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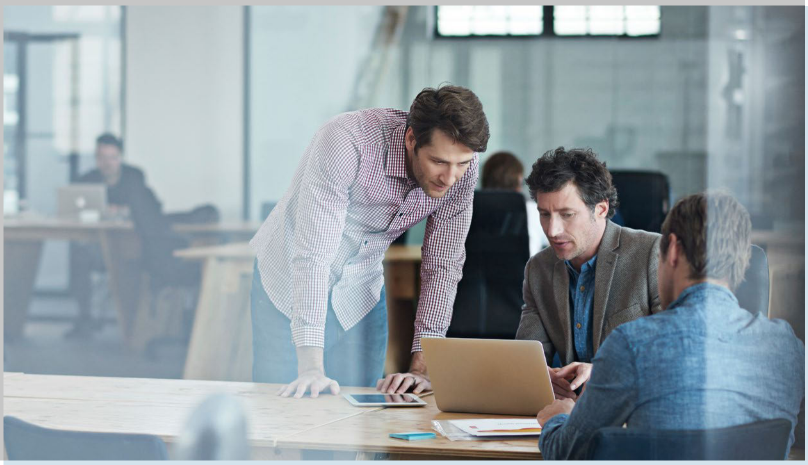
Repo Rates and the Collateral Spread: Evidence



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Abstract

Repo Rates and the Collateral Spread: Evidence

The spread between unsecured and repo rates (collateral spread) fluctuates substantially and is negative on a significant portion of days. Recent theoretical work argues that collateral spreads are determined by a constrained-arbitrage relation between the unsecured rate, the repo rates, and the expected rate of return of the underlying security. Negative collateral spreads arise in equilibrium if unsecured markets are sufficiently tight, unsecured rates spike down, or security markets are sufficiently depressed in terms of prices, liquidity, and volatility. The objective of this paper is to examine the determinants of collateral spreads by testing the constrained-arbitrage theory. The findings are supportive.

Keywords: collateral spread, liquidity, unsecured rate, repo rate, general collateral, Eurex Repo

JEL: G01, G12, G21

1 Introduction

In their work on general collateral (GC) repo rates, Bartolini, Hilton, Sundaresan, and Tonetti (2011) also document that spreads between the Fed funds rate and repo rates exhibit substantial variability over time. Traditional wisdom says that unsecured rates are larger than repo rates because the latter represent secured borrowing. However, from evidence in Bartolini et al. (2011), it is apparent that repo rates sometimes exceed the Fed funds rate. As seen in Figures 1a and 1b below, the picture in the euro area is similar. The figures plot the overnight collateral spread, that is, the unsecured rate less the repo rate, for the two most active baskets on Eurex Repo, the GC Pooling ECB and GC Pooling ECB Extended baskets, and using the Eonia as the unsecured rate.[1] Several features are apparent: both spreads exhibit substantial volatility, the spread based on the higher quality basket (ECB basket) is typically above that based on the lower quality basket (ECB Extended basket), and the spreads are often negative. For these two baskets, the overnight collateral spread is negative on 22.9% and 28.7% of days, respectively. In this paper, we study the determinants of the spread between unsecured and repo rates and shed light on the puzzle of negative collateral spreads. Our focus on repo rates relative to the unsecured rate differentiates our paper from that of Bartolini et al. (2011), whose focus is on the spreads between repo rates on different underlying collateral.

The tests we conduct are based on a recent theory by Nyborg (2019) that is capable of explaining negative spreads as an equilibrium phenomenon. The fundamental result in this theory is a constrained arbitrage relation between the repo rate, the unsecured rate, and the expected rate of return of the underlying security (taking into account illiquidity). The theory is consistent with the result in Bartolini, Hilton, Sundaresan, and Tonetti (2011) that repo rates are higher for lower quality baskets, but also gives rise to a rich set of additional predictions. The objective of this paper is to contribute toward a better understanding of the determinants of repo rates and collateral spreads through testing the constrained-arbitrage theory.

[1]The GC Pooling baskets and the data are described more fully in the body of the paper. What we refer to as the "collateral spread" differs from the usage in Bartolini, Hilton, Sundaresan, and Tonetti (2011), who use the terminologies collateral spread and repo spread to refer to the difference between two repo rates. Our "collateral spread" is their "collateral rent."

[insert Figures 1a and 1b about here]

Understanding the economic forces that drive repo rates relative to unsecured rates is important for a number of reasons. As explained by Duffie (1996), repos are an important vehicle in the market for liquidity, and frictions in this market may give rise to financial instability (Bhattacharya and Gale, 1987). By some accounts, repo markets may be a specific source of instability (Gorton and Metrick, 2011), while others argue that the effect may be overstated (Krishnamurthy, Nagel, and Orlov, 2014) or that repos can be a source of stability (Mancini, Ranaldo, and Wrampelmeyer, 2016) when unsecured markets are stressed (Afonso, Kovner, and Schoar, 2011). This may depend on market design (Martin, Skeie, and von Thadden, 2014). As seen in the turmoil after Lehman's default in September 2018, problems in the market for liquidity can spill over to securities markets. Boissel, Derrien, Ors, and Thesmar (2017) argue that stressed securities markets may cause an increase in central counterparty (CCP) repo rates because they may affect the creditworthiness of the CCP. However, the constrained-arbitrage theory predicts an increase in repo rates even in the absence of credit risk when securities prices fall and expected returns rise. The data we use in this paper is also from a CCP, namely Eurex, which is widely viewed as extremely safe.

The theory we test models repos as a vehicle to obtain liquidity. It is most relevant for general collateral (GC) repos, which are typically thought of as being driven by this objective. This differs from the seminal work of Duffie (1996), whose focus is on special repos, which are driven by the need to obtain a particular security. In GC repos, the cash taker (borrower) initially receives funds from the cash provider (lender) and hands over a security from a given basket of eligible collateral. The security is then returned at the maturity of the repo, or loan. This transfer of collateral differentiates a repurchase agreement from a plain collateralized loan and is also a key feature of the theory. The basic point of the theory is that the cost of raising liquidity through a repo is linked to the cost of raising liquidity in the security cash market. This is so because the alternative to a repo is a "home-made" repo, where the underlying security is sold in the cash market and repurchased at a future date (to match the repo).

The model is based on capacity constraints in the unsecured market, which make it necessary to trade in the security cash market. Capacity constraints mean that repo or home-made repo need to be used in combination with unsecured borrowing to raise the requisite quantity of liquidity. The potential cash provider in a repo also faces capacity constraints in the unsecured market and, therefore, will need to sell a portion of the underlying security to finance the reverse repo. Capacity constraints, therefore, generate a constrained arbitrage link between the unsecured rate, the repo rate, and the expected rate of return of the underlying security in the security cash market. From the cash taker's perspective, the weighted average cost of liquidity down the repo path (repo in combination with unsecured borrowing) cannot be larger than the weighted average cost of liquidity down the home-made repo path. From the cash provider's perspective, an opposite condition applies. This creates bounds on feasible equilibrium repo rates that depend on players' capacity constraints in the unsecured market.

Under this argument, repo rates are increasing in the cost of raising liquidity in the security cash market. Thus, the collateral spread is increasing in the expected rate of return, illiquidity, and volatility of the underlying security. As a corollary, collateral spreads are increasing the quality of the basket, consistent with what we observe in Figure 1 as well as with Bartolini, Hilton, Sundaresan, and Tonetti (2011). Collateral spreads are also increasing in the unsecured rate. So, according to the theory, negative collateral spreads can arise if unsecured rates spike down, as they typically do in the euro area at the end of maintenance periods. They may also occur if security markets are sufficiently depressed, illiquid, or volatile or unsecured markets are sufficiently tight. The latter also implies that liquidity-easing central bank policies can cause negative collateral spreads to reverse.

We use data provided by Eurex Repo to test several predictions of the theory. For all tests, we employ the two GC baskets with the most active overnight trading on the Eurex platform, namely the GC Pooling ECB basket and the GC Pooling Extended basket. The collateral spreads in Figure 1 are also based on these two baskets.

In the first test, we exploit the feature of the unsecured market that it spikes, up or down, at the end of the reserve maintenance period. This relates to the central bank's operational framework (Nyborg, Bindseil, and Strebulaev, 2002). Thus, by the arbitrage relation discussed above, the repo rate would be predicted to move less than the unsecured rate. As a result, the collateral spread is predicted to spike in the same direction as the unsecured rate. The evidence is strongly in support of the theory.

In the second test, we use an exogenous change to haircuts to test the prediction of the model that the collateral spread is increasing in the haircut (when the collateral spread is positive). The intuition for this result is that an increase in the haircut raises the proportion of relatively expensive unsecured liquidity. The repo rate must increase by less, ceteris paribus, to keep the cost of liquidity down the repo path in balance with the cost down the home-made repo path. Our test of this prediction uses the institutional feature of our data that Eurex, not the counterparties, determines the haircuts. This corresponds to an assumption in the model that haircuts are exogenous. Moreover, Eurex uses the same haircuts as in Eurosystem repos (Mancini, Ranaldo, and Wrampelmeyer, 2016; Nyborg, 2016), which, as shown by Nyborg (2016), have historically been updated every three to four years.[2] On September 27, 2013, the ECB announced changes to haircuts in Eurosystem repos as of October 1, 2013. For the most part, haircuts were lowered. We have obtained actual haircuts from Eurex around this time and show that haircuts for the securities in the two baskets we are studying fell on October 2, 2013, consistent with Eurex' policy of using Eurosystem repo haircuts. Our tests show that collateral spreads also fell, as predicted by the theory.

In the third test, we examine the effect of volatility on collateral spreads. The theory predicts that higher security cash market volatility is associated with a lower collateral spread. The intuition is that the higher volatility feeds into a higher repo rate because it becomes more costly' for a risk averse cash provider to (partially) finance the reverse position through the cash market. Hence he requires a higher repo rate as compensation. To examine this, we study the change in the collateral spread on days with ECB Governing Council meetings where the policy rate is subject to change (typically every second Governing Council meeting). The securities in the two baskets we study are bonds of various kinds. As bond return volatility is closely linked to changes in interest rates, the uncertainty before a Governing Council meeting, in which they decide on a change in the policy rate, is higher than on the day itself, when the decision is announced. Thus, the model predicts that the change in the collateral spread is negative, which is also what we find in the data.

[2]The Eurosystem is comprised of the ECB and euro area member states' national central banks.

These findings lend support to the idea that repo rates and collateral spreads are determined by a constrained arbitrage link between the repo rate, the unsecured rate, and the cost of liquidity in the security cash market. Under this view, prolonged periods of negative collateral spreads reflect depressed, illiquid, and volatile security markets and/or "very" tight conditions in the market for liquidity.

The theory has implications with respect to the effects of liquidity-easing central bank policies. In particular, such policies are predicted to increase collateral spreads. There are two effects, and these work in the same direction. First, liquidity-easing policies may improve securities markets in terms of putting upward pressure on prices, improving market liquidity, and reducing volatility. Second, they may expand capacity constraints in the unsecured markets through the provisioning of central bank liquidity. The prolonged period of negative collateral spreads in 2008 seen in Figure 1 and the reversal to positive spreads upon the introduction of the ECB's full allotment policy in October 2008 is consistent with this perspective. The explanation is that over the course of 2008, security markets became increasingly depressed, illiquid, and volatile. At the same time, stress also developed in the interbank market (see, e.g., the accounts in Afonso, Kovner, and Schoar, 2011; Abbassi, Bräuning, Fecht, and Peydró, 2014). The stress in these markets peaked in the aftermath of Lehman's default on September 15, 2008. The subsequent introduction of the full allotment policy then improved conditions sufficiently for the collateral spread to turn positive again. Empirical evidence on the effect of central bank policies is discussed further in Section 6.

The rest of the paper is organized as follows. Section 2 describes the data and the institutional setting. The empirical tests are carried out in Section 3 (spikes), Section 4 (haircuts), and Section 5 (volatility). Section 6 discusses the evidence on liquidity-easing central bank policies, and Section 7 concludes.

2 Data and institutional setting

We make use of a comprehensive intraday dataset of repo transactions from Eurex Repo, who offers a trading platform for anonymous repo transactions.[3] The sample period runs

[3]See www.eurexrepo.com/repo-en/ and www.eurexgroup.com.

from January 2, 2007 to June 30, 2015. The dataset contains both general collateral and special contracts. Because our model is based on using repos to raise liquidity, we focus on general collateral repos.[4] For the unsecured rate, we use the Eonia, which is a volume-weighted average of overnight unsecured euro transactions by reporting (European) banks.[5] Abbassi, Bräuning, Fecht, and Peydró (2014) provide evidence that trading in the unsecured market remained active after the start of the financial crisis and the collapse of Lehman Brothers (September 15, 2008), especially at the short end. Our repo data allows us to calculate overnight volume-weighted repo rates. Thus, we calculate collateral spreads by using overnight volume-weighted unsecured and repo rates on a day-by-day basis.

