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Kjell G. Nyborg
University of Zurich, Swiss Finance Institute, and CEPR

Jiri Woschitz
University of Zurich

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Kjell G. Nyborg
University of Zurich,
Swiss Finance Institute,
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Jiri Woschitz
University of Zurich

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Nyborg (corresponding author): Department of Banking and Finance, University of Zurich, Plattenstrasse 14, CH-8032 Zurich, Switzerland. email: kjell.nyborg@bf.uzh.ch.
Woschitz: Department of Banking and Finance, University of Zurich, Plattenstrasse 14, CH-8032 Zurich, Switzerland. email: jiri.woschitz@bf.uzh.ch.

Abstract

The Price of Money:
How Collateral Policy Affects the Yield Curve

Central-bank collateral policy governs the convertibility of assets into central-bank money provided directly by the central bank. Focusing on government bonds, we develop clean identification of variation in such convertibility by exploiting differential treatment of same-country government bonds in the euro area. Combining difference-in-differences analysis with yield-curve modeling on four separate events, we show that reduced convertibility lifts yields, but with the effect tapering off at longer maturities. Our findings imply that central-bank money is priced in the market and that a central bank can move and shape the yield curve through collateral policy.

JEL classification: G12, E43, E52

Keywords: Yield curve, central bank, collateral policy, monetary policy, haircuts, repo, asset prices, liquidity, central-bank money, government bonds.

1. Introduction

Treasury and other fixed income security prices are affected by a variety of factors (Dai and Singleton, 2003; Gürkaynak and Wright, 2012; Duffee, 2013). In this paper, our focus is on the effect of monetary policy. While the literature mostly addresses the effects of interest-rate policy, we investigate the influence of a monetary policy tool that has received substantially less attention and whose impact is much less understood, namely collateral policy. As an initial contribution, we develop novel and clean identification of variation in collateral policy. Our approach exploits differential treatment of same-country central-government bonds in the euro area and specific events where this changed. Our main analysis combines difference-in-differences (DiD) regressions with yield-curve modeling, which, as far as we know, is a first in the literature. The setting and methodology allow us to study potential heterogeneity in the effect of collateral policy over the term structure. We estimate spot curves using cubic specifications as well as the Diebold and Li (2006) factorization of Nelson and Siegel's (1987) seminal model, with very similar results and excellent fits. All four events that we have identified tell the same story. Central-bank collateral policy has significant impact on government-bond prices. Bonds that are treated "more generously" within the central bank's collateral framework have lower yields, ceteris paribus. The effect varies across maturities, which suggests a habitat (Culbertson, 1957; Modigliani and Sutch, 1966 and 1967) dimension to the influence of collateral policy.

Central-bank collateral policy governs the terms of exchange between central-bank money (reserves, liquidity), *provided directly by the central bank*, and collateral, provided by eligible counterparties (Nyborg, 2017). Our focus in this paper is on haircuts in central-bank repos. Collateral policy specifies which securities are eligible as collateral and the quantity of reserves the central bank is willing to provide against specific collateral. In particular, if the price of security i at date t is $p_{i,t}$ and the central bank sets a haircut of $h_{i,t}$, the amount that can be borrowed, the security's *collateral value* within the central bank's collateral framework, is $V_{i,t} = (1 - h_{i,t})p_{i,t}$. Focusing on central-government bonds, the questions we address in this paper are whether haircuts affect prices in the first place and to what extent this depends on time-to-maturity.

The idea that central-bank haircuts can affect asset prices has circulated for some time. Our specific setting is that of haircuts in Eurosystem liquidity injections (repos), officially referred to as refinancing operations, which are central instruments in the operational framework of the European Central Bank (ECB). Essentially, the ECB controls the policy rate by injecting liquidity through these operations.[1] In the context of Eurosystem repos, Bindseil, Nyborg, and Strebulaev (2002) provide evidence that haircuts do not equilibrate the opportunity costs of eligible collateral; Buiter and Sibert (2005) contend that there are haircut subsidies for some government bonds and argue that this improves the yields of these bonds; and Bindseil and Papadia (2006) look into the existence of an eligibility premium for corporate and credit bonds, but with inconclusive results. In contrast, studying a Federal Reserve crisis facility to support asset-backed securities in the aftermath of Lehman's default in the fall of 2008, Ashcraft, Gârleanu, and Pedersen (2010) find that eligible securities improve yields by around forty basis points on average. We expand on the literature by studying the effect of haircuts in regular liquidity-providing operations on the government-bond yield curve and using clean identification. This is important because government bonds play a central role in the conduct of monetary policy, as benchmarks in a variety of settings, and in the pricing of other assets.

As a preview, our DiD analysis yields three broad and robust findings. (1) Government-bond yields are increasing in central-bank haircuts, ceteris paribus. For example, one-year spot rates move down by approximately two basis points per percentage point decrease in haircuts. (2) The effect is stronger at the short- to mid-range of the term structure, becoming largely statistically insignificant at the long end. (3) There are significant haircut revision announcement *and* implementation effects. In contrast, beyond the very short end, traditional monetary (interest-rate) policy wields its influence mainly through its effects on expectations (Bernanke, Reinhart, and Sack, 2004; Gürkaynak, Sack, and Swanson, 2005). Evidently, collateral policy operates through a different mechanism.

The first of these findings says that government bonds that can be exchanged for relatively more central-bank money, provided directly by the central bank, trade at a premium, ceteris paribus. This premium can be interpreted as a convenience yield (or as a difference in convenience yields between bonds). The literature offers several potential explanations as to the fundamental source of this monetary convenience yield; for instance, demand for central-bank money as a medium of exchange (Chapman, Chiu, and Molico, 2011; Lagos, Rocheteau, and Wright, 2017) or demand for leverage by investors (Ashcraft, Gârleanu, and Pedersen, 2010). We discuss this further in Section 7.

[1] The refinancing operations work in tandem with a marginal lending facility (discount window) and a deposit facility. For details, see Bindseil, Nyborg, and Strebulaev (2009), or ECB (2014b). The set of eligible collateral and the haircuts are the same in the refinancing operations and the marginal lending facility. The Eurosystem comprises the ECB and the national central banks in the euro area.

The existence of both announcement and implementation effects (finding 3) can be understood with reference to the monetary convenience yield. A haircut reduction, for example, enhances a security's convertibility into central-bank money and, as a consequence, the stream of "monetary dividends" (utility) the convenience yield represents. A price uptick at implementation is consistent with binding constraints that relax when the additional liquidity is available. Standard logic suggests that we should also see an announcement effect and that the relative prices of affected securities should keep rising until the implementation date, as the present value of the convenience enhancement increases. This is also what we observe in the data.

The vanishing term effect (finding 2) is at first glance a puzzle because, in our DiD events, the haircut changes are especially large for long-term bonds. However, ours is a natural setting for habitat effects because banks only are eligible as counterparties in Eurosystem repos, and banks are known to hold predominantly short- to mid-term paper (Koijen, Koulischer, Nguyen, and Yogo, 2021). In fact, Fecht, Nyborg, Rocholl, and Woschitz (2016) report that the average duration of collateral posted by German banks for the specific purpose of Eurosystem repos is between two and three years. Hence, this is where we would expect the haircut effect to be the largest, which is also what we find. Our finding contributes to the recent habitat literature (e.g. D'Amico and King, 2013; Vayanos and Vila, 2021) by providing evidence that collateral policy can channel habitat effects.

