non-financial corporate borrowing rates refer to the annualized borrowing costs of non-financial firms for new loans. New housing rates refer to bank interest rates on new loans to households for house purchases with an initial rate fixation period of between one and five years. Both lending rates are available from the ECB's MFI interest rate statistics. $\Delta MMRate$ denotes the change in the EONIA rate. $D^{DK_{GC}}$ equals one if the dispersion measure for the GC market is above its median. $D^{DK_{Special}}$ equals one if the dispersion measure for the Special market is above its median. $D^{DK_{Repo}}$ equals one if any of the GC and special repo market dispersion measures is above its median. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. All regressions include country-year fixed effects and standard errors accounting for clustering at the year level. Data are at a monthly frequency for all European countries for the period 2010–2016.

Results for different money market rates

Table OA3.4.2: Repo dispersion and the pass-through to lending rates: Different money market rates

Non-fin. corporate

	(1a)	(2a)	(3a)	(4a)	(5a)	(6a)	(7a)
	EONIA Δr^L b/t	€STR Δr^L b/t	euro LIBOR Δr^L b/t	zero OIS Δr^L b/t	zero EURIBOR Δr^L b/t	OIS 1W Δr^L b/t	GC Pooling Δr^L b/t
$\Delta MMRate$	0.501***	0.500***	0.454**	0.479***	0.478**	0.522***	0.483***
	(3.327)	(3.319)	(2.488)	(3.376)	(2.526)	(4.055)	(4.761)
$\Delta MMRate \cdot D^{DK_{Repo}}$	−0.526**	−0.511**	−0.454*	−0.485**	−0.590**	−0.471**	−0.445***
	(−3.072)	(−3.085)	(−2.249)	(−2.872)	(−2.386)	(−2.645)	(−4.092)
N	1,101	1,101	1,101	1,101	1,085	1,101	1,101
R^2	0.125	0.125	0.123	0.125	0.128	0.127	0.129

New housing

	(1b)	(2b)	(3b)	(4b)	(5b)	(6b)	(7b)
	EONIA Δr^L b/t	€STR Δr^L b/t	euro LIBOR Δr^L b/t	zero OIS Δr^L b/t	zero EURIBOR Δr^L b/t	OIS 1W Δr^L b/t	GC Pooling Δr^L b/t
$\Delta MMRate$	0.792**	0.791**	0.733*	0.728**	0.821	0.831**	0.652***
	(2.778)	(2.768)	(2.084)	(2.485)	(1.803)	(2.655)	(3.668)
$\Delta MMRate \cdot D^{DK_{Repo}}$	−0.723**	−0.688*	−0.689*	−0.567	−0.744	−0.695*	−0.647***
	(−2.286)	(−2.246)	(−1.845)	(−1.698)	(−1.606)	(−1.901)	(−3.475)
N	1,017	1,017	1,017	1,017	1,005	1,017	1,017
R^2	0.173	0.174	0.171	0.170	0.174	0.179	0.159

The table reports the regression results examining the pass-through of changes of different money market benchmark rates into lending rates faced by corporate borrowers and private households. The dependent variable is the change of a given lending rate Δr^L. Non-financial corporate borrowing rates refer to the annualized borrowing costs of non-financial firms for new loans. New housing rates refer to bank interest rates on new loans to households for house purchases with an initial rate fixation period of between one and five years. Both lending rates are available from the ECB's MFI interest rate statistics. $\Delta MMRate$ denotes the change in different money market rates. $D^{DK_{GC}}$ equals one if the dispersion measure for the GC market is above its median. $D^{DK_{Special}}$ equals one if the dispersion measure for the Special market is above its median. $D^{DK_{Repo}}$ equals one if any of the GC and special repo market dispersion measures is above its median. ***, **, and * represent significance at a 1, 5, and 10% level, respectively; t-statistics are in parentheses. All regressions include country-year fixed effects and standard errors accounting for clustering at the year level. Data are at a monthly frequency for all European countries for the period 2010–2020.

Curriculum Vitae

Born on December 20, 1990 in Bonn, Germany.
Married, one child.

Education

Ph.D. **Finance** 2023
University of St. Gallen, Switzerland
Supervisor: Prof. Angelo Ranaldo
Dissertation: Essays on Short-Term Funding Markets

M.A. **Banking & Finance** (*top 5%*) 2017
University of St. Gallen, Switzerland

B.A. **Economics** 2014
University of St. Gallen, Switzerland
University of California, San Diego, USA (2012)

Work Experience

World Bank Group, USA since 2019
Fellowship awarded by the German Government (until 2021)

University of St. Gallen, Switzerland 2017 - 2018
Research and Teaching Assistant

Credit Suisse Group, Switzerland 2016 - 2017
Corporate Development

World Bank Group, USA 2016
Fellowship awarded by the German Government