These overnight collateral spreads are then used to test the theory summarized in the Introduction with respect to how the collateral spread reacts to changes in the unsecured rate, haircuts, and volatility. Our tests exploit different institutional elements in the market for liquidity in the euro area.

2.1 General collateral repos: Contracts and transactions

We start by describing our general collateral repo data in terms of types of contract and volume by contract type and tenor. Eurex Repo provides two types of general collateral contracts; namely, GC Pooling and Euro Repo. Trading in both GC Pooling and Euro Repo is open to credit institutions and investment firms. All trades are anonymous, cleared by the CCP Eurex Clearing, and settled by Clearstream. Tenors may be overnight, tomorrow-next, spot-next, longer-term, and variable term. We focus on overnight and tomorrow-next. Volume at other maturities is small and, in any case, not relevant with respect to calculating overnight collateral spreads.

GC Pooling (GCP) includes the ECB and ECB Extended baskets, which will be our focus, as well as a basket containing equities. "Basket" refers to a list of securities (by ISIN) that can be used as collateral. The GCP ECB and GCP ECB Extended baskets are subsets of the 30,000 to 40,000 securities on the public list of eligible collateral in Eurosystem liquidity injecting operations (see Nyborg, 2016). In September 2013, there were around 7,000 securities in the GCP ECB basket and 20,000 in the GCP ECB Extended

[4] See Rösler (2017) for an analysis of the special repo transactions.

[5] Eonia is an acronym for Euro Overnight Index Average. See http://www.euribor-rates.eu/eonia.asp.

basket, ranging from government bonds to unsecured bank bonds with different domiciles. The ECB basket represents higher quality collateral than the ECB Extended basket. For example, securities in the GCP ECB basket need a minimum rating of A− (on the S&P scale), while those in the GCP ECB extended basket need at least a BBB− rating.[6] The ECB Extended basket was created after the ECB started admitting collateral rated below A− (down to BBB−) in its operations on October 25, 2008. Thus, the sample start date is later for the ECB Extended basket (November 24, 2008) than the ECB basket (January 2, 2007).

Unlike the GCP baskets, Euro Repo baskets are constrained to one type of security, e.g. French covered bonds. The minimum rating for inclusion is A−. There are two other notable differences between GC Pooling and Euro Repo contracts. First, in a GC Pooling transaction, the cash taker pledges securities from her collateral account; whereas, in Euro Repo transactions, she transfers these securities physically to the counterparty. While re-use in Euro Repo has no limitations, collateral obtained in a GC Pooling transaction can only be used in other GC Pooling transactions, in Eurosystem operations, and, in the case of the GCP ECB basket, in other transactions at the CCP (e.g. in futures contracts). It can also be used to substitute for another security the cash provider may have pledged. Second, haircuts are different. Eurex' policy is to derive haircuts for the GC Pooling contracts from haircuts in Eurosystem operations. Nyborg (2016) provides evidence that they are identical in around 90% of cases. Eurex may increase haircuts for paper where it deems risk to be especially large. In contrast, Euro Repo haircuts are set by the clearing counterparty, Eurex Clearing, without an explicit link to Eurosystem haircuts.

[insert Table 1 about here]

Table 1 reports volume and rate statistics for all GC Pooling and Euro Repo baskets, based on all 261,663 general collateral transactions in our dataset. There are 28 different baskets in total. These are ranked in the table by transaction volume per trading day. The GC Pooling ECB and ECB Extended baskets are the most active, with average trading-day volumes of EUR 40,311 and 18,333 million, respectively. These two baskets account for

[6] S&P denotes Standard and Poor's. All references to ratings in this paper are on the S&P scale unless otherwise specified.

approximately 84% of all transactions. The majority of these are overnight repos. These two GC Pooling baskets comprise around 99.5% of all overnight repo transactions.

The most active Euro Repo basket is the German KfW/Laender basket, with an average daily volume of EUR 1,645 million. All transactions in this basket have a tomorrow-next tenor, as do most transactions in the Euro Repo space.

Table 1 also reports on volume-weighted average collateral spreads, relative to the Eonia, for all baskets. We use overnight transactions for the GC Pooling ECB and ECB Extended baskets and tomorrow-next transactions for all other baskets. In the former case, we use the Eonia of the day of the transaction, and, in the latter case, we use the next day's Eonia. The volume-weighted average collateral spread across all overnight transactions is 4.07 basis points (bps) for the ECB basket and 1.38 bps for the ECB Extended basket. The larger average collateral spread for the higher quality baskets is consistent with the predictions of the constrained-arbitrage theory as well as with the results in Bartolini, Hilton, Sundaresan, and Tonetti (2011). Overall, the largest (smallest) collateral spread is for the Euro Repo Germany 10 Year basket (Euro Covered bonds), with 15 (-6.14) bps.

[**insert Table 2 about here**]

In the more formal empirical tests below, we use overnight repo trades only to calculate collateral spreads (since the Eonia is an overnight rate). Thus, our focus is on the two main GC Pooling baskets, since these represent nearly all overnight transactions. Table 2 provides descriptive statistics on the collateral spreads based on overnight trades in these two baskets. The underlying data is the same as what is used in Table 1. However, for Table 2, we first calculate volume-weighted average collateral spreads for each day. The table then reports summary statistics of the resulting sample of these daily averages. This is also what is plotted in Figure 1.

Both GCP collateral spreads are positive on average, but lower for the lower quality basket. The Eonia – GCP ECB (Extended) basket has a mean of 3.773 (1.362) bps. Both are significant at the 1% level and significantly different from each other. The median is positive for both: 4.109 bps and 2.371 bps, respectively. The collateral spread calculated using the ECB Extended basket is lower than that based on the ECB basket on 97.506% of the 1,604 overlapping days. For the ECB basket, the collateral spread is negative on

22.889% of all days; whereas for the ECB basket, it is negative 28.741% of the time. These findings also mean that repo rates for the higher quality ECB basket are almost always lower than those of the lower quality ECB Extended basket. Lower repo rates for higher quality collateral mirror the findings in Bartolini, Hilton, Sundaresan, and Tonetti (2011) using US data. It is consistent with both Nyborg's (2019) constrained-arbitrage theory as well as the more classical no-arbitrage argument in Bartolini et al.

3 Empirical test: Spikes

In this section, we test the constrained-arbitrage theory with respect to the effect of changes in the unsecured rate on the collateral spread. We first briefly review the constrained-arbitrage link between the unsecured rate, the repo rate, and the expected rate of return of the underlying security from which the empirical predictions are derived.

3.1 Theoretical relation between rates

Capacity constraints in the unsecured market is an important element in the constrained-arbitrage theory of collateral spreads. Some important predictions relate to differences in unsecured borrowing capacities between the cash taker and provider and to changes in these. For simplicity, such asymmetry is ignored here. As seen in Nyborg (2019), this does not affect the three main specific predictions tested in this paper. The link between the three rates when unsecured capacity constraints are identical and the collateral spread is positive is given by

$$(1-h)r + hu = \Omega(1-\varepsilon_0)\hat{y}(\Omega) + (1-\Omega(1-\varepsilon_0))u, \tag{1}$$

where h is the haircut, r is the repo rate, u is the unsecured rate, Ω is the optimal quantity to sell down the home-made repo path, ε_0 is an illiquidity parameter, and $\hat{y}(\omega)$ is the cost of liquidity from selling ω units in the cash market and buying this back at the maturity date (of the repo). This is an increasing function of the expected rate of return of the underlying security in a frictionless market, illiquidity, and volatility (because of risk aversion). Given (1), the collateral spread, $u - r$, is increasing in the unsecured rate and the haircut and decreasing in the cost of liquidity of the underlying security. Specifically, it is decreasing in illiquidity and volatility. These predictions carry over to the case that players have different capacity constraints (Nyborg, 2019).

Negative collateral spreads may only arise if the cash provider has a larger unsecured capacity constraint than the cash taker and give rise to different expressions for the constrained-arbitrage link between the three rates. However, comparative statics are the same as for positive collateral spreads except that haircuts no longer matter (since the cash taker now wants to borrow up to her constraint since repo is expensive).

3.2 The test

To test the prediction that repo rates do not move one-for-one with unsecured rates (unless the cost of liquidity in the security cash market does so), we exploit a feature of money markets that unsecured rates tend to spike, up or down, toward the end of the reserve maintenance period. Since longer-term rates and securities market do not experience these spikes, this allows us to test the prediction that the collateral spread is increasing in the unsecured rate. That is, the collateral spread is predicted to spike in the same direction as the unsecured rate, but less.

We carry out the "spikes test" on the subset of the sample period when the ECB operated with a liquidity-neutral policy (Nyborg, Bindseil, and Strebulaev, 2002).[7] That is, it aimed to inject the quantity of central bank money (liquidity) that banks needed to fulfill reserve requirements and satisfy other liquidity needs *in aggregate* within each (approximately monthly) maintenance period. At the end of the maintenance period, an excess of liquidity in the system would drive the overnight rate down toward that of the deposit facility, 100 bps below the policy rate. A liquidity shortage would drive the overnight rate up toward the marginal lending facility ("discount window") rate, 100 bps above the policy rate. Thus, equal likelihood of an excess or a shortage should then, in theory, keep the overnight rate close to the policy rate before the end of the maintenance period. As documented, for example, by Perez-Quiros and Mendizabal (2006), Nautz and Offermanns (2007), Linzert and Schmidt (2011), the ECB was successful in controlling the

[7]For descriptions of the basic Eurosystem monetary policy framework see European Central Bank (2002) or European Central Bank (2011).

overnight rate this way. The relevant takeaway for this paper is that spikes were built in to the operational framework of the ECB under the liquidity-neutral policy. This policy stayed in place until October 2008, when, in the aftermath of Lehman's bankruptcy, the ECB introduced its full allotment policy.

We run our spikes test over the period January 2, 2007, to August 29, 2008, with the end-date representing the end of the last month before Lehman's default. This represents twenty-one reserve maintenance periods, with the first maintenance period starting on December 13, 2006 and the last ending on September 9, 2008. So we have the end-periods of twenty reserve maintenance periods, with the twentieth maintenance period ending on August 12, 2008.

End-of-calendar-month spikes in the Eonia have also been documented in the literature, which may be related to window dressing by banks (Bindseil, Weller, and Wuertz, 2003; Fecht, Nyborg, and Rocholl, 2008). This is also considered in the tests below. Unlike end-of-maintenance period spikes, which may be up or down, end-of-month spikes are (nearly) uniformly up. They are also somewhat weaker.

Eonia: End-of-maintenance-period and end-of-month spikes

As a first step in our spikes test, we first verify spikes in the Eonia over the sample period. We do this by calculating abnormal, or standardized, levels of the Eonia at the end of each maintenance period and calendar month. We then look at the average standardized end-of-maintenance-period and end-of-calendar-month Eonia over the sample period, breaking the data out into positive and negative end-of-period changes. We also look at the ranks of days within maintenance periods based on the Eonia.

We proceed as follows: First, for each maintenance period, m, we calculate the mean, $\overline{u}_m$, and standard deviation, s_m, of the Eonia, excluding the last five days of the reserve maintenance period and the last trading day of the calendar month. For each day, t, within the maintenance period, we then calculate the standardized Eonia as

$$\text{stand. Eonia}_{t,m} = \frac{u_{t,m} - \overline{u}_m}{s_m}. \tag{2}$$

[insert Table 3 about here]

Table 3 reports on the standardized Eonia, across maintenance periods, for the last five days of the maintenance period, labeled endmp (last day) to endmp-4 (four days before the last day), and the last day of each calendar month, labeled endmonth. The average for endmp is -7.675. In other words, the Eonia is, on average, 7.675 standard deviations lower on the last day of the maintenance period than its normal, within-maintenance period, level. Thus, the Eonia typically spikes down at the end of the maintenance period. This overall downward move is also seen in the days immediately before the last day, with the standardized Eonia ranging from -3.585 (endmp-1) to -1.474 (endmp-2) on average. These large negative averages mask the fact that the Eonia also may spike up. The table shows that there are nine up-spikes on the last day of the maintenance period, with five of these representing spikes of more than two standard deviations. There are eleven down-moves, with seven of these representing spikes of more than two standard deviations. The absolute value of the standardized Eonia on the last day of the maintenance period averages to 16.310 across maintenance periods. In short, there are both statistically significant up- and down-spikes in the Eonia at the end of the maintenance period over the sample period.

With respect to the end of the month, the last row in Table 3 shows that there are nineteen end-of-month up-moves, with only one small down-move. Thirteen of the up-moves represent standardized Eonias of more than two standard deviations. The average end-of-month standardized Eonia is 3.583. Thus, the Eonia tends to spike up at the end of the month.