The existence of habitat effects is important from a policy perspective. While our results suggest that central banks can use collateral policy more deliberately to shape the yield curve, they also indicate that this may be more difficult to accomplish at the long end of the maturity spectrum. Having said that, in comparison to unsterilized large-scale asset purchases or outright yield-curve control, for instance, collateral policy has the advantage of not growing the central bank's balance sheet or interfering directly with market processes.

Collateral policy can also affect asset prices more generally. A topic of debate in policy circles is whether haircuts can be used to affect the relative prices of green versus brown bonds and stimulate to green investments (Villeroy de Galhau, 2019; Schoenmaker, 2021). Our findings raise the issue that this depends on the extent to which eligible counterparties hold the targeted assets or can be induced to change their holdings.

Our paper relates to the general literature on collateral policy. For example, Nyborg (2017) describes the collateral framework of the Eurosystem in detail and argues that collateral-framework design has implications for the real economy and what kind of securities banks choose to produce. Consistent with this, Van Bekkum, Gabarro, and Irani (2018) and Lentner (2021a) find that collateral policy influences banks' lending behavior and the type of securities they issue. Koulischer and Struyven (2014) suggest that loosening collateral policy can improve welfare by easing constraints, while Nyborg and Strebulaev (2001) conclude that the outcome of any easing depends on which players hold the assets that benefit. Cassola and Koulischer (2019) provide evidence that haircuts influence what assets banks prefer to pledge in central-bank repos.

While the aspects of collateral policy we study are part and parcel of conventional monetary policy, our paper also relates to a growing literature on bond markets and unconventional policies. For example, Eser and Schwaab (2016), Todorov (2020), and Lentner (2021b) study the effects of large scale asset purchases on bond prices in the euro area using DiD designs. In the context of our collateral framework setting, we expand on these papers methodologically by combining a DiD setup with techniques from the curve-fitting literature to estimate differential treatment effects over the term structure.

1.1 Identification strategy: High- versus low-haircut bonds

Our identification strategy exploits a feature of the collateral framework of the Eurosystem noted by Nyborg (2017) whereby different bonds by the same issuer may receive haircuts based on different ratings. It is possible, for example, that two same-country government bonds that mature on the same day and carry the same coupon have different haircuts. For a given country, eligible bonds can be divided into two categories based on the rating on which haircuts are based. We refer to these as rating category 1 and 2, respectively, with the former giving lower haircuts, ceteris paribus (see Section 2.2 for details). Nyborg (2017) provides some examples of same-country zero-coupon bond couplets that mature on the same date, but are in different rating categories. He finds that the bond with the lower haircut has a lower yield.

In this paper, we document all occurrences of same-country central-government bonds that are in different rating categories on the same day over the period April 8, 2010 to May 24, 2017. We refer to this phenomenon, as a haircut, or rating category, inconsistency. A large number of bonds from several countries are involved. However, over time and across the maturity spectrum, haircut inconsistencies are especially prevalent in Italy and Spain. Therefore, our empirical analysis focuses on these two countries. The basic empirical idea is to estimate yield curves of same-country government bonds for the two rating categories. We find that low-haircut bonds trade at a premium to high-haircut bonds over the full range of maturities. However, to isolate the effect of haircuts from other, unknown characteristics of the bonds, our main analysis is carried out in a DiD setting.

We identify four events with exogenous shocks to the relative haircuts of same-country government bonds in different rating categories. The events share a common backdrop, namely collateral policy implementation mistakes by the Eurosystem itself.[2] A story broke on Reuters on November 4, 2012 that "The European Central Bank (ECB) is checking whether it may have contravened its own strict rules by lending to Spanish banks on overly generous terms, an ECB spokeswoman said on Sunday."[3] In a press conference on November 8, 2012, Mario Draghi, President of the ECB at the time, said that "...we take this mistake very seriously. And so the Governing Council has mandated the Eurosystem Audit Committee ... to assess the implementation of the collateral framework in the Eurosystem ..."[4] While the initial story referred to mistakes on Spanish bonds, many countries were involved. The rule infraction amounted to placing same-country government bonds in a single rating category based on the country's rating. While this may sound sensible, it was in violation of the formal rules which gave precedence to individual bond ratings over country ratings. What happened subsequently is what allows us to cleanly identify the effect of collateral policy on the market prices of bonds. This is sketched below, with details provided in Section 3.

The first event date (one for each country) corrects the mistake. On June 3 and August 9, 2013, several Spanish, respectively Italian, central-government bonds had their haircuts increased, reflecting their individual bond ratings and in compliance with the official collateral framework rules at the time. In our terminology, the bonds were moved from rating category 1 to 2. Defining bonds that were moved as treated, we would expect to see the post-event yield curve of treated bonds shift up relative to that of non-treated control bonds. This is also what we find, with a term effect that vanishes at longer maturities.

Subsequent event dates are the same for both countries. The second event is a haircut update on October 1, 2013.[5] Historically, the ECB revises haircuts only every three to four years (Nyborg, 2017), and this is the only update over the sample period that affects government bonds. The revision in this case raises the difference in haircuts between bonds in rating categories 1

[2]Within the Eurosystem, the ECB formulates rules and policy and the national central banks (NCBs) are tasked with implementation.

[3]See article published by Reuters (written by Gareth Jones, edited by Jason Neely), November 4, 2012: "ECB says checking status of loans made to Spanish banks," https://www.reuters.com.

[4]See ECB Introductory statement to the press conference (with Q&A), November 8, 2012, https://www.ecb.europa.eu/press/pressconf/2012/html/is121108.en.html.

[5]This event is also used by Nyborg and Rösler (2019) to study the effect of haircuts on general collateral repo rates relative to unsecured rates.

and 2. Thus, we would expect to see a divergence in the yield curves of these two classes of bonds. This is what we find, with, again, a declining term effect.

The third and fourth event dates relate to a change in collateral policy to harmonize haircuts for same-country government bonds. In particular, on September 1, 2014, the ECB announced that as of December 15, 2014, only country ratings would be used to set haircuts for government bonds, thereby eliminating government bond haircut inconsistencies. Reflecting their country ratings, on December 15, 2014, all Spanish and Italian government bonds were moved to rating category 1, thus receiving the lowest possible haircut.

The two-stage process (announcement followed by implementation) allows us to comment on anticipated versus actual haircut changes. Usually in finance, one focuses on announcement effects. However, if the value to having a lower haircut in a central-bank repo lies with the right to have immediate access to additional central-bank money and players face binding monetary constraints, there may also be a significant implementation effect. Consistent with the other two event studies, we find that the overall effect of harmonization is a convergence of the yield curves of the two classes of bonds. There is both an announcement and an implementation effect, but with the latter being larger.