To further examine end-of-maintenance period spikes in the Eonia, we rank the standardized Eonia within each maintenance period, focusing on the last five days. The order of the ranking is determined by the standardized Eonia on the last day of the maintenance period. If this is negative (positive), the ranking is in ascending (descending) order. So if the standardized Eonia on the last day of the maintenance period is negative (positive) a rank of one is given to the day with the lowest (highest) standardized Eonia. A rank of two is given to the day with the second lowest (highest) standardized Eonia, and so on. For each maintenance period, Table 4 reports the rankings of the five last days.

We also rank the last day of the month within the maintenance period. Since the standardized Eonia (with one exception) is positive at the end of each calendar month, this is always done in descending order.

[insert Table 4 about here]

The ranking results are in Table 4. The five last days of the maintenance period contains the first rank, i.e. the day with the largest standardized Eonia (either positive or negative), in fifteen out of the twenty maintenance periods. The last day has the first rank in ten maintenance periods. The last day of the calendar month has the first positive rank (within the maintenance period) in ten maintenance periods and has a rank of three or better in fifteen cases. This is further evidence of spikes in the Eonia at the end of the maintenance period and up-spikes at the end of the calendar month.

Collateral spread spikes test

Based on Propositions 1 and 2 in Nyborg (2019), we expect end-of-maintenance-period down- and up-spikes in the Eonia to have a negative and positive effect, respectively, on the collateral spread. This is so because these spikes are not driven by general market conditions, but the operational framework of the ECB. Under the liquidity-neutral policy, spikes at the end of the maintenance period are driven by the central bank's injections of reserves relative to aggregate needs and, to some extent, also by allocational imperfections in the interbank market for liquidity (Bindseil, Nyborg, and Strebulaev, 2009). Thus, end-of-maintenance period spikes provide us with an ideal opportunity to test a central implication of the constrained-arbitrage theory of repo rates.

As a first step, we identify days with spikes in the Eonia by the 10th and 90th percentiles of the Eonia in each maintenance period. Dummy variables to capture these days are labeled perc10 and perc90, respectively.[8] Second, we condition these spikes on whether they occurred in one of the last five days of the maintenance period or not. Thus, we generate the variables perc10|endres, perc90|endres, perc10|nonendres, and perc90|nonendres to capture down and up spikes, respectively, for the last five days and for other days, respectively.

We run two regressions. The first specification is:

$$y_t = \beta_0 + \beta_1 \text{perc10}_t + \beta_2 \text{perc90}_t + \beta_3 \text{fincrisis}_t + \beta_6 \text{monthend}_t + \varepsilon_t, \tag{3}$$

[8] The last day of the month is not included when determining perc10 and perc90.

where y_t is the collateral spread, fincrisis is an indicator variable for the financial crisis (days after August 07, 2007, inclusive), and monthend indicates the last trading day of the calendar month. The collateral spread on day t is the Eonia less the volume-weighted average GC Pooling ECB basket rate (for overnight repos only).

The second specification is:

$$\begin{aligned} y_t =& \beta_0 + \beta_1 \text{perc10}|\text{nonendres}_t + \beta_2 \text{perc90}|\text{nonendres}_t \\ &+ \beta_3 \text{perc10}|\text{endres}_t + \beta_4 \text{perc90}|\text{endres}_t + \beta_5 \text{fincrisis}_t + \beta_6 \text{monthend}_t + \varepsilon_t. \end{aligned} \tag{4}$$

We base inference on Newey-West standard errors with the number of lags equal to the fourth root of the number of observations, as recommended by Greene (2008). Here, this means five lags.

[insert Table 5 about here]

Table 5 displays the results. In the first specification, the coefficient on perc10 is negative and statistically significant at the 5% level. The coefficient on perc90 is positive and statistically significant at the 10% level. This is consistent with the theoretical predictions. The results for Specification 2, show that it is especially spikes at the end of the maintenance period that matter. As predicted by the theory, the coefficients on perc10|endres and perc90|endres are negative and positive, respectively, and statistically significant at the 5% and 1% levels, respectively. Spikes outside the end of the maintenance period do not seem to matter. This is highly supportive of the theory because the spikes at the end of the maintenance period are driven by the operational framework of the ECB, that is, by a dominating factor with respect to the general level of unsecured rates. The coefficients on monthend are insignificant in both regressions, suggesting that the factors that drive these spikes are not unique to the unsecured market.

Finally, the coefficient on fincrisis is negative and statistically significant at the 1% level in both specifications. This also relates to Nyborg's model. The financial crisis was a period of reduced liquidity and depressed security prices. Both of these effects would be expected to lead to a reduction in the collateral spread (Propositions 1 and 2). Thus, our findings are consistent with the theory with respect to the negative coefficient on the financial crisis indicator variable. Overall, the spikes tests support the constrained-arbitrage theory.

The work in this section shows that repo rates do not move one-for-one with unsecured rates. In particular, a shock to the unsecured rate results in a smaller movement in the same direction for the repo rate. In short, the collateral spread is increasing in shocks to the unsecured rate.

4 Empirical test: Haircuts

In this section, we examine the effect of haircuts on the collateral spread. Our objective is to test the theoretical prediction that the spread is increasing in haircuts (when the spread is positive). The test uses the fact that Eurex sets haircuts in GC Pooling ECB and ECB Extended basket repo using the haircuts set by the ECB in Eurosystem repos.[9] The haircuts are identical for around 90% of securities. Moreover, as documented by Nyborg (2016), the ECB has historically updated haircuts only every three to four years. Thus, Eurosystem haircuts do not reflect current developments in money markets. A change to Eurosystem haircuts, therefore, provides an ideal natural experiment for studying the effect of a change in haircuts on the collateral spread (given that the collateral spread is positive to begin with).

During our sample period, the Eurosystem changed haircuts on marketable securities three times. We use the third haircut adjustment in our test as it occurred during a relatively calm period and involved wide-ranging cuts to haircuts. Collateral spreads were also positive at that time. The third haircut adjustment was announced on September 27, 2013 and implemented on October 1, 2013.[10]

The Eurosystem's collateral framework sets haircuts based on the type of security,

[9] This is as reported by Eurex and is confirmed by Nyborg (2016), Table 5.6.

[10] The first Eurosystem haircut adjustment occurred on October 25, 2008, shortly after Lehman's default. This had little effect on the GCP ECB basket since, as documented by Nyborg (2016), haircuts for A− or better rated securities did not change, with the exception of unsecured bonds, which are relatively unimportant for the ECB basket (see Table 7). The ECB Extended basket had not been created yet. The second haircut adjustment occurred on January 1, 2011. This was during a stressed time for the euro area. Moreover, as seen in Nyborg (2016), there was only a limited change in haircuts (for lower quality collateral).

time to maturity, and rating.[11] For the purpose of determining the haircut, marketable securities are classified into five "liquidity categories," briefly summarized as: (I) central government debt instruments, (II) local and regional government debt instruments as well Jumbo covered bank bonds and supranational/agency bonds, (III) corporate bonds and and non-Jumbo covered bonds, (IV) unsecured bank bonds, and (V) asset-backed securities (ABS's). Haircuts increase in the liquidity category, *ceteris paribus*.

The changes to Eurosystem haircuts for marketable securities on October 1, 2013 are displayed in Table 6. This is computed from Tables 5.3 and 5.4 in Nyborg (2016). For eligible securities with a rating of at least A−, haircuts predominantly fall. The most notable exception is for liquidity category IV, where they do not change. There are also two cases with small increases. For securities with a rating in the BBB− to BBB+ range, Eurosystem haircuts also fall, except for liquidity categories I and II, where they rise. Overall, haircuts fall, especially for the ECB basket.

[**insert Tables 6, 7, and 8 about here**]

To examine the relevance of these Eurosystem haircut changes to the two GC Pooling baskets, Tables 6 and 7 show the distributions of securities in the GC Pooling ECB and ECB Extended baskets, respectively, across the five liquidity categories on September 26, 2013, one day before the announced change. As seen, the two baskets do not contain any securities in category V (ABS's). The GC Pooling ECB basket only contains securities with a rating of at least A−, with 96.5% of all securities being in liquidity categories I to III. Thus, Table 5 confirms that Eurosystem haircuts fall for securities in the GC Pooling ECB basket.

For the GCP ECB Extended basket, Table 7 shows that 94.1% of all securities are rated A− or higher, thus falling in the higher rating category. Thus, Eurosystem haircuts predominantly fall for securities in the Extended basket also, but with some exceptions for lower-rated collateral.

The relevance of changes to Eurosystem haircuts derives from the institutional feature that Eurex Repo sets haircuts for securities in the GCP ECB and ECB Extended baskets equal to those in Eurosystem repos (with some exceptions). To examine this more carefully

[11] An exact description of this framework and its evolution over time is provided by Nyborg (2016).

for the October 1, 2013 Eurosystem haircut adjustments, we have obtained GC Pooling haircuts on a daily basis from Eurex Repo over the period September 16 to October 15, 2013. Using this data, we calculate the daily average haircut for each basket. The resulting time series of average haircuts for both baskets are plotted in Figure 2. The change in haircuts is evident. However, it takes place on October 2, 2013 rather than October 1, 2013. On this date, haircuts in the GCP ECB basket fell by 84 bps on average. In the GCP ECB Extended basket, they fell by 49 bps. Assuming collateral spreads are positive, the theory says that this should be associated with a drop in collateral spreads.

[insert Figures 2, 3, and 4]

The development of the Eonia and GC Pooling overnight repo rates can be seen in Figure 3, with the associated collateral spreads in Figure 4. These figures show that collateral spreads were positive prior to the haircut change, except for an end-of-month dip for the GCP ECB Extended basket. Consistent with the theory, Figure 4 shows that collateral spreads were lower after the drop in haircuts on October 2, 2013.

To formally test the effect of the haircut change, we run the following regression:

$$y_t = \beta_0 + \beta_1 \text{newhaircut}_t + \beta_2 \text{endmp1}_t + \beta_3 \text{endmp2}_t + \varepsilon_t, \tag{5}$$

where y_t denotes the collateral spread, based on either the GCP ECB or GCP ECB Extended baskets.[12] The variable of interest, newhaircut, is a dummy variable that is equal to one starting October 2, when the new haircuts are applied by Eurex Repo. We control for the last day of each of the two maintenance periods covered by the test periods, September 10, 2013 and October 8, 2013, with two separate indicator variables, endmp1 and endmp2, respectively. The regression is run for two-, three-, and four-week periods around October 2, 2013, with the following days removed: the announcement day, September 27, 2013, the last trading day of September, the first trading day of October, and the last trading day of August. Inference is based on Newey-West standard errors with two lags.

[insert Table 9 about here]

[12]As always, we take the Eonia less the volume-weighted overnight repo rates for either basket.

Table 9 shows the results. Consistent with the constrained-arbitrage theory, the coefficient on newhaircut is statistically significantly negative for both collateral spreads and for all three test periods. For example, for the test period where we use two weeks either side of October 2, 2013, the collateral spread based on the GCP ECB basket falls by 1.461 bps (statistically significant at the 1% level), and the collateral spread for the GCP ECB Extended basket falls by 1.289 bps (statistically significant at the 5% level). When using four weeks around October 2, the coefficients are 1.005 and 1.097, respectively (both statistically significant at the 5% level). In short, consistent with the theory, in the data, an exogenous decrease in haircuts results in lower collateral spreads.

5 Empirical test: Volatility

In this section, we examine the effect of security market volatility on the collateral spread. Our objective is to test the prediction of the constrained-arbitrage theory that the collateral spread is decreasing in volatility, σ_y^2. Intuitively, a higher volatility translates into a larger risk and illiquidity adjusted return of the underlying security, which increases the cost of raising liquidity through trading in the security cash market. In other words, the cost of liquidity in the home-made repo alternative becomes more expensive. This leads players that are short liquidity to be willing to accept a higher repo rate and puts downward pressure on the collateral spread. To test the prediction, we use the overnight collateral spread based on the GC Pooling ECB and ECB Extended baskets over their respective sample periods.

The basic idea of our test relates to the general finding by Brenner, Pasquariello, and Subrahmanyam (2009) that return volatility increases before the announcement of macroeconomic news. We focus on the central bank's policy rates, which directly affect the pricing of fixed income securities, such as what are in the two GC Pooling baskets. In the euro area, decisions on monetary policy are made by the Governing Council of the ECB, which meets twice within each maintenance period. Interest rates and the monetary policy stance are subject to change in the second of these meetings.[13] Interest rate uncertainty is

[13]The dates of the Governing Council are determined by the ECB one year in advance. Policy rates include the minimum bid rate in the Eurosystem's main refinancing operations (MROs) (under the liquidity-

elevated before these meetings. It drops back after the meetings as uncertainty is realized. In turn, this should translate into a reduction in security volatility. Thus, the theory predicts that collateral spreads fall after the announcement of the monetary policy stance.