The rest of this paper is organized as follows. Section 2 explains the institutional framework relating to haircuts and our strategy for finding haircut inconsistencies. It also describes the underlying data and provides a complete overview of the incidence of haircut inconsistencies across countries. Section 3 lays out the four events discussed above in more detail and the classification of Italian and Spanish bonds into treated and control subsamples. Section 4 contains preliminary analysis, comparing yields of high- versus low-haircut bonds. Section 5 reports the event study results based on cubic yield-curve specifications and discusses the importance of using a DiD setup that allows for flexible effects across the term structure. Section 6 repeats the DiD analysis using the Diebold and Li (2006) representation of the Nelson and Siegel (1987) model. Section 7 discusses different perspectives on the economics of the haircut effect, and Section 8 concludes.

2. Data, rating categories, and haircut inconsistencies

After introducing the data, we explain how haircuts are set by the ECB, how inconsistencies arise, and our methodology for finding them. Two examples illustrate the key points and also speak to the effect of haircuts on yields. Recall that a "haircut inconsistency" refers to same-country government bonds in different rating categories on the same day. The section ends with an overview of the incidence of haircut inconsistencies across countries.

2.1 Data

The underlying data are the public lists of Eurosystem eligible collateral from April 8, 2010 to May 24, 2017, inclusive. These are updated every business day and posted on the ECB's website the evening before they apply. In total, there are 1,845 lists over this time period.[6] They provide information on the individual eligible securities, such as ISINs, maturity, coupon type, issuer, type of security ("liquidity category"), and official haircuts in Eurosystem repos.[7] While the lists do not provide ratings, it is possible to use the information in them to back out rating categories for individual bonds and, therefore, detect haircut inconsistencies by applying the collateral framework rules that apply at any point in time (see below).

Over the sample period, the number of ISINs on the public lists ranges from 28,083 to 44,288. Central-government securities are in what is referred to as Liquidity Category 1, together with paper issued by national central banks. This category represents approximately six percent of securities on average. Across lists, the number of unique ISINs that appear in Liquidity Category 1 at least once is 7,546. From these, we drop 219 floating-rate securities, 89 securities that sometimes appear under a different liquidity category and/or change coupon type between fixed (or zero) and floating, and five national central-bank securities. This leaves 7,233 central-government bonds, all with either a fixed or zero coupon, for a total of 3,571,527 security-day observations. Across lists, the number of ISINs in this basic dataset fluctuates between 1,587 and 2,340.

The 7,233 ISINs were fed into Bloomberg to get historical price data. 1,044 securities were not in Bloomberg and 1,676 securities were in Bloomberg but without price data. Of the remaining 4,513 securities, 1,036 had theoretical prices only, leaving us with 3,477 ISINs with market prices.[8] Of these we drop 398 ISINs where Bloomberg reports that the securities are consols or the coupons are linked to inflation, security specific information on the public list and Bloomberg

[6]We have excluded the list published on Friday, April 24, 2015, since another list was posted on Saturday, April 25, which we include since it presumably replaces the first list. The two lists are almost identical.

[7]ISIN stands for "International Securities Identification Number."

[8]Bloomberg provides market prices from different sources, in our case, BGN, LCPR, CBBT, and EXCH, according to a waterfall principle (for details, type "LPHP PCS:0:1 3280159 <GO>" into the Bloomberg mask). The flag for theoretical, or model, prices is BVAL. ISINs with BVAL prices were re-fed into Bloomberg to specifically ask for market prices. In our sample of securities with market prices, 97.30% are flagged as BGN, which gives bid, ask, and mid-point market quotes.

do not match or changes over time, or the data is not good in some other way.[9] The resulting dataset consists of 3,079 fixed or zero-coupon central-government securities on the public list of eligible collateral and with market prices from Bloomberg. After dropping common European holidays,[10] the total number of security-day observations is 1,796,288, and the average number of securities per daily public list over the sample period is 986.4. Below, we provide statistics on the incidence of haircut inconsistencies for the full sample of 7,233 securities as well as for the filtered sample of 3,079 securities with market prices in Bloomberg.

2.2 Ratings and haircut rules

Eurosystem haircuts are a function of asset type, coupon type, maturity, and – since October 2008 – the ECB's own definition of two rating categories. The official collateral framework acts and decisions lay this out in tables that, historically, are updated every three to four years (Nyborg, 2017). Central-government securities, which are the focus of this paper, are in what the tables refer to as Liquidity Category 1.[11] Securities in this category receive the lowest haircuts, ceteris paribus. Eligible securities may have fixed, zero, floating, or inverse floating coupons.[12] Fixed- and zero-coupon bonds are placed in one of six maturity buckets (0–1, 1–3, 3–5, 5–7, 7–10, >10 years) within individual subdivisions. Haircuts are constant within each bucket subdivision and increasing in maturity across them, ceteris paribus. Securities in the highest rating category receive lower haircuts and zero-coupon bonds have higher haircuts than those with fixed coupons, ceteris paribus.

Insert Table 1 here.

The exact mapping between government bond characteristics (for fixed- and zero-coupon bonds) and haircuts for each day in the sample period is laid out in Table 1.[13] Panel A contains the (ordinary) haircut rules for euro-denominated assets in Liquidity Category 1, that is, the

[9] See the Internet Appendix for details.

[10] January 1, May 1, Good Friday, Easter Monday, December 25 and 26.

[11] The terminology "liquidity category" was replaced with the terminology "haircut category" in September/October 2013 (see Nyborg, 2017).

[12] Inverse floating rate debt is eligible only until January 3, 2013 (see ECB, 2012).

[13] For simplicity, we refer to central-government securities as "government bonds." Table 1 is based on the complete set of collateral framework documents relevant for the sample period, available on the ECB's webpage. Most of the work is from Nyborg (2017), who provides a detailed description of the Eurosystem's collateral framework until February 16, 2016. Table 1 draws particularly on his Sections 5.3, 5.4, and A.3, and, in particular, Tables 5.2, 5.3, 5.4, 5.5, and A.2, and the ECB collateral framework references therein. Additionally, we have examined all collateral framework updates relating to ordinary haircuts (ECB, 2016c) and those relating to extraordinary haircuts for Greece and Cyprus (ECB, 2016a and 2016b) between February 16, 2016 and May 25, 2017.

mapping between security characteristics and haircuts. Panel B provides extraordinary haircuts applied to Greek and Cypriot sovereign paper. As the financial crisis evolved and ratings dipped, Portugal, Ireland, Greece, and Cyprus received temporary exemptions from Eurosystem minimum rating requirements (at least the equivalent of BBB− on the S&P scale). While Portuguese and Irish government bonds continued to receive ordinary haircuts during these exemption periods, the ECB set extraordinary haircuts for Greece and Cyprus.[14] Panel C shows additional haircuts to assets denominated in foreign currency. Using Table 1 and the haircuts and other individual security information provided in the public lists of eligible collateral, it is possible to back out the rating category of each eligible zero- and fixed-coupon central-government security.

To understand why different same-country government bonds may have been assigned to different rating categories, it is necessary to provide some further details about how the collateral framework determines ratings for the purpose of setting haircuts. For securities on the public list of eligible collateral, the two rating categories in Table 1, Panel A can be described in terms of long-term ratings from the four official rating agencies.[15] Rating category 1 corresponds to a long-term rating of at least A− on the S&P scale, and rating category 2 corresponds to a long-term rating in the range BBB+ to BBB−. Table 2 shows how this maps into the long-term rating scales of the three other official rating agencies, Moody's, Fitch, and DBRS. For most securities, including government bonds, only the highest rating matters. However, issue ratings take precedence over issuer (or guarantor) ratings. In short, the general rule is that for the purpose of determining the haircut, only the highest issue rating matters. If there is no issue rating, then only the highest issuer (in our case, country) rating is taken into account.[16] For government securities, the precedence of issue ratings was dropped by the ECB as of December 15, 2014 so as to prevent further haircut, or rating category, inconsistencies for government bonds (see below for details).

Insert Table 2 here.

Given these rules, and especially issue-rating precedence, it is possible that different same-

[14]Rating rules exemptions were temporarily suspended at various points in time for Greece and Cyprus (for details see Nyborg, 2017, Subsections 5.4, 6.2, and A.5, and the references therein).

[15]From October 25, 2013 to April 30, 2015, the rating categories were defined in terms of long-term ratings only. After this period, short-term ratings may, in some cases, serve as a substitute. For our purposes, the details of this are not important and so we simply discuss the rating categories in terms of long-term ratings. See Nyborg (2017) and the references therein for a comprehensive presentation of the rules. The terminology "rating category" follows Nyborg. The ECB operates with the terminology "credit quality steps," which are defined in terms of long- and short-term ratings. See Nyborg (2017) for details.

[16]Full details of the priority rules over time are in Nyborg (2017), Chapter 6, and the references therein.

country government bonds are in different rating categories simply because they are rated by different agencies. For example, some bonds may be individually rated by "less generous" agencies only and receive a highest issue rating in the BBB+ to BBB− range and, hence, a relatively high haircut. Other bonds may be rated by "more generous" agencies and receive ratings of A− or higher and thus relatively low haircuts. Most government bonds, however, are not rated individually and, therefore, receive haircuts based on the highest country rating. If this is A− or higher, non-rated bonds and those with a highest individual rating in the BBB+ to BBB− band receive different haircuts, even if otherwise identical.

2.3 Examples

Table 3 provides two examples of haircut inconsistencies, both from June 16, 2014. Each example comprises a pair of zero-coupon Spanish government bonds maturing on the same date and with market prices available in the Bloomberg system. Columns 2 and 3 show the maturity date and haircuts, respectively, from the public list of eligible collateral.[17] Column 4 shows the resulting rating categories, as implied from the mapping in Table 1. Column 5 provides end-of-day market yields from Bloomberg. The last columns give the long-term issue and country ratings from the four official rating agencies (from Bloomberg).

Insert Table 3 here.

In Example 1, both securities mature on January 31, 2015. The first bond is in rating category 1 and receives a haircut of 0.5%, whereas the second bond is in rating category 2 and has a haircut of 6.0%. This haircut inconsistency results from the bonds' individual ratings. The first security has a highest rating of AL by DBRS (equivalent to A− on the S&P scale) and, therefore, receives a low haircut. In contrast, the highest (and only) issue rating for the second security is BBB+ from Fitch, which earns it a higher haircut.

Because maturity dates are matched, we can take a cursory look at yield differentials between high- and low-haircut bonds. In Example 1, the yield on the security with the higher haircut is 0.284% as compared with 0.205% for the other, a difference of approximately eight basis points (bps). This translates into an increase in yield of 1.4 bps per percentage point increase in haircut.

The two securities in Example 2 mature on January 31, 2018 and have Eurosystem haircuts of 2.5% and 10.0%, respectively. The first security has no individual issue rating and, therefore,

[17]Public list posted on June 13, 2014. Maturity dates are cross-checked with Bloomberg.

receives a collateral framework rating based on the highest country rating for Spain. This is AL by DBRS, which places the security in rating category 1. The second bond, however, is rated BBB+ by Fitch. Since it has no other rating, it is assigned to rating category 2. Again, the security with the higher haircut has the higher yield, 1.283% versus 1.108%. This translates into an increase in yield of 2.3 bps per percentage point (pp) increase in haircut.

2.4 Incidence of haircut inconsistencies

In this subsection, we use the mapping in Table 1 and security-specific information in the public lists of eligible collateral to report on the distribution of bonds across rating categories as well as on the incidence of haircut inconsistencies. The daily distributions of rating categories are plotted over time in Figure 1a for the full dataset of 7,233 government bonds and in Figure 1b for the subset of 3,079 bonds with market prices. The vast majority of paper is in rating category 1. For example, in the full dataset, 91.44% of the security-day observations are in rating category 1, 6.26% are in rating category 2, and 2.26 % represent exempt Greek and Cypriot securities.

Insert Figure 1 and Table 4 here.

Table 4, Panel A shows the incidence of haircut inconsistencies across countries in the full dataset of 7,233 securities. Panel B repeats the exercise for the subset of 3,079 securities with market prices. Out of twenty-nine countries, there are nine with inconsistencies. These are Italy, Spain, Slovenia, Ireland, Hungary, Latvia, Portugal, Greece, and Cyprus. Panel A (B) shows that there are a total of 1,621 (1,142) country-days and 1,141 (589) securities involved. In either panel, the majority of securities are from Italy and Spain. These two countries are especially dominant in the subset of securities with market prices, combining for 68.8% of country-days with haircut inconsistencies and 79.8% of all securities. Not surprisingly, they are also the countries with the best coverage of haircut inconsistencies across the maturity spectrum over time (see Table A.1 in the Internet Appendix). As a result, in the remainder of the paper, we focus on Italy and Spain.

3. Event dates and treated and control bonds

In this section, we discuss the four event dates that form the basis of the identification in the DiD analysis in Section 5. We also specify the sets of treated and control bonds.

3.1 Event dates

As discussed in Section 1.1, the events relate to haircut inconsistencies arising from corrections of collateral framework implementation mistakes. To help see the events, Figure 2 provides time-series plots of the daily distributions of rating categories for Italian and Spanish government bonds with market prices. For each country, the occurrence of bonds in both rating categories on the same day implies a haircut, or rating category, inconsistency.

Insert Figure 2 here.

Two features are immediately obvious from the figure. First, for each country, there is an initial date when a large mass of bonds are moved into rating category 2. This represents mass corrections of the collateral framework implementation errors discussed in the Introduction. Second, haircut inconsistencies suddenly disappear again on December 15, 2014. The explanation is that, as of this date, the ECB implemented a rule change designed for that exact purpose (Nyborg, 2017, Table 6.1). Vertical bars in Figure 2 represent these and other key event dates that affect haircuts differentially across bonds and that we use in our DiD analysis below.[18] In chronological order these are:

- June 3, 2013, (brown dashed line). First major correction of Spanish government bond collateral framework implementation errors. As a result, haircuts diverged on this date, with fifteen bonds moved from rating category 1 to category 2. We refer to this as *Divergence date 1* for Spain.