To examine this, we run four models using daily changes in the collateral spread as the dependent variable. The four models are all variations of the following general regression specification:

$$\begin{aligned}\Delta y_t =& \beta_0 + \beta_1 \text{govcouncil\_mp}_t + \beta_2 \text{govcouncil\_nonmp}_t + \beta_3 \text{vstoxx}_{t-1} \\ &+ \beta_4 \text{excessliq}_{t-1} + \Gamma_1' \boldsymbol{X}_t + \Gamma_2' \boldsymbol{Z}_t + \varepsilon_t.\end{aligned} \tag{6}$$

The dependent variable, Δy_t, is the change in the overnight collateral spread from day $t-1$ to day t based on the GCP ECB basket or the GCP ECB Extended basket, respectively ΔCollspread_1 and ΔCollspread_2. We use Newey-West standard errors, with the number of lags equal to the fourth root of the number of observations, as recommended by Greene (2008). See Table 10, which reports on the results, for details.

The main right-hand side variables in (6) are govcouncil_mp and govcouncil_nonmp. These are indicator variables for Governing Council meeting days where the policy rates are subject to change and not subject to change, respectively. Given that volatility should be affected only in the former case, the theory would say that the coefficient on govcouncil_mp should be positive, whereas that on govcouncil_nonmp should be insignificant.

The regression specification includes three sets of controls. First, all specifications control for market volatility through the vstoxx and excess liquidity injections into the banking system as reported by the ECB, excessliq.[14] Excess liquidity is measured as the sum of aggregate volumes at the Eurosystem deposit facility and current accounts less volumes at the lending facility and reserve requirements.

Second, we include a vector of control variables, $\boldsymbol{X}$, that are used in all four specifications, but not reported on in the results in Table 10. The individual variables are:

neutral policy) and the fixed tender rate (under the full-allotment policy), the marginal lending facility rate, and the deposit rate. The standard rate change, if any, is 25 basis points.

[14] vstoxx is the implied volatility from options (30 days constant maturity) on the Euro Stoxx 50 (analogous to the VIX in the US), see https://www.stoxx.com/index-details?symbol=V2TX, and is downloaded from Bloomberg. Excess liquidity, excessliq, is taken from the ECB's webpage, see https://www.ecb.europa.eu/stats/policy_and_exchange_rates/minimum_reserves/html/index.en.html.

perc10|endres, perc90|endres, fincrisis, monthend (see Section 3 for definitions), and an indicator variable for the first trading day of each calendar month.[15]

Third, we include another vector of control variables, $\boldsymbol{Z}$, in all specifications except the first one (which serves as a baseline). These capture various dates that relate to the ECB's unconventional monetary policies. This is motivated by Szczerbowicz (2015), who argues that there were strong reactions to these policies in the unsecured and repo markets. Following her approach, we include indicator variables for: the settlement days of the first one-year longer term refinancing operation (LTRO, 1yearltro) on June 25, 2009, and both three-year LTROs (3yearltros) on December 22, 2011 and March 1, 2012; the introduction of a zero deposit facility rate (zerorate) on July 11, 2012; and full allotment announcements on October 9, 13, and 15, 2008 (fullallot).[16] These are all reported on in the output in Table 10. The fullallot dummy is not used in the ΔCollspread_2 regressions, since the sample period for the GCP ECB Extended basket starts at a later date. $\boldsymbol{Z}$ also includes several other key dates relating to ECB unconventional monetary policies which are suppressed in the output.[17]

The third and fourth specifications refine the analysis in the second specification by modifying the underlying data in two ways. Specifically, in the third specification we seek to isolate the effect of potential interest changes on volatility from the effect on expected rates of return of the underlying collateral. A change in the interest rate, if unanticipated, changes the expected rate of return of the underlying collateral and, by the constrained-arbitrage theory, also the collateral spread unless the unsecured rate changes by the same amount. Brand, Buncic, and Turunen (2010) show that short-term news by the ECB, such as interest rate decisions, have a significant impact on the yield curve, especially at the short end. So in order to capture the volatility effect more cleanly, in the third

[15]The indicator variable fincrisis is 1 from August 7, 2007 to the end of the sample period.

[16]Full allotment for MROs was announced on October 8, 2008. However, Szczerbowicz (2015) reports that this was in the evening, which is why we dummy the following day. On October 13, 2008, the ECB announced full allotment USD injecting operations (in cooperation with the Fed). On October 15, full allotment was announced for the LTROs.

[17]The additional indicator variable elements of $\boldsymbol{Z}$, which are not reported on in the regression results in Table 10, are: (i) news on EFSF/ESM on May 10, 2010, March 14, 2011, and March 26, 2011; (ii) announcements of covered bond purchase programs on May 7, 2009, October 6, 2011, and September 4, 2014; (iii) announcements on one-year and three-year LTROs on May 7, 2009, and December 8, 2012. (iv) the announcement of the public sector purchase programme on January 22, 2015. For discussions of these events, see Szczerbowicz (2015) and Nyborg (2016).

specification, we exclude Governing Council meeting days when the main policy rate is actually changed.[18]

In addition, in the fourth model, we account for the fact that monetary policy decisions by the Governing Council are announced in the middle of the day, namely through a press release posted on the ECB's webpage at 13:45 CET. Thus, when calculating the daily change in the collateral spread on Governing Council meeting days when interest rates are subject to change, we only use repo transactions with timestamps after 13:45:00 to calculate collateral spreads.

[**insert Table 10 about here**]

Table 10 shows the results. We first discuss the collateral spread based on the higher quality basket, GCP ECB.

In our baseline specification (Model 1), the coefficient on our main variable of interest, govcouncil_mp, is 0.640 (statistically significant at the 5% level). So, on average, the collateral spread increases by approximately 0.640 bps on days when policy rates are subject to change. This is around 16% of the average collateral spread of 3.773 bps over the sample period and 9.5% of the sample standard deviation (see Table 2). In contrast, the coefficient on govcouncil_nonmp is not statistically significantly different from zero. So there is a systematic relationship between Governing Council days and the collateral spread only when the policy rates are subject to change and, therefore, volatility is affected. The positive coefficient on govcouncil_mp and the insignificant coefficient govcouncil_nonmp are consistent with the predictions of the constrained-arbitrage theory.

Our baseline findings hold up in Model 2, which includes a larger set of controls, as described above. The coefficients on govcouncil_mp and govcouncil_nonmp and their standard errors are almost identical to what they are in Model 1. The results in Model 3 are also very similar. This speaks to the robustness of the findings in Model 1.

The results are even stronger in Model 4, where we restrict ourselves to transactions timestamped after 13:45:00 CET on Governing Council days where interest rates are sub-

[18]The main policy rate is the minimum bid rate in the MROs over the liquidity-neutral period and the tender rate in the full-allotment period.

ject to review.[19] The coefficient on govcouncil_mp shoots up to 2.168 bps, nearly three times as large as before and almost 60% of the average in-sample collateral spread. In a test not reported in the table, we have used pre-13:45 transactions instead. In this case, the coefficient is statistically insignificant, which supports the view that the announcement of the interest rate decision matters in that it resolves uncertainty and reduces volatility. The coefficient on govcouncil_nonmp remains insignificant in Model 4. So, overall, the results using the collateral spread based on overnight trades in the GCP ECB basket are solidly consistent with the prediction of the constrained-arbitrage theory that a decrease in volatility leads to a higher collateral spread.

As a counterpoint to this, the coefficient on govcouncil_mp is not significant in any of the regressions involving the collateral spread based on the GCP ECB Extended basket. A potential explanation can be that the securities in this basket are so risky and illiquid that relatively small changes in the central bank's policy rate do not matter much. As seen in Table 8, more than half of all securities in the GCP ECB Extended basket are unsecured bank bonds.

To summarize, using ECB Governing Council meetings where the policy rate is subject to change to capture elevated volatility, the results in this section show that collateral spreads are decreasing in volatility. This is consistent with the constrained-arbitrage theory.

6 Central bank liquidity policy and collateral spreads

In this section, we look more closely at the effect of liquidity-easing central bank policies on collateral spreads. Note first that Figure 1 shows frequent spikes in either collateral spread, whether based on the ECB basket or the lower quality ECB Extended basket. As studied in Section 3, this relates to end-of-maintenance period spikes in the unsecured rate. Because unsecured rates often spike down as a result of the central bank injecting an excess of liquidity within the reserve maintenance period, this results in frequent end-of-

[19] The number of observations drops in Model 4 because there are some Governing Council meeting days with no trades after 13:45 CET.

maintenance period negative collateral spreads.[20] In this section, however, our focus will be on non-end-of-maintenance-period effects.

According to the theory, negative collateral spreads are a symptom of tight conditions in the unsecured market and/or depressed, illiquid, and volatile security markets. If conditions in the unsecured market ease up sufficiently, collateral spreads can flip from being negative to positive because capacity in the unsecured market expands. Central-bank liquidity-easing policies may, therefore, cause collateral spreads to change sign from negative to positive. The opposite applies to liquidity tightening policies. In addition, liquidity-easing (tightening) policies may also affect collateral spreads by improving (depressing) securities markets in terms of prices, liquidity, and volatility. According to the theory, this effect works in the same direction as the capacity effect. Thus, central bank liquidity-easing (tightening) policies are predicted to cause collateral spreads to increase (decrease) and, possibly, change sign. In this subsection, we examine this prediction.

The main liquidity-easing policies of the ECB during the financial crisis are, (i) the full-allotment policy, (ii) the first one-year LTRO (EUR 442 billion injected), (iii) the two three-year LTROs (around EUR 1 trillion injected), and (iv) quantitative easing (around 2 trillion over four years), see, e.g., Szczerbowicz (2015) or Nyborg (2016).[21] These are indicated as vertical bars in Figure 1. Below we study collateral spreads around and between these events.

The full set of periods indicated by the vertical bars in Figure 1. For each collateral spread and each period, descriptive statistics and means tests are shown in Table 11. We discuss each period in turn.

[insert Table 11 about here]

1. Pre-crisis, Jan 2, 2007 – Jul 31, 2007.

    - As a benchmark, Table 11 shows that over the pre-crisis period, Jan 2, 2007 –

[20] Even a small excess of liquidity will cause a downturn in unsecured rates. For the logic, see, e.g., (Nyborg, Bindseil, and Strebulaev, 2002).

[21] Before the financial crisis, LTROs typically had approximately 3-month maturities. After the onset of the crisis, these maturities were gradually increased. The ECB held several one-year LTROs and two three-year LTROs.

Jul 31, 2007 the average collateral spread (ECB basket only) is not statistically significantly different from zero.

2. Early crisis, Aug 1, 2007 – Oct 8, 2008.

    - The average Eonia−GCP ECB collateral spread is now −3.085 bps (statistically different from zero at the 1% level). The spread is negative on 78.2% of days. The negative collateral spreads over this period is consistent with the constrained-arbitrage theory of collateral spreads and the commonly accepted narrative of the unfolding financial crisis as being characterized by severely stressed interbank and securities markets. Either of these conditions may cause collateral spreads to turn negative according to the theory.

3. Start of full allotment, Oct 9, 2008 – Jun 24 2009.

    - The full allotment policy provides banks with whatever quantity of liquidity they ask for in the Eurosystem's main and longer term refinancing operations at a fixed rate. This was introduced to ease stress in the market. Thus, according to the theory, collateral spreads should increase. This is also what happened. As seen in Figure 1, the collateral spread (ECB basket) reacted immediately by flipping from negative to positive and remained positive (except for the occasional downward spike). The average collateral spreads are 11.699 and -2.822 bps for the ECB and ECB Extended baskets, respectively. Both are statistically significant at the 1% level. The negative average spread and the high incidence of negative collateral spread days (57.426%) for the lower quality collateral basket suggests that problems remained in this segment of the market of the underlying securities.

4. First one-year LTRO by the ECB, Jun 25, 2009 – Jul 1, 2010.

    - Collateral spreads in the previous period were declining over time. In the period after the first one-year LTRO, the average spreads are 5.317 and 2.902 bps for the higher and lower quality baskets, respectively. Both are statistically different from zero at the 1% level. As seen in Figure 1, the ECB Extended basket collateral spread flips from negative to positive with the introduction of this liquidity-easing policy.

5. Growing euro area sovereign crisis, Jul 2, 2010 – Dec 21, 2011.

    - In the eighteen months after the maturity of the first one-year LTRO, the Eonia−GCP ECB collateral spread averages to 3.502 bps and the Eonia−GCP ECB Extended basket averages to −2.284 bps (both significant at the 1% level).