- August 9, 2013, (mint-green solid line). First major correction of Italian government bond collateral framework implementation errors. Haircuts diverged, with sixty-three bonds moved from rating category 1 to category 2. This is *Divergence date 1* for Italy.

  - There was a second, smaller mass correction of collateral framework implementation errors on April 1, 2014 (blue longdash-dotted line in Figure 2). This involved sixteen Italian and ten Spanish short-dated (less than one year of residual maturity) bonds. Because of the small number of bonds and the short range of residual maturities, this event, which we refer to as *Divergence date 2*, is not used in the DiD analysis below.

- October 1, 2013, (grey dash-dotted line). ECB haircut update. From March 2004 to the

[18]These key dates are not affected by whether we use the full dataset or only the subset of bonds with market prices. In particular, there is no additional mass correction date for bonds without market prices.

end of the sample period of this study (May 2017), the ECB updated haircuts on sovereign bonds only once (October 1, 2013), as reflected in Table 1.[19] This update widens the haircut differential between government bonds in rating categories 1 and 2. The haircut revision was announced on Friday, September 27 and implemented on Tuesday, October 1, 2013, which coincides with a regularly scheduled main refinancing operation. Since there is only one business day between the announcement and implementation dates, we estimate the combined announcement and implementation effect in the DiD analysis below.

- September 1, 2014, (orange shortdashed line). Announcement of haircut harmonization (ECB, 2014a). On this date, the ECB announced a collateral framework update to harmonize haircuts and ratings on sovereign bonds within countries by changing the rating priority rule for central-government securities. Whereas the general rule is that issue ratings take precedence over issuer ratings, the update says that, for government bonds, issuer (i.e., country) ratings will take precedence. Thus, as of the implementation date (December 15, 2014), all same-country government bonds are placed in the same rating category, namely, that of the highest country rating given by one of the four official rating agencies.

- December 15, 2014, (magenta-colored longdashed line). Haircut harmonization is implemented. As seen in Figure 2, Italian and Spanish government securities in rating category 2 shift back to category 1 on this date (ECB, 2014a). This upgrade occurs because both Italy and Spain had a country rating of AL from DBRS.

Figure 2 also shows that all Italian bonds moved from rating category 1 to category 2 in January 2017. This is a result of DBRS' downgrade of Italy from AL to BBBH and is not related to haircut inconsistencies.

3.2 Treated and control bonds

Henceforth, we set the sample period as being fifteen business days before the first Spanish divergence date to fifteen business days after harmonization (May 13, 2013 to January 7, 2015, inclusive), and work only with the subset of bonds for which we have market prices. We think of bonds that were moved into rating category 2 and received higher haircuts on the first Spanish and Italian divergence dates as being treated. For the next two events, we continue to identify

[19]See Nyborg (2017, Subsections 5.3, 5.4, and A.3, and, in particular, Tables 5.2, 5.3, 5.4, 5.5, and A.2) and the Eurosystem collateral framework references therein, as well as ECB (2016a, 2016b, and 2016c).

rating category 2 bonds as treated. For the fourth and final event, treated bonds are those that switch from rating category 2 to 1.

In the Italian sample, it turns out that all rating category 2 securities, and thus all treated bonds, are without coupons. Since fixed and zero-coupon bonds may trade differently in the market, for example, because of clientele effects, we use only zero-coupon bonds as controls. Thus, we retain all Italian zero-coupon bonds over the sample period, except one bond that changed rating category on a day other than the two divergence (mass correction) dates identified above. We also filter out ten security-days where five newly issued bonds spend at most three days each in rating category 2.

In the Spanish sample, bonds in rating category 2 are comprised of thirty-two zero-coupon and seven fixed-coupon bonds. The latter are in category 2 for only a few days each, for a total of 117 security-day observations, and are dropped. Thus, for Spain, we also consider only zero-coupon bonds. We exclude bonds that mature after April 2018, since these are almost exclusively in category 1, one bond that changed rating category on a day other than the two divergence (mass correction) dates identified above, and twenty-one security-days involving seven bonds that spent at most three days each in rating category 2.

In both the Italian and Spanish samples, security-day observations with less than ten calendar days to maturity are excluded. For Italy (Spain), we are left with 177 (72) zero-coupon bonds for a total of 45,690 (16,558) security-day observations on 422 sample days. The total number of bonds that at some point in time are in rating category 2 are 96 (25) for Italy (Spain), comprising 23,554 (4,905) security-day observations. Further information on these final samples is provided separately for Italy and Spain in the plots collected in Figure 3.

Insert Figure 3 here.

For each country, Figure 3a shows the number of bonds in each rating category over time. For both countries, there are bonds in each rating category every day from the first divergence date until haircut harmonization. Italy has more bonds in the high-haircut category. For Spain, it is the opposite.

With respect to the residual maturities of Italian bonds, Figures 3b and 3c show that they stretch out to almost twenty-five years for both rating categories, but being somewhat less densely distributed for maturities beyond twenty years. In the Spanish sample, the distribution of residual maturities for either rating category extends up to around five years at the first divergence date, dropping to around three years toward the end.

4. Yields of high- versus low-haircut bonds

This section takes a first look at yield differentials between bonds in different rating categories, that is, high- and low-haircut bonds. We use the final sample with daily observations on 177 Italian and 72 Spanish zero-coupon bonds, as described in Section 3.2. All surviving securities have the BGN pricing source (see Footnote 8), and we take the mid-point of the end-of-day bid and ask prices, expressed in terms of yield. Security-day observations with stale prices are dropped.[20] These are defined as cases where the bid, ask, and mid-prices are unchanged from the previous day. All securities are euro-denominated.

For each country, we initially report on unconditional differences in yields between the two groups. We then introduce a simple control for residual maturity (term structure) effects using Eurosystem haircut maturity buckets (see Table 1). Finally, we estimate daily spot curves for each country, controlling for rating category, using cubic regressions. The fit is extremely good. The average adjusted R^2 of the individual, daily cross-sectional regressions is 99.6% for Italy and 97.3% for Spain. Hence, this provides us with accurate estimates of average differences between the spot curves of high- and low-haircut bonds over time.[21]

In the DiD analysis below, we also estimate Italian yield curves using the Diebold and Li (2006) factorization of the Nelson-Siegel (1987) model. This does not work for Spain because, over the relatively short maturity range in our Spanish sample, the yield curve is upward sloping and convex on many days. Thus, in the preliminary analysis in this section, we use the more versatile cubic specification.

4.1 Overview and summary statistics

For both countries, Italy and Spain, Figure 4 provides time-series plots on the number of bonds in each rating category, average residual maturities, and average yields from the first divergence date (August 9, 2013 in Italy and June 3, 2013 in Spain) to the last business day before haircut harmonization (December 12, 2014). Table 5 provides summary statistics across sample days,

[20] There are 550 (142) security-day observations with stale prices in the Italian (Spanish) sample.