6. Three-year LTROs, Dec 22, 2011 – Jun 30, 2013.

    - As seen in Figure 1 and Table 11, the first three-year LTRO had positive impact on collateral spreads. For the lower quality basket, the spread flipped from negative to positive and there was also an increase in the spread for the higher quality basket. Over the next year and a half, these collateral spreads averaged to 7.145 and 5.602 bps, respectively (both significant at the 1% level). This is consistent with the constrained-arbitrage theory.

7. One-third of LTROs repaid early, Jul 1, 2013 – Jan 21, 2015.

    - Over this period, collateral spreads were: 2.485 (significant, 1% level) and 0.091 (not significant) bps for the higher and lower quality baskets, respectively. In light of the theory, the decrease in spreads suggest that markets were once again starting to experience weakness.

8. The period after the announcement of the Public Sector Purchase Programme (PSPP) by the ECB on Jan 22, 2015.

    - The PSPP constitutes the largest program within the ECB's Quantitative Easing program which was initially announced for covered bonds and asset-backed securities on September 4, 2014. Figure 1 shows that this period is associated with an increase yet again in both spreads. The collateral spread for the higher and lower quality baskets now average to 7.321 and 5.133 bps, respectively (both significant at the 1% level). For the higher quality basket, there are no days over this period with negative collateral spreads. This is consistent with the constrained-arbitrage theory of collateral spreads and the view that quantitative easing both eased liquidity conditions and improved conditions in securities markets.

To summarize, the overall picture is that liquidity-easing central bank policies lead to increases in collateral spreads, as predicted by the theory.

7 Concluding remarks

In this paper, we have studied the determinants of the collateral spread, that is, the difference between unsecured and repo rates. As seen, for example, in Figure 1, the collateral spread fluctuates substantially and is negative around a quarter of the time. This is noteworthy because the contracts used in Figure 1 are CCP repos and represent the most active overnight repo contracts on Eurex. The empirical tests we have carried out to understand movements in the collateral spreads and the conditions under which spreads turn negative are motivated by the constrained-arbitrage theory in Nyborg (2019). Specifically, we have focused on the theoretical predictions with respect to unsecured rates, haircuts, volatility, and underlying liquidity conditions.

The theory predicts that changes in the unsecured rate will not be fully reflected in the repo rate (unless they are also fully reflected in security prices). We have examined this using end-of-maintenance period spikes in the unsecured rate as an exogenous shock to these. Our findings are concordant on this point with the theory.

The theory also predicts that an increase in haircuts will increase the collateral spread. To test this, we have used the institutional fact that Eurex sets haircuts in the two GC Pooling contracts according to haircuts in Eurosystem repos. Identification is helped by the fact that the ECB updates haircuts in Eurosystem repos with a multi-year frequency. Using the haircut reduction on October 1, 2013 (implemented on Eurex the day after), we find that collateral spreads fall. This is consistent with the constrained-arbitrage theory.

For our third test, we examine the effect of volatility. The theory predicts that an increase in the volatility of the underlying security reduces the collateral spread. Using governing council meetings where the policy rate is subject to change, we once again find that collateral spreads move in the direction predicted by the theory.

Finally, we look into the impact of central bank policies. Under the view that unconventional, liquidity-easing policies improve conditions in the market for liquidity as well as securitiy markets, the theory predicts that collateral spreads should increase and, if negative, possibly reverse back to the more normal positive. Again, the empirical evidence supports the theory.

The constrained-arbitrage perspective of repo versus unsecured rates is fundamentally different from the more traditional credit risk perspective. With respect to empirical predictions, what sets the constrained-arbitrage theory apart is its ability to explain the puzzle of negative collateral spreads in a fairly simple way. According to the theory, these are symptoms of tight liquidity conditions and/or severely depressed securities markets. In future work, it would be interesting to examine the behavior of collateral spreads in other markets to test the broader applicability of the constrained-arbitrage theory.

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Appendix: Figures

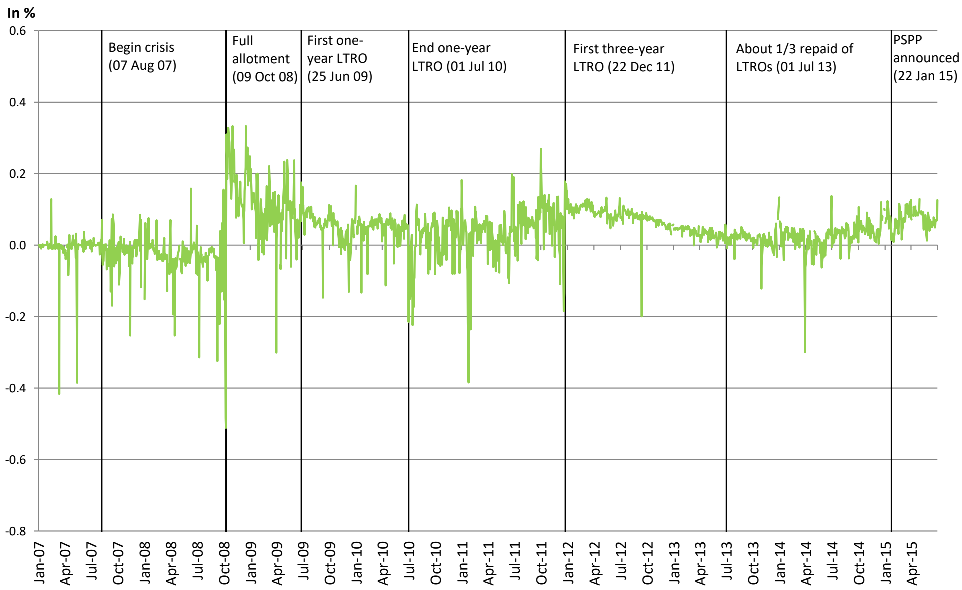

Figure 1a: Overnight collateral spread, Eonia−GCP ECB basket (in percent), January 2, 2007 to June 30, 2015. Eonia is a volume-weighted average of overnight unsecured euro transactions by reporting panel banks. o calculate the collateral spreads in Figure 1, we have used the Eonia as the unsecured rate. This is a volume-weighted average of overnight transactions by reporting (European) banks. Eonia is an acronym for Euro Overnight Index Average. See http://www.euribor-rates.eu/eonia.asp. The repo rate is the daily volume-weighted average of overnight transactions in Eurex Repo's GC Pooling ECB basket. Vertical bars relate to the financial crisis and ECB unconventional monetary policies (see Section 6).

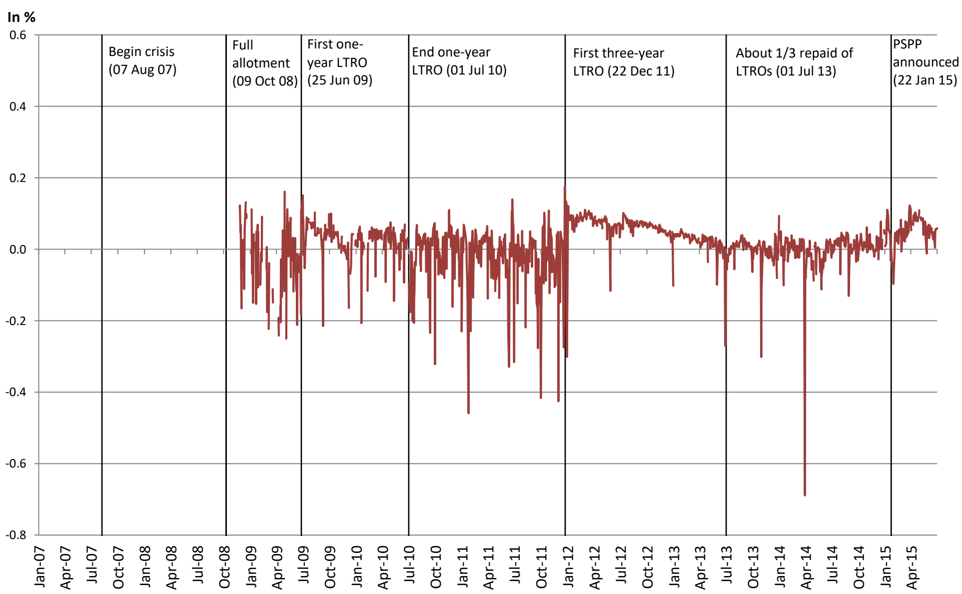

Figure 1b: Overnight collateral spread, Eonia−GCP ECB Extended basket (in percent), November 25, 2017 to June 30, 2015. The repo rate is the daily volume-weighted average of overnight transactions in Eurex Repo's GC Pooling ECB Extended basket.

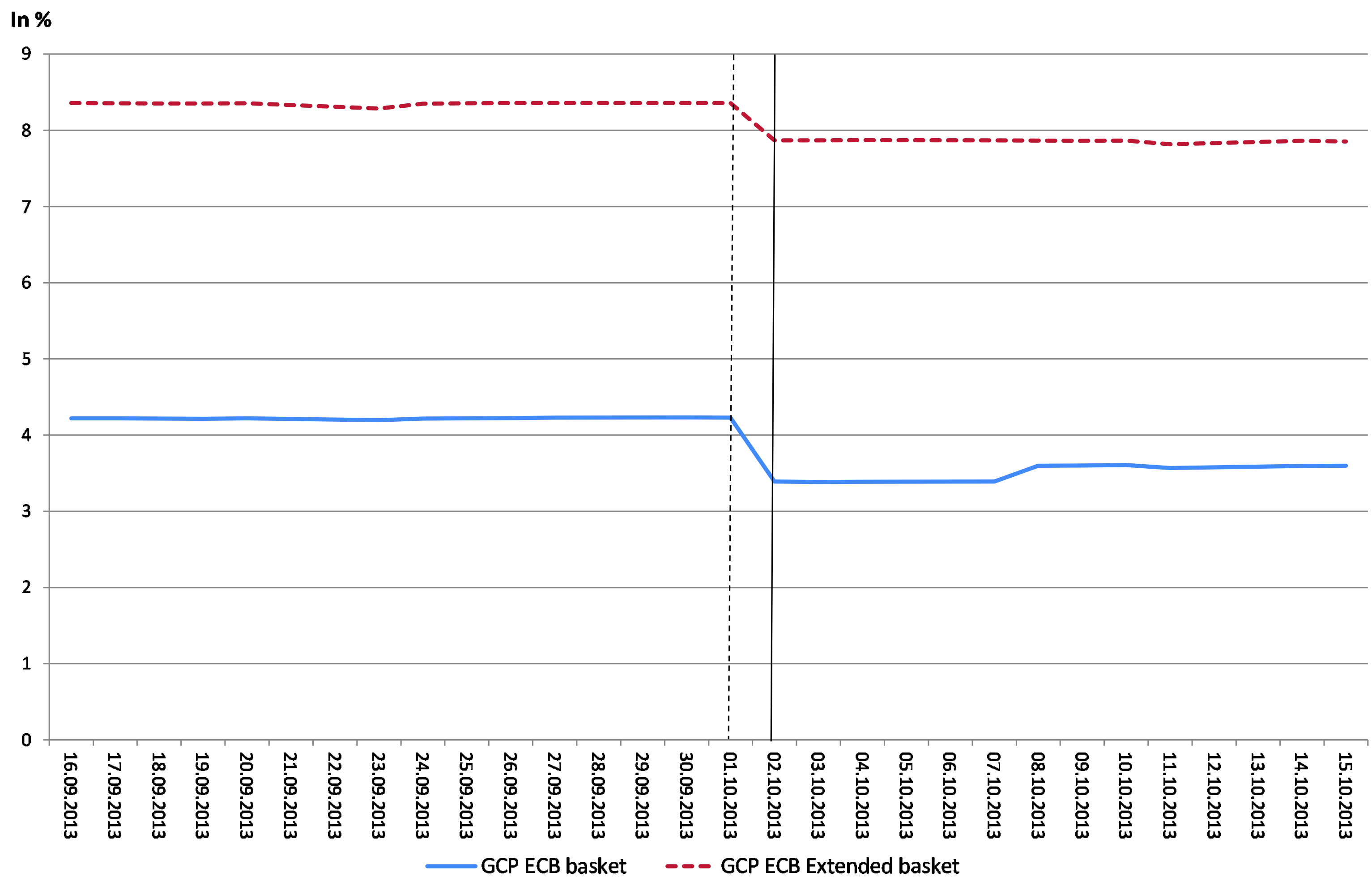

Figure 2: Daily average haircuts (in percent) applied by Eurex Repo in the two baskets, GC Pooling ECB and GC Pooling ECB Extended, September 16, 2013 to October 15, 2013. Eurosystem haircuts changed on October 1, 2013, as indicated by the dashed vertical line. Eurex Repo changed haircuts for securities in the two baskets on October 2, 2013, as indicated by the solid vertical line.

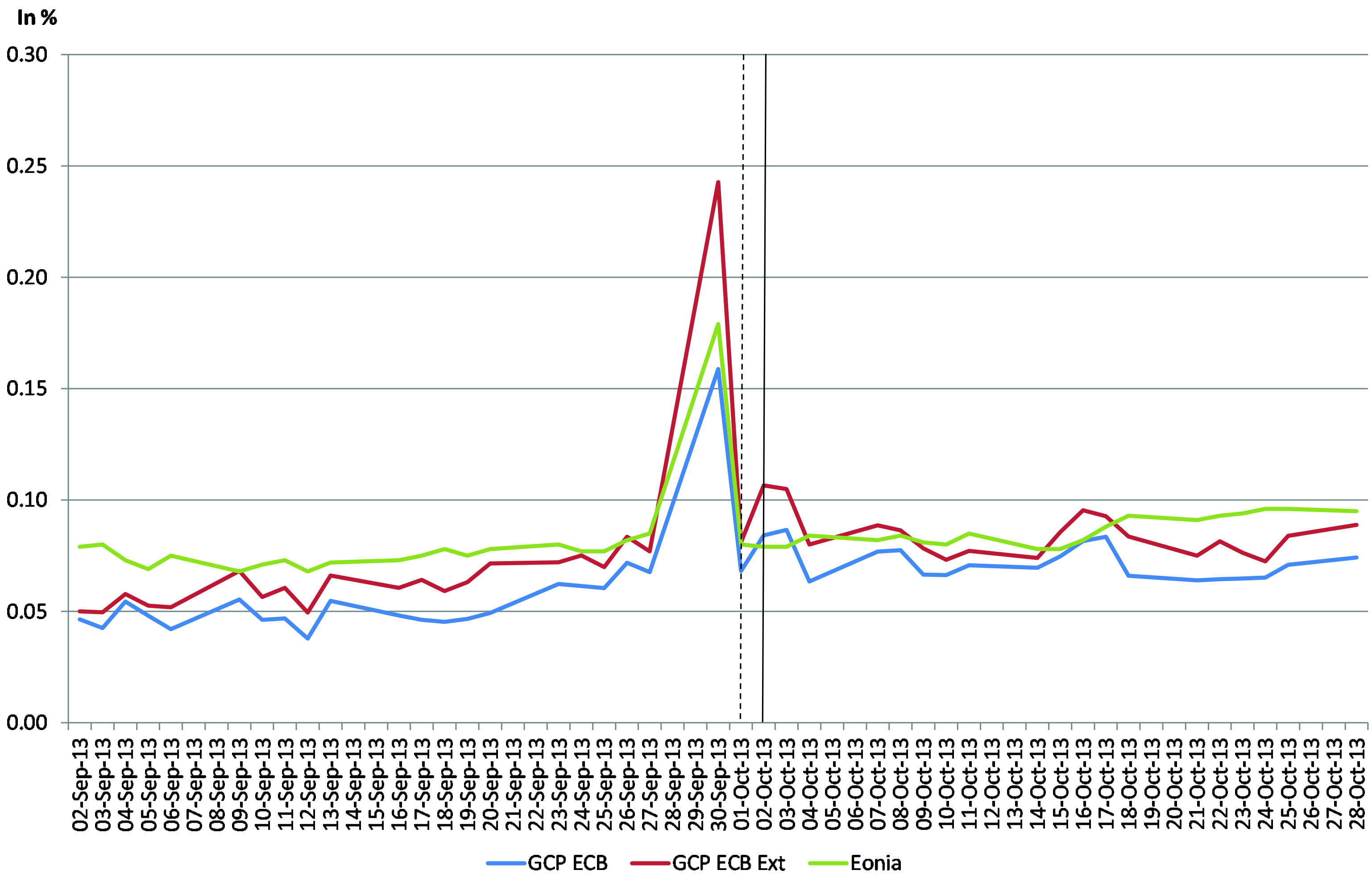

Figure 3: Eonia and GC Pooling overnight rates (daily volume-weighted averages, in percent), September 2, 2013 to October 28, 2013. Eurosystem haircuts changed on October 1, 2013, as indicated by the dashed vertical line. Eurex Repo changed haircuts for securities in the two baskets on October 2, 2013, as indicated by the solid vertical line.

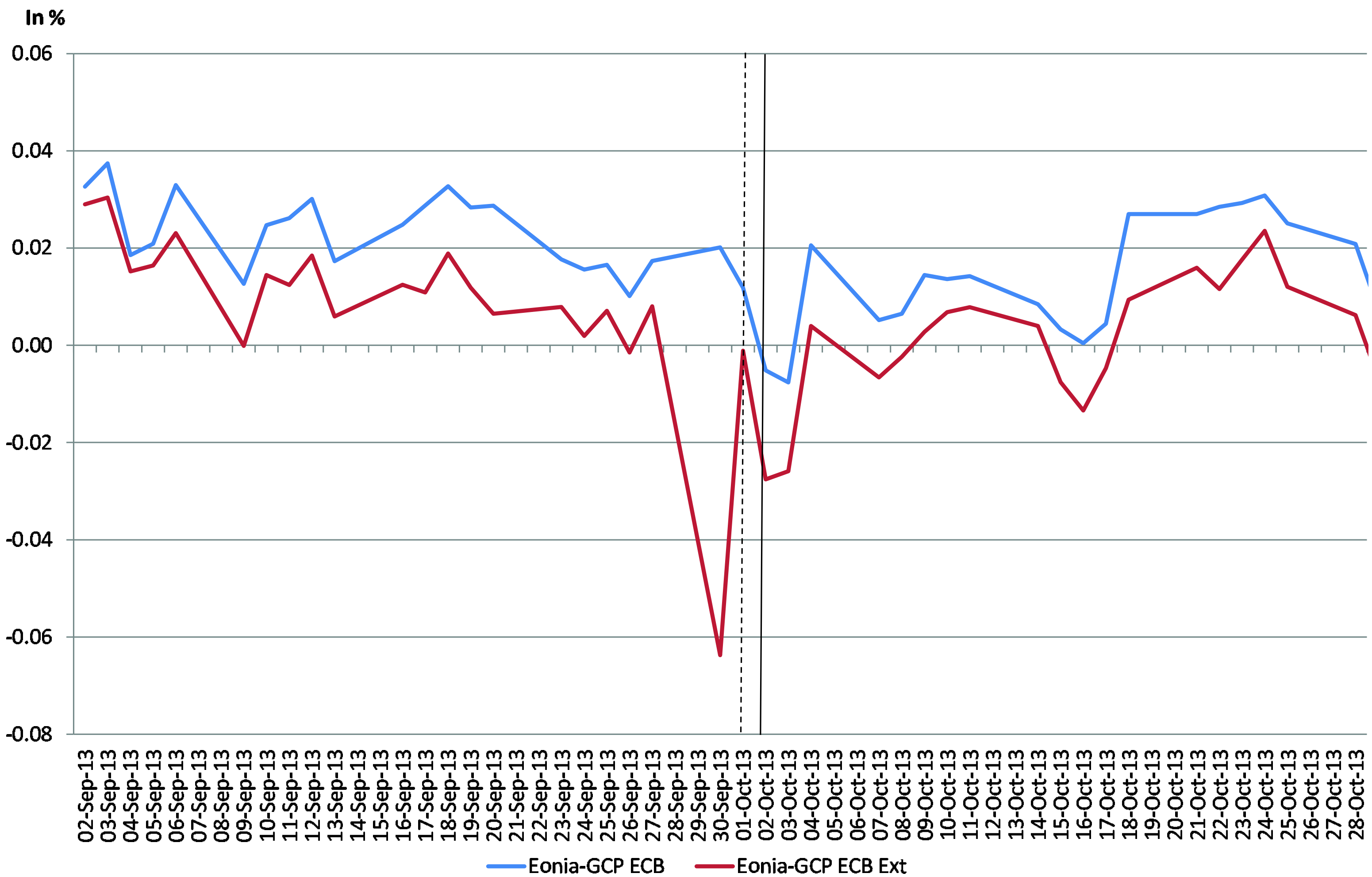

Figure 4: Overnight collateral spreads, Eonia less GC Pooling ECB and GC Pooling ECB Extended baskets, (daily volume-weighted averages, in percent), September 2, 2013 to October 28, 2013. Eurosystem haircuts changed on October 1, 2013, as indicated by the dashed vertical line. Eurex Repo changed haircuts for securities in the two baskets on October 2, 2013, as indicated by the solid vertical line.

Appendix: Tables

Table 1: Statistics on Eurex Repo baskets

This table displays descriptive statistics on the different GC baskets of Eurex Repo for the period January 2, 2005 to June 30, 2015. The sample contains 4 GC Pooling baskets, and 24 Euro Repo baskets. The first column shows when the first and last trades in each basket occur. The second column, No. Obs., counts the number of trades. The third column, ON obs., displays the number of trades with the term overnight. The fourth column, % of total, shows the percentage of the ON transactions of all transactions. The fifth column, TN obs., displays the number of trades with the term tomorrow-next. The sixth column, % of total, is the percentage of the TN transactions of all transactions. The seventh column, Av. Rate, shows the volume-weighted average ON (TN) rate across all observations for the GC Pooling ECB and ECB Ext. (all other) baskets. Using the same tenors, the next column, Av. Coll. Spread, displays the volume-weighted collateral spread, Eonia−repo rate. For the GCP ECB and ECB Ext. (all other) baskets, we use the Eonia of the day of (after) the transaction. The ninth column, Volume - Total, is the sum of the total transacted volume across all tenors in that basket. The next column, Volume - By Trading Day, shows the average volume by trading day (period that the basket is traded). The last column, Volume - By Transact., captures the average transaction volume of each basket.

							Av. Rate	Av. Coll. Spr.	Volume (in EUR million)		
	first - last trade	No. Obs.	ON obs.	% of total	TN obs.	% of total	(in bps)	(in bps)	Total	By Trading day	By Transaction
GC Pooling ECB	Jan 2, 07 – Jun 30, 15	151,330	83,804	55.38	26,707	17.65	84.05	4.07	87,434,094	40,311	578
GC Pooling ECB Ext.	Nov 24, 08 – Jun 30, 15	67,944	32,846	48.34	15,181	22.34	26.12	1.38	30,908,936	18,333	455
German KfW / Laender	Jan 3, 07 – Sep 14, 12	8,457	0	0.00	3,804	44.98	100.54	-0.42	2,403,894	1,645	284
EIB / KFW	May 25, 11 – Sep 14, 12	2,399	0	0.00	1,701	70.90	42.24	11.43	541,672	1,598	226
KFW	Sep 17, 12 – Jun 30, 15	3,217	154	4.79	2,497	77.62	3.91	2.36	883,928	1,250	275
Euro Covered Bond	Jan 9, 07 – Aug 14, 14	7,474	8	0.11	4,882	65.32	151.19	-6.14	2,415,711	1,243	323
Germany	Jan 9, 07 – Jun 30, 15	3,534	107	3.03	2,054	58.12	67.85	5.28	2,444,870	1,130	692
EIB	Sep 17, 12 – Jun 29, 15	2,869	186	6.48	2,292	79.89	4.45	2.49	783,557	1,110	273
EFSF	Sep 17, 12 – Jun 30, 15	2,129	47	2.21	1,873	87.98	2.91	1.87	422,073	598	198
French Covered Bond	Apr 4, 09 – May 19, 15	4,467	35	0.78	2,792	62.50	40.20	0.84	777,149	496	174
German Jumbo Pfandbrief	Jan 2, 07 – Jul 2, 13	2,045	0	0.00	1,141	55.79	205.38	-1.58	741,682	446	363
German Laender	Sep 18, 12 – Jun 30, 15	865	48	5.55	327	37.80	2.24	3.88	279,568	396	323
Agency	Feb 9, 07 – Dec 17, 14	3,645	4	0.11	1,972	54.10	61.06	-3.35	697,299	347	191
Germany 10 Year	Jan 8, 07 – Jan 6, 15	236	0	0.00	72	30.51	258.23	15.22	679,004	332	2,877
German Corporate	Feb 18, 08 – Dec 17, 12	216	0	0.00	73	33.80	111.47	0.32	102,330	82	474
German Pfandbrief	Mar 6, 08 – Jan 15, 15	206	0	0.00	94	45.63	284.56	-5.58	103,299	59	501
GC Pooling Equity	Mar 16, 11 – Jun 23, 15	153	6	3.92	23	15.03	11.26	-19.44	38,810	36	254
Austrian Government	Dec 14, 12 – Jun 17, 15	77	9	11.69	32	41.56	-4.27	3.93	20,964	33	272
German Gov. Guaranteed	Oct 16, 12 – Sep 4, 14	40	0	0.00	38	95.00	6.05	4.08	8,841	18	221
French Government	Nov 12, 12 – Jun 16, 15	35	4	11.43	6	17.14	3.08	3.62	11,339	17	324
Finnish Government	Apr 22, 13 – Mar 18, 15	18	2	11.11	13	72.22	4.46	5.18	7,884	16	438
GC Pooling INT MXQ	Mar 05, 14 – Sep 26, 14	8	2	25.00	4	50.00	5.25	-3.57	1,840	13	230
Dutch Government	Jan 17, 14 – Jun 26, 15	18	1	5.56	7	38.89	-0.14	3.98	3,920	11	218
European Government	Jan 9, 07 – May 8, 15	150	0	0.00	17	11.33	276.09	-5.55	22,775	11	152
Belgian Government	Sep 27, 12 – Jun 10, 15	39	1	2.56	17	43.59	-0.35	2.50	6,806	10	175
European Corporate	Feb 12, 09 – Feb 19, 14	75	0	0.00	45	60.00	78.51	-8.00	9,674	8	129
Euro Gov. Guaranteed	Nov 14, 12 – Dec 17, 14	11	0	0.00	0	0.00	0.00	0.00	1,426	3	130
Spanish Government	Jun 4, 13 – Apr 14, 15	6	0	0.00	1	16.67	10.00	-1.90	606	1	101