[21] Nguyen (2020) looks at the relation between yields and Eurosystem haircuts by running Fama-MacBeth regressions with government-bond yields relative to Germany on the left-hand-side and haircuts and controls on the right-hand-side, pooling together different countries, maturities, coupons, and rating categories, and finds a positive correlation between yields relative to those of German government bonds and haircuts. This reflects that yields relative to Germany increase in residual maturity and as ratings worsen and that Eurosystem haircuts also increase in residual maturity and rating category (Table 1).

including on yield spreads between rating categories. Because Figure 4 shows that average residual maturities and relative yields in the four country and rating-category subpopulations change after the second divergence date, summary statistics are provided separately for the periods before and after this date (April 1, 2014).

Insert Figure 4 and Table 5 here.

As seen in Figure 4a and Table 5, Panel A for Italy, the number of bonds in rating category 2 (1) hovers around sixty (mid forties) until the second divergence date (April 1, 2014), when it jumps up (down) to the mid seventies (mid to low thirties), where it resides until haircut harmonization. For Spain, the average number of bonds across days in the first subperiod is approximately thirty-two and nine for rating category 1 and 2, respectively. In the second subperiod, the corresponding numbers are twenty and seventeen.

For each country, Figure 4b shows the average spot rate within each rating category over time. As seen, high-haircut bonds have higher yields than low-haircut bonds. For Italy, in the subperiod prior to the second divergence date, the difference in yields (rating category 2 less category 1) is 2.006 percentage points (pps); and between the second divergence date and haircut harmonization, the difference is 0.491 pps (both statistically significant at the 1% level, see Table 5). For Spain, the difference is 0.521 pps and −0.136 pps in the first and second subperiods, respectively (both statistically significant at the 1% level).

These raw yield-difference estimates do not correct for term structure effects. As seen in Figure 4c and the corresponding numbers in Table 5, for each country, residual maturities are, on average, longer for rating category 2 bonds. For Italy, as an average across days, rating category 2 bonds have a residual maturity that is around seven years longer than category 1 bonds in the first subperiod, dropping to 1.82 years thereafter. For Spain, the corresponding numbers are 0.63 and −0.72 years. Given upward sloping term structures, differential residual maturities impart biases in the raw yield-difference estimates that need to be corrected for.

Figure 4d presents a simple correction for term structure effects. For each country, this plots the average spot rate within each rating category controlling for residual maturity. In particular, at each date, we place bonds in the maturity buckets used by the ECB to set haircuts. These are the six buckets shown in Table 1, namely (in years): 0-1, 1-3, 3-5, 5-7, 7-10, more than 10. At each date, for each country and rating-category combination, we first average yields across all bonds in the same maturity bucket. We then take the average over the six maturity buckets for Italy and three maturity buckets for Spain. This gives us four time series with simple maturity-controlled average spot rates.

Figure 4d and the corresponding statistics in Table 5 show that this simple term-structure correction has significant impact on the measured difference in yields between bonds in rating categories 1 and 2. For Italy, the average difference across days is 8.4 and 2.8 bps in the first and second subperiods, respectively. For Spain, the corresponding numbers are 18.6 and 5.5 bps, respectively. These differences are all statistically significant at the 1% level. So controlling for residual maturity has a strong effect on the measured effect of haircuts on yields.

Table 5 also includes information on the ranges of residual maturities across days in the Italian and Spanish samples. For Italy, the ranges of residual maturities never fall below 23.00 and 24.00 years for rating category 1 and 2 bonds, respectively. For Spain, residual maturities are shorter in the second half of the sample period, with average ranges of 3.34 and 3.36 years for rating categories 1 and 2, respectively. Hence, for Spain, caution needs to be exercised with respect to extrapolating curves beyond three years.

4.2 Average daily spot and delta curves

To control more precisely for term-structure effects, in this subsection, we estimate daily rating category 1 spot curves and delta curves using a cubic specification. The delta curve is the difference between the spot curves of the two rating categories. Estimation is carried out separately for Italy and Spain, and we report the averages of these daily runs. Specifically, we employ the Fama-MacBeth procedure with the following specification over the same periods for Italy and Spain as in Figure 4:

$$yield_{it} = \boldsymbol{\Gamma}_1' \, \mathbf{Mat}_{it} + \boldsymbol{\Gamma}_2' \, \mathbf{Mat}_{it} \, \mathbb{1}_{RC2,it} + \varepsilon_{it}, \tag{1}$$

where $yield_{it}$ is the yield-to-maturity of bond i on day t; $\mathbf{Mat}_{it}$ is a 4×1 dimensional vector with a constant as first element, the residual maturity of bond i on day t as second element, and higher orders (quadratic and cubic terms) of it as further elements;[22] $\boldsymbol{\Gamma}_j$, $j = 1, 2$, is a vector of coefficients with individual elements $\gamma_{k,j}$, $k = 0, \ldots, 3$; and $\mathbb{1}_{RC2,it}$ is an indicator variable that is one if bond i is in rating category 2 on day t and zero otherwise.

The Fama-MacBeth procedure runs Specification (1) for each sample day and, in a second step, calculates the averages of each of the eight coefficients across the individual sample day

[22] Specifically, $\mathbf{Mat}_{it}' = [1 \quad x_{it} \quad x_{it}^2 \quad x_{it}^3]$, where x_{it} is the residual time-to-maturity.

regressions. Thus, the estimated average spot curve for rating category 1 is

$$s_1(x) = \widehat{\gamma}_{0,1} + \widehat{\gamma}_{1,1}x + \widehat{\gamma}_{2,1}x^2 + \widehat{\gamma}_{3,1}x^3, \tag{2}$$

where $\{\widehat{\gamma}_{k,1}\}_{k=0}^{3}$ are the estimated regression coefficients and x is residual maturity. Similarly, the estimated average difference between the spot curves of rating categories 2 and 1 is

$$\Delta(x) = \widehat{\gamma}_{0,2} + \widehat{\gamma}_{1,2}x + \widehat{\gamma}_{2,2}x^2 + \widehat{\gamma}_{3,2}x^3, \tag{3}$$

where $\{\widehat{\gamma}_{k,2}\}_{k=0}^{3}$ are the estimated regression coefficients.

Insert Table 6 here.

Table 6 reports the results. t-statistics (in brackets underneath the coefficients) are based on Newey-West standard errors with five lags.[23] The letters a, b, and c denote statistical significance (two-sided) at the 1%, 5%, and 10% levels, respectively. The average adjusted R^2 of the individual cross-sectional regressions (in step 1 of the Fama-MacBeth procedure) is 99.59% for Italy and 97.27% for Spain, showing that the cubic specification fits the data very well.

Panel A shows the results for Italy. The coefficient vector of interest is $\mathbf{\Gamma}_2$, that is, the interaction coefficients that describe $\Delta(x)$. The results show that only the intercept coefficient is statistically significant. This is 6.0 bps (statistically significant at the 1% level). The point estimates of the slope and curvature coefficients (of $\Delta(x)$) are neither economically nor statistically significantly different from zero. In other words, on average over sample days, the spot curve of the high-haircut bonds (rating category 2) lies a level 6.0 bps over that of the low-haircut bonds (rating category 1).