Table 2: Descriptive statistics on the collateral spread

This table displays descriptive statistics of our sample of daily average overnight collateral spreads. For each day, the collateral spread (in bps) is calculated as the difference between the unsecured volume-weighted average overnight rate, the Eonia, and the daily volume-weighted average overnight repo rate, GCP ECB or GCP ECB Ext. rate. The sample period for Eonia – GCP ECB is January 2, 2007 to June 30, 2015, and for Eonia – GCP ECB Ext. it is November 24, 2008 to June 30, 2015. Columns 2-7 capture the number of observations (days), the mean, the standard error, the median, the standard deviation, the minimum, and the maximum. The last two columns show the negative occurrence of the collateral spread: the second last column counts the number of negative days observed, and the last column displays the percentage of negative days of the total number of days, when trades occur in that basket.

	No. Obs.	Mean	St. Error	Median	St. Deviation	Min	Max	# negative days	% of neg. days of obs.
Eonia – GCP ECB rate	2,167	3.773	0.145	4.109	6.743	-51.135	33.271	496	22.889%
Eonia – GCP ECB Ext. rate	1,604	1.362	0.167	2.371	6.685	-68.919	17.618	461	28.741%

Table 3: Standardized Eonia at end of maintenance period and month

This table displays statistics on the standardized Eonia for the five last days of the maintenance period and the last day of the month. endmp to endmp-4 denote the last five days of the maintenance period, where endmp is the last day and endmp-4 is the fourth day before the end. monthend refers to the last trading day of the month. The sample period is January 2, 2007 to August 29, 2008, representing twenty-one maintenance periods. However, the last maintenance period does not include endmp-4 to endmp, and the first one does not capture monthend, yielding 20 observations for each of these days. Eonia is the volume-weighted average unsecured overnight rate. For each maintenance period, we compute the standardized Eonia, stand. Eonia, as defined by (2), excluding data from the five last days of the maintenance period and the last day of all calendar months. The third column shows the average of the standardized Eonia across maintenance periods on the indicated days. The fourth column shows the averages in terms of absolute values. The fifth (sixth) column, positive (negative), displays the average value, when the standardized Eonia is positive (negative). The column upspike-total (downspike-total) shows the number of times when the standardized Eonia is positive (negative). The column upspike-abs. >2 (downspike-abs. >2) displays the number of times when the absolute standardized Eonia exceeds two.

		stand. Eonia				upspike		downspike	
	No. Obs.	average value	absolute value	positive	negative	total	abs. >2	total	abs. >2
endmp	20	-7.675	16.310	9.594	-21.805	9	5	11	7
endmp-1	20	-3.585	5.012	4.759	-5.057	3	1	17	9
endmp-2	20	-4.181	4.650	1.566	-5.195	3	1	17	8
endmp-3	20	-3.267	3.766	1.247	-4.395	4	1	16	7
endmp-4	20	-1.474	2.415	1.568	-2.778	6	2	14	8
monthend	20	3.583	3.585	3.773	-0.021	19	13	1	0

Table 4: Standardized Eonia rankings, end of maintenance period and month

This table shows the rankings of the standardized Eonia on the five last days of each maintenance period, endmp to endmp-4, and the last day of each calendar month, monthend. The sample period is January 2, 2007 to August 12, 2008, representing twenty maintenance periods (the first maintenance period starts on December 13, 2006). Eonia is the volume-weighted average unsecured overnight rate. For each maintenance period, we compute the standardized Eonia, stand. Eonia, as defined by (2), excluding data from the five last days of the maintenance period and the last day of all calendar months. For the last five days of the maintenance period, the ranking order is determined by the sign of the collateral spread on the last day of the maintenance period, endmp. If it is negative (positive), all values in the maintenance period are ranked in ascending (descending) order, starting with the lowest negative (highest) value. For the last day of the month, the ranking order is always descending from the highest value. Days in the last week of the maintenance period that are ranked first are marked in bold.

	Period 1		Period 2		Period 3		Period 4		Period 5		Period 6		Period 7	
	stand. Eonia	rank	stand. Eonia	rank	stand. Eonia	rank	stand. Eonia	rank	stand. Eonia	rank	stand. Eonia	rank	stand. Eonia	rank
endmp	**-5.51**	**1**	**23.37**	**1**	**-107.52**	**1**	-2.45	3	**-113.47**	**1**	-0.85	5	0.13	13
endmp-1	-4.27	3	-2.80	17	-11.24	2	**-9.77**	**1**	-38.96	3	-0.20	7	-0.78	8
endmp-2	-5.51	2	-4.44	18	-11.24	3	-6.84	2	-41.53	2	0.13	9	-0.78	7
endmp-3	-4.27	4	-6.08	19	-6.54	4	-0.26	12	-33.83	4	-4.14	2	-1.69	3
endmp-4	-3.64	5	-6.08	20	-4.19	5	0.47	19	-5.57	5	**-4.47**	**1**	**-5.33**	**1**
monthend	–	–	3.74	2	7.55	1	5.60	1	9.85	1	1.12	1	6.50	1
	Period 8		Period 9		Period 10		Period 11		Period 12		Period 13		Period 14	
endmp	**28.01**	**1**	-1.22	5	-0.09	10	**-3.61**	**1**	0.05	9	1.20	5	1.44	4
endmp-1	0.37	5	**-3.29**	**1**	-1.52	3	-2.44	4	-3.03	4	-0.29	15	-0.67	16
endmp-2	-3.08	17	-1.53	3	-1.29	5	-0.92	5	-4.19	2	-0.27	13	-0.65	15
endmp-3	-4.81	20	-0.05	16	-0.68	6	0.38	15	**-5.11**	**1**	1.02	6	-0.29	11
endmp-4	-3.08	18	3.36	25	-0.53	8	0.46	21	-4.12	3	**1.93**	**1**	-0.16	9
monthend	2.10	2	1.48	3	0.87	3	1.74	1	0.05	10	-0.02	10	3.14	1
	Period 15		Period 16		Period 17		Period 18		Period 19		Period 20			
endmp	**24.85**	**1**	**-3.01**	**1**	-0.06	9	**4.12**	**1**	-2.04	2	3.18	2		
endmp-1	13.20	2	-0.74	6	**-3.81**	**1**	-1.49	19	-0.67	4	0.70	12		
endmp-2	3.86	3	-0.91	5	-2.95	2	-1.82	20	-0.36	8	0.70	11		
endmp-3	0.63	7	-0.45	8	-0.40	7	-1.35	18	-0.39	7	2.96	3		
endmp-4	-0.06	11	-0.35	9	0.54	12	-0.77	12	-0.54	6	2.64	4		
monthend	3.17	4	1.16	4	2.75	1	2.33	2	3.32	1	9.96	1		

Table 5: Spikes test - regressions

This table shows time-series regressions of the overnight collateral spread, Eonia-GCP ECB (in bps), on indicator variables of spikes in the Eonia. The unsecured rate, Eonia, and the secured rate, GCP ECB, are daily volume-weighted overnight averages. The sample period is January 2, 2007 to August 29, 2008. The independent variables are as follows: perc10 (perc90) is a dummy variable that takes the value of one when the Eonia is in the lower 10% (upper 90%) in the respective maintenance period, excluding the last day of the month. The indicator variable perc10|nonendres (perc90|nonendres) is one if perc10 (perc90) is one and the day is not one of the last five days of the maintenance period. The indicator variable perc10|endres (perc90|endres) is one if perc10 (perc90) is one and the day is one of the last five days of the maintenance period. fincrisis is a dummy variable that is equal to one from August 7, 2007 to August 29, 2008. monthend is an indicator variable for the last trading day of the month. The following regression is run: $y_t = \beta_0 + \beta_1 \text{perc10|nonendres}_t + \beta_2 \text{perc90|nonendres}_t + \beta_3 \text{perc10|endres}_t + \beta_4 \text{perc90|endres}_t + \beta_5 \text{fincrisis}_t + \beta_6 \text{monthend}_t + \varepsilon_t$. Newey-West standard errors with five lags (Greene, 2008) are in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Eonia – GCP ECB	Eonia – GCP ECB
constant	-0.241	-0.062
	(0.292)	(0.257)
perc10	-3.191**	
	(1.394)	
perc90	2.349*	
	(1.307)	
perc10|nonendres		-0.556
		(1.337)
perc90|nonendres		-0.056
		(0.750)
perc10|endres		-5.212**
		(2.191)
perc90|endres		6.143***
		(2.367)
fincrisis	-2.186***	-2.469***
	(0.544)	(0.521)
monthend	0.960	0.964
	(0.833)	(0.836)
No. Obs.	422	422
Adj. R^2	0.914	0.132

Table 6: Changes in Eurosystem Haircuts

This table shows the changes in Eurosystem haircuts (in percentage points) on October 1, 2013 for marketable securities. This is based on securities' liquidity categories, maturity buckets, and ratings. The changes in haircuts are computed from Tables 5.3 and Tables 5.4 in Nyborg (2016). There are five liquidity categories, briefly summarized as: I) government securities, II) local and regional government securities as well Jumbo-style supranational/agency bonds, III) corporate, non-Jumbo and financial securities, IV) unsecured bank bonds, V) asset-backed securities. "fixed" and "zero" indicate fixed and zero coupon instruments, respectively. Eligible floating rate instruments in Categories I to IV receive the same haircuts as what is applied to an instrument with in the same category and the same rating in the zero to one year maturity bucket.

Bonds rated AAA to A-, Haircut changes	Cat I		Cat II		Cat III		Cat IV		Cat V
Time to maturity	fixed	zero	fixed	zero	fixed	zero	fixed	zero	
0-1	0.0	0.0	0.0	0.0	-0.5	-0.5	0.0	0.0	-6.0
1-3	-0.5	0.5	-1.0	0.0	-1.0	0.0	0.0	0.0	-6.0
3-5	-1.0	-0.5	-1.0	-0.5	-2.0	-1.0	0.0	0.0	-6.0
5-7	-1.0	-0.5	-1.0	-0.5	-2.0	-1.5	0.0	0.0	-6.0
7-10	-1.0	-0.5	-1.0	0.0	-2.5	-1.5	0.0	0.0	-6.0
>10	-0.5	-1.5	0.5	-1.5	-2.0	-3.5	0.0	0.0	-6.0
Bonds rated BBB+ to BBB-									
Time to maturity	fixed	zero	fixed	zero	fixed	zero	fixed	zero	fixed
0-1	0.5	0.5	1.0	1.0	0.0	0.0	-2.0	-2.0	-10.0
1-3	0.5	1.5	-0.5	3.0	-3.0	-3.0	-3.0	-3.0	-10.0
3-5	1.5	2.0	0.0	3.5	-3.0	-3.0	-4.0	-3.0	-10.0
5-7	2.0	3.0	-2.0	1.5	-2.0	-1.5	-2.5	-3.0	-10.0
7-10	2.5	3.5	-1.0	5.0	-2.0	-1.0	-2.0	-2.0	-10.0
>10	2.5	2.5	2.5	4.0	-2.0	-3.0	-2.0	-2.0	-10.0

Table 7: GCP ECB basket - distribution of securities

This table displays the distribution of the securities contained in the GC Pooling ECB basket across the ECB liquidity categories and maturity buckets on September 26, 2013. There are five liquidity categories, briefly summarized as I) government securities, II) local and regional government securities as well Jumbo-style supranational/agency bonds, III) corporate, non-Jumbo and financial securities, IV) unsecured bank bonds, V) asset-backed securities.

A- to AAA	Liquidity Group				
Years to Maturity	Cat I	Cat II	Cat III	Cat IV	Total
0-1	177	1,103	1,469	132	2,881
1-3	137	444	711	38	1,330
3-5	120	335	522	33	1,010
5-7	99	217	310	20	646
7-10	121	207	274	13	615
>10	369	170	130	14	683
Total	1,023	2,476	3,416	250	7,165

Table 8: GCP ECB Extended basket - distribution of securities

This table displays the distribution of the securities contained in the GC Pooling ECB Extended basket across the Eurosystem liquidity categories, maturity buckets and ratings on September 26, 2013. There are five liquidity categories, briefly summarized as: I) government securities, II) local and regional government securities as well Jumbo-style supranational/agency bonds, III) corporate, non-Jumbo and financial securities, IV) unsecured bank bonds, V) asset-backed securities.

A- to AAA	Liquidity Group				
Years to Maturity	Cat I	Cat II	Cat III	Cat IV	Total
0-1	291	1,227	1,705	4,682	7,905
1-3	186	487	863	2,996	4,532
3-5	160	373	634	1,911	3,078
5-7	133	244	396	938	1,711
7-10	156	222	376	608	1,362
>10	446	184	270	252	1,152
Total	1,372	2,737	4,244	11,387	19,740
BBB- to BBB+	Liquidity Group				
Years to Maturity	Cat I	Cat II	Cat III	Cat IV	Total
0-1	12	2	99	265	378
1-3	9	3	69	187	268
3-5	7		68	117	192
5-7	8	1	71	64	144
7-10	10		41	50	101
>10	39		55	56	150
Total	85	6	403	739	1,233

Table 9: Effect of haircut changes on the collateral spread

This table shows output from the regression: $y_t = \beta_0 + \beta_1 \text{newhaircut}_t + \beta_2 \text{endmp1}_1 + \beta_3 \text{endmp2}_t + \varepsilon_t$, where y is the Eonia-GCP ECB or the Eonia-GCP ECB Ext. (both in bps). The ECB announced haircut changes on September 27, 2013 starting October 1, 2013. Haircuts in the GCP ECB and ECB Ext. baskets were changed by Eurex Repo on October 2, 2013. We run the regression over periods of two weeks (Sep 13 – Oct 14, 2013), three weeks (Sep 6 – Oct 21,2013), and four weeks (Aug 29 – Oct 28, 2013) around the haircut change. The unsecured rate, Eonia, and the secured rates, GCP ECB, and GCP ECB Ext., are daily volume-weighted overnight averages. The dummy variable newhaircut is equal to one starting October 2, 2013. endmp1 and endmp2 are indicator variables for the end of the maintenance periods on September 10, 2013 and October 8, 2013, respectively. The following days are removed: the announcement day, September 27, 2013, the last trading days in August, September, and October, and the first trading day in October. Newey-West standard errors (two lags) are in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Sep 13, 2013 – Oct 14, 2013	
	Eonia – GCP ECB Ext	Eonia – GCP ECB
constant	0.819***	2.205***
	(0.236)	(0.340)
newhaircut	-1.289**	-1.461***
	(0.572)	(0.412)
endmp2	0.234	-0.098
	(0.574)	(0.319)
No. Obs.	20	20
Adj. R^2	0.231	0.407
	Sep 6, 2013 – Oct 21, 2013	
	Eonia – GCP ECB Ext.	Eonia – GCP ECB
constant	0.969***	2.303***
	(0.198)	(0.249)
newhaircut	-1.138**	-1.201**
	(0.471)	(0.437)
endmp1	0.478**	0.170
	(0.198)	(0.249)
endmp2	-0.068	-0.456
	(0.468)	(0.399)
No. Obs.	30	30
Adj. R^2	0.175	0.234
	Aug 29, 2013 – Oct 28, 2013	
	Eonia – GCP ECB Ext.	Eonia – GCP ECB
constant	1.250***	2.414***
	(0.255)	(0.208)
newhaircut	-1.097**	-1.005**
	(0.484)	(0.425)
endmp1	0.198	0.059
	(0.255)	(0.208)
endmp2	-0.389	-0.762*
	(0.444)	(0.398)
No. Obs.	40	40
Adj. R^2	0.145	0.171

Table 10: Volatility

This table shows output from four regressions based on the following general specification: $\Delta y_t = \beta_0 + \beta_1 \text{govcouncil\_mp}_t + \beta_2 \text{govcouncil\_nonmp}_t + \beta_3 \text{vstoxx}_{t-1} + \beta_4 \text{excessliq}_{t-1} + \Gamma_1' \boldsymbol{X}_t + \Gamma_2' \boldsymbol{Z}_t + \varepsilon_t$, where Δy is the change in the collateral spread Eonia-GCP ECB (ΔCollspread_1) or Eonia-GCP ECB Ext. (ΔCollspread_2). The unsecured rate, Eonia, and the secured rates, GCP ECB, and GCP ECB Ext., are daily volume-weighted overnight averages (in bps). All four models include, as regressors, the dummy variables govcouncil_mp and govcouncil_nonmp, which are equal to one on Governing Council meeting days where policy rates are, respectively, are not, subject to change; vstoxx (in index points), which is an implied volatility of options on the Euro Stoxx 50; excessliq (in EUR billion), which is excess Eurosystem liquidity injections as reported by the ECB; and $\boldsymbol{X}$, which is a vector of control variables for which the output is suppressed, namely, perc10|endres, perc90|endres, monthend, fincrisis (equal to one starting on August 7, 2007), and dummy variables for the first and last trading days in a month. Model 2, 3, and 4 also include a vector of indicator variables, $\boldsymbol{Z}$, to control for: settlement days of the first one-year LTRO (1yearltro) on June 25, 2009 and both three-year LTROs (3yearltros) on December 22, 2011 and March 1, 2012; the introduction of a zero deposit facility rate (zerorate) on July 11, 2012; the introduction and implementation of full allotment on October 9, 2008, October 13, 2008, and October 15, 2008 (fullallot); and the announcement days of other key unconventional monetary policies by the ECB. These announcement days, which are not reported on, involve news on EFSF/ESM, i.e., May 10, 2010, March 14, 2011, and March 26, 2011; the announcements of covered bond purchase programmes on May 7, 2009, October 6, 2011, and September 4, 2014; the implementation of very long-term LTROs, one-year and three-year, made public on May 7, 2009, and December 8, 2012; and the announcement of the public sector purchase programme on January 22, 2015. Model 3 excludes Governing Council meeting days on which an interest rate change is announced. In addition, Model 4 only uses repo data on monetary policy meetings after 13:45:00 CET when calculating the collateral spread. The sample period of each regression is from January 2, 2007 to June 30, 2015. Newey-West standard errors are shown in parentheses (lags are determined by $N^{\frac{1}{4}}$ (Greene, 2008), where N denotes the number of days in the sample). The superscripts *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	Model 1		Model 2		Model 3		Model 4	
	Δ collspread 1	Δ collspread 2	Δ collspread 1	Δ collspread 2	Δ collspread 1	Δ collspread 2	Δ collspread 1	Δ collspread 2
constant	8.853	0.524	9.046	0.543	9.048	0.572	9.132	0.640
	(7.546)	(0.386)	(7.566)	(0.384)	(7.564)	(0.388)	(7.563)	(0.397)
govcouncil_mp	0.640**	0.115	0.630**	0.085	0.567*	-0.093	2.168***	-0.023
	(0.282)	(0.312)	(0.284)	(0.305)	(0.296)	(0.291)	(0.620)	(0.387)
govcouncil_nonmp	-0.185	0.002	-0.216	-0.052	-0.223	-0.057	-0.249	-0.058
	(0.373)	(0.524)	(0.352)	(0.481)	(0.352)	(0.480)	(0.352)	(0.480)
vstoxx_{t-1}	0.017	0.028	0.005	0.024	0.005	0.023	0.003	0.017
	(0.012)	(0.017)	(0.009)	(0.017)	(0.009)	(0.017)	(0.009)	(0.017)
excessliq_{t-1}	-0.001***	-0.002***	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
1yearltro			9.290***	28.185***	9.284***	28.194***	9.236***	28.262***
			(0.146)	(0.251)	(0.147)	(0.252)	(0.148)	(0.241)
3yearltros			6.549	5.725	6.558	5.722	6.543	5.674
			(4.134)	(8.086)	(4.127)	(8.091)	(4.162)	(8.140)
zerorate			4.857***	4.493***	4.847***	4.484***	4.885***	4.440***
			(0.153)	(0.150)	(0.154)	(0.151)	(0.168)	(0.153)
fullallot			16.943*		16.943*		17.011*	
			(9.692)		(9.692)		(9.681)	
No. Obs	2,158	1,558	2,158	1,558	2,140	1,546	2,089	1,481
Adj. R^2	0.035	0.175	0.049	0.186	0.049	0.186	0.059	0.190

Table 11. Central bank policies and collateral spreads

This table provides descriptive statistics of the collateral spreads Eonia - GCP ECB and Eonia-GCP ECB Ext. (both in bps) in eight different time periods. The unsecured rate, Eonia, and the secured rates, GCP ECB, and GCP ECB Ext., are daily volume-weighted overnight averages. The sample period for the spread Eonia – GCP ECB is January 02, 2007 to June 30, 2015, and for the spread Eonia – GCP ECB Ext. it is November 24, 2008 to June 30, 2015. Columns 2-7 capture the number of observations, the mean, the standard error, the median, the standard deviation, the minimum and the maximum. The last two columns show the negative occurrence of the collateral spread: the second last column counts the number of negative days observed, and the last column displays the percentage of negative days of the total number of days. Means are tested against the null hypothesis that they are zero (two-tailed test). Statistical significance at the 1, 5, and 10 percent levels are indicated by $***$, $**$, and $*$, respectively.

	No. Obs.	Mean	St. Error	Median	St. Deviation	Min	Max	# neg. days	% neg. days
1. Pre-crisis: Jan 02, 2007 - Jul 31, 2007 (147 trading days)									
Eonia – GCP ECB rate	147	-0.480	0.408	0.031	4.951	-41.537	13.085	62	42.177
2. Early crisis: Aug 1, 2007-Oct 08, 2008 (303 trading days)									
Eonia – GCP ECB rate	303	-3.085***	0.378	-2.157	6.581	-51.106	15.882	237	78.218
3.Start of full allotment: Oct 09, 2008–Jun 24, 2009 (179 trading days)									
Eonia – GCP ECB rate	178	11.699***	0.664	11.279	8.858	-30.045	33.279	13	7.263
Eonia – GCP ECB Ext. rate	101	-2.822***	0.936	-1.699	9.409	-25.000	16.100	58	57.426
4. First one-year LTRO: Jun 25, 2009–Jul 1, 2010 (262 trading days)									
Eonia – GCP ECB rate	262	5.317***	0.265	5.955	4.284	-21.485	17.534	18	6.870
Eonia – GCP ECB Ext. rate	227	2.902***	0.303	3.700	4.562	-21.500	15.100	35	15.419
5. Growing euro area sovereign crisis: Jul 2, 2010–Dec 21, 2011 (382 trading days)									
Eonia – GCP ECB rate	382	3.502***	0.355	4.759	6.933	-38.457	26.991	85	22.251
Eonia – GCP ECB Ext. rate	381	-2.284***	0.413	-0.022	8.052	-45.883	13.989	191	50.131
6. First three-year LTRO: Dec 22, 2011–Jun 30, 2013 (387 trading days)									
Eonia – GCP ECB rate	387	7.145***	0.172	7.472	3.387	-19.815	17.863	2	0.517
Eonia – GCP ECB Ext. rate	387	5.602***	0.207	6.390	4.076	-30.168	17.618	15	3.876
7. One third of three-year LTROs repaid early: Jul 1, 2013–Jan 21, 2015 (397 trading days)									
Eonia – GCP ECB rate	397	2.485***	0.174	2.578	3.472	-29.940	13.737	56	14.106
Eonia – GCP ECB Ext. rate	397	0.091	0.245	0.717	4.886	-68.919	11.043	144	36.272
8. Quantitative easing (PSPP): Jan 22, 2015–Jun 30, 2015 (111 trading days)									
Eonia – GCP ECB rate	111	7.321***	0.255	7.429	2.687	0.912	12.887	0	0.000
Eonia – GCP ECB Ext. rate	111	5.133***	0.364	5.429	3.833	-9.723	12.270	11	9.910
Whole sample period (all periods combined)									
Eonia – GCP ECB rate	2,167	3.773***	0.145	4.109	6.743	-51.135	33.271	496	22.889
Eonia – GCP ECB Ext. rate	1,604	1.362***	0.167	2.371	6.685	-68.919	17.618	461	28.741

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