For Spain (Panel B), higher haircuts are also associated with a statistically significant shift up in the spot curve. But the shift is not parallel on average. The intercept coefficient, $\widehat{\gamma}_{0,2}$, is 10.3 bps. The other coefficients are: $\widehat{\gamma}_{1,2} = -8.1$, $\widehat{\gamma}_{2,2} = 5.2$, and $\widehat{\gamma}_{3,2} = -0.7$. All are statistically significant at the 1% level. These point estimates imply that the spot curve of rating category 2 lies above that of rating category 1 for all maturities in the sample range. At a residual maturity of one year, the difference, $\Delta(1)$, is 6.8 bps. At a residual maturity of three years, the difference is 14.4 bps. In short, for both countries, high haircut bonds have higher yields than low haircut bonds over the full sample ranges of maturities.

[23]The number of lags equals the fourth root of the number of observations, rounded up to the nearest integer, as recommended by Greene (2008).

5. Difference-in-differences regressions

While the cubic regressions in Section 4.2 provide precise control for differences in residual maturities between low- and high-haircut bonds, it is possible that bonds in different rating categories also differ in other, unknown respects. To address this concern, in this section, we run DiD regressions around the four events discussed in Section 3. As discussed above, for each event, a bond is classified as treated if it is in rating category 2 before or after the event.[24] The remaining bonds, those that are in rating category 1 both before and after the event, are controls.

In the DiD regressions in this section, we continue to use a cubic spot curve specification. In Section 6, we complement this with estimates based on the Diebold-Li (2006) factorization of the Nelson-Siegel (1987) curve, with similar overall results. Inference is based on standard errors clustered at the individual bond level.

As detailed in Section 3, the first two events involve a divergence of haircuts between bonds in the two rating categories, while the last two events involve haircut convergence. Thus, we would expect to see positive treatment effects on the first two events and negative effects on the last two events. Specifically, in the first event, divergence date 1, several bonds experience an increase in haircuts as a result of mass corrections of collateral framework implementation mistakes. In our terminology, they are moved from rating category 1 to 2. On the second event date, the haircut policy update on October 1, 2013, haircut differences between rating categories 1 and 2 increase, as seen in Table 1. Thus, under the hypothesis that an increase in haircuts depresses prices, we would expect to see the difference in yields between treated and control bonds to increase around the first two event dates.

The third event date, the announcement of haircut harmonization, heralds a convergence of the haircuts of treated and control bonds. On the fourth and final event date, this is implemented. Thus, we would expect the difference in yields between treated bonds and controls to fall on these two dates. Usually in finance, one focuses on announcement effects. However, if lower haircuts ease constraints, then we may also see an implementation effect. Nyborg (2019) shows in a constrained-arbitrage setup that the *current* haircut has a *current* effect on the relation between repo and unsecured rates and the expected rate of return of the underlying collateral. By comparing harmonization announcement and implementation treatment effects, we can examine

[24] Recall that for the first event, treated bonds are moved from rating category 1 to 2. For the next two events, treated bonds are in rating category 2 before and after the event. For the fourth event, treated bonds are moved back to rating category 1.

the relative importance of anticipated versus current haircuts in the data.

The question as to the relative impact of anticipated versus current haircuts is also relevant with respect to the first event dates. It is unclear to what extent market participants anticipated the first mass corrections of collateral framework implementation mistakes of Italian and Spanish bonds. We have not found press releases or news reports that speak to this. However, if yields are affected by the implementation of haircut harmonization, which was fully anticipated, then we would expect to see bond prices react to the mass-correction events too. This is, of course, contingent on the bond market's awareness of the implemented changes.

5.1 Data

We run DiD specifications (see below) over event windows of ten and twenty business days around each of the four event dates.[25] Hence, there are eight event windows in total for each country. The underlying data is the cleaned sample of zero-coupon bonds discussed in Section 3.2 and used in Section 4. From this, for each event, we filter out bonds that move across ECB maturity buckets (see Table 1) or experience rating changes by one of the four official rating agencies within the twenty-day window. In addition, for each event window, we filter out bonds that do not have fresh (non-stale) market prices every day within the window. This ensures equal consideration of sample bonds with respect to the estimation of yield curves and treatment effects.[26]

Insert Table 7 here.

For each event window and country, Table 7 reports on the number and percentage of bonds in the treated and control samples by ECB maturity bucket. In the case of Italy (Panel A), for the first event, thirty-nine control and sixty-one treated bonds pass the filters for the ten-day event window. Two of the controls are filtered out for the twenty-day window. For the first two events, control bonds are concentrated toward the short end of the maturity spectrum, whereas treated bonds are concentrated toward the long end. Italian control and treated bonds are more evenly distributed for the last two events.

[25]For the second event (haircut update), we form windows after excluding the announcement date (September 27, 2013) and the single business day between the announcement and implementation (September 30, 2013). So, for this event, we estimate a combined announcement and implementation effect.

[26]In the Spanish sample, prices are missing for several bonds on three haircut harmonization event-window days; namely, August 25, 2014 (announcement, ten- and twenty-day windows) and December 24 and 31, 2014 (implementation, twenty-day window). Filtering out the affected bonds would severely limit our ability to estimate yield curves over these windows. Thus, we replace these days in our analysis of Spain with days "to the left" and "to the right" so that ten- and twenty-day windows are maintained.

For Spain (Panel B, Table 7), there are bonds in only the first three ECB maturity buckets (up to five years). The first two events see relatively many treated bonds in the 1-3 year bucket. For the last two events, treated bonds shift toward the 0-1 year bucket.

5.2 Alternative specifications with cubic curves

We consider two DiD specifications with cubic representations of the term structure. The first specification is, for each event,

$$yield_{it} = \mathbf{\Gamma}' \, \mathbf{Mat}_{it} + \alpha \, \mathbb{1}_{Treated,i} + \delta \, \mathbb{1}_{Post,t} + \beta_{DiD} \, \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} + \varepsilon_{it}, \tag{4}$$

where $\mathbb{1}_{Treated,i}$ ($\mathbb{1}_{Post,t}$) is an indicator variable that is one for treated bonds (the event and post-event dates) and zero otherwise. α and δ are the corresponding coefficients. β_{DiD} is the DiD estimator. The rest of the notation is as in Subsection 4.2 so that $\mathbf{\Gamma}'\mathbf{Mat}_{it}$ represents a polynomial of degree three.

Equation (4) is a standard DiD specification from the literature, transferred to a yield-curve setting. Through $\mathbf{\Gamma}'\mathbf{Mat}_{it}$, the specification explicitly controls for the term structure of interest rates. However, it does so while imposing a parallel-shift restriction between all yield curves: controls, pre and post event; treated, pre and post event; treated versus controls, pre and post event. In particular, Specification (4) imposes a level treatment effect across the maturity spectrum. Put differently, it captures the average treatment effect across the treated bonds in the sample.

A limitation of Specification (4), therefore, is that it does not capture *differential* treatment effects across maturities. This may be an issue because of clientele, or habitat, effects. Bonds with different maturities may be held and traded by different types of market participants and, as a result, have different reactions to haircuts set by the central bank. As noted in the Introduction, banks, who are the only eligible counterparties in Eurosystem repos, typically hold relatively short duration bonds. Insurance companies and pension funds, who are natural clienteles for longer duration bonds, are not eligible counterparties. Thus, bonds with relatively long residual maturities may react less strongly than shorter maturity bonds to Eurosystem haircut changes.

Controlling and testing for differential treatment effects across the maturity spectrum is of interest by and of itself. For example, with respect to central bank collateral policy, it is important to know how different segments of the yield curve react to haircut changes. Furthermore, failing to control for differential treatment effects may bias the results. For instance, if long-dated bonds, say, are not much impacted by haircut changes, e.g., because of clientele effects, and long-dated bonds are over-represented in the treated sample, then imposing a level treatment effect across the term structure reduces the power of the DiD test. Conversely, if short-dated bonds are over-represented among the treated bonds, Specification (4) could overestimate the overall treatment effect.

This is germane in our setting because treated bonds are not uniformly distributed across maturities (Table 7). For Italy, there is a skew toward longer maturities, especially for the first two events. For Spain, the distributions of maturities also vary across events. Thus, if haircuts impact bond prices differentially over the maturity spectrum, Specification (4) is prone to errors of both types across the four event dates and the two countries.

In the broader literature, differential treatment effects are typically dealt with through fixed effects on the different discrete units or "habitats" present in the data structure.[27] Time to maturity, however, is a continuous variable. As such, it demands a different approach. Our solution is to fit a fully flexible model, where no particular relation is imposed between pre- and post-event spot curves for treated and control bonds.

In particular, for each event, our second, and main, specification is

$$yield_{it} = \mathbf{\Gamma}_1' \,\mathbf{Mat}_{it} + \mathbf{\Gamma}_2' \,\mathbf{Mat}_{it} \,\mathbb{1}_{Treated,i} + \mathbf{\Gamma}_3' \,\mathbf{Mat}_{it} \,\mathbb{1}_{Post,t} + \mathbf{\Gamma}_4' \,\mathbf{Mat}_{it} \,\mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} + \varepsilon_{it}. \quad (5)$$

The notation is the same as above. Specifically, the $\mathbf{\Gamma}_j$'s are vectors of coefficients, with individual elements $\gamma_{k,j}$, $k = 0, \ldots, 3$. The estimated spot curve for controls over the pre-event period is

$$s(x) = \widehat{\gamma}_{0,1} + \widehat{\gamma}_{1,1}x + \widehat{\gamma}_{2,1}x^2 + \widehat{\gamma}_{3,1}x^3, \quad (6)$$

[27] A common DiD specification in the general literature is:

$$y_{it} = \alpha_i + \delta_t + \beta_{DiD} \,\mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} + \varepsilon_{it} \quad (4')$$

where the α_i's and δ_t's are individual unit and time fixed effects, respectively, and y_{it} is the outcome variable. This is sometimes adopted in fixed-income settings, with the outcome variable being the yield on bond i at time t (e.g., Todorov, 2020). In our case, the results on β_{DiD} using this specification are similar to those using (4), but the fit is substantially worse (see Table A.2 in the Internet Appendix). Specification (4) fits the data much better, as measured by R^2, because it models more accurately the nature of the variables and the relationship between them in the data. Empirically, yield is a non-linear function of maturity and maturity is time-varying. Neither bond nor time fixed effects capture the non-linear relationship or the time-varying nature of maturity. In addition, Specification (4′) is subject to the same sample-driven biases as (4) because it does not allow for differential treatment effects across maturities.

where $\{\widehat{\gamma}_{k,1}\}_{k=0}^{3}$ are the estimated regression coefficients and x is residual maturity. This serves as the baseline. Incremental differences for treated bonds ($j = 2$), the post-event estimation period ($j = 3$), and treated bonds over the post-event estimation period ($j = 4$) are given by

$$\Delta_j(x) = \widehat{\gamma}_{0,j} + \widehat{\gamma}_{1,j}x + \widehat{\gamma}_{2,j}x^2 + \widehat{\gamma}_{3,j}x^3, \tag{7}$$

where $\{\widehat{\gamma}_{k,j}\}_{k=0}^{3}$ are the estimated regression coefficients, $j = 2, \ldots, 4$. The DiD estimator is given by the vector $\widehat{\mathbf{\Gamma}}_4$, and the delta curve of interest is $\Delta_4(x)$.

In running Specification (5), we essentially estimate four yield curves. By adding the delta curves to the baseline curve for controls pre-event, $s(x)$, we obtain the estimated spot curve for (i) treated bonds pre-event, $s(x) + \Delta_2(x)$; (ii) controls post-event, $s(x) + \Delta_3(x)$; and (iii) treated bonds post-event, $s(x) + \sum_{j=2}^{4} \Delta_j(x)$. The DiD vector, $\widehat{\mathbf{\Gamma}}_4$, and the delta curve, $\Delta_4(x)$, capture the treatment effect at each maturity, not as an average across sample bonds. The estimated treatment effect depends on, and controls for, maturity in a fully flexible way.

By fitting yield curves and requiring fresh daily market prices, we control for the impact of mechanical day-to-day changes in bonds' residual maturities. With respect to the exclusion restriction, we are not aware of reasons as to why the DiD delta curve would change systematically around our events other than through differential variation in haircuts. First, over the event windows, none of the bonds experience ratings changes or move across ECB maturity buckets. Second, there are no coupon payments. Third, by virtue of being on the public list of eligible collateral, none of the bonds have option features. Fourth, government bonds generally do not change characteristics after issuance. Fifth, our empirical design fully controls for individual country effects. Sixth, controlling for maturity, spot rates in the two rating categories are highly correlated; the correlations between the two rating-category yield series in Figure 4d are 99.72% for Italy and 98.75% for Spain. Finally, we place the bar high by using *all* four events with mass changes in relative haircuts for same-country central-government bonds.

5.3 Results

The results for Specifications (4) and (5) are in Tables 8 and 9, respectively. For each event and country, each model is estimated over ten- and twenty-day event windows using OLS. We run estimations separately for each country to avoid biases that may arise in running pooled tests of treatment effects on securities from different countries that may experience different true impacts. Standard errors are clustered at the individual bond level and statistical significance at the 1%, 5%, or 10% levels are denoted by superscripts a, b, or c, respectively. In each table, the four events are presented chronologically, from Panel A to Panel D.

Insert Tables 8 and 9 here.

Before discussing the main results, we comment briefly on goodness of fit. For Italy, the fit is extremely good for both specifications, with the fully flexible model in Table 9 having a slight edge. Across the two specifications and all events and windows, the lowest adjusted R^2 is 99.18%.[28] So the cubic specification provides a consistently excellent fit for Italy. For Spain, the fit is also good, but not as consistent. Across the two specifications, adjusted R^2 does not drop below 98.00% over the first two events, but goes as low as 86.08% over the last two events.[29] Again, the fully flexible model, (5), fits better.

5.3.1 Parallel-shifts specification

The results on the treatment effect in the parallel-shifts model are in Table 8. We start in reverse chronological order by first discussing Panels C and D, which concern the announcement and implementation of haircut harmonization, respectively. This allows us to comment immediately on announcement versus implementation effects, which may also be relevant with respect to the first events to the extent they were anticipated by market participants. As discussed above, if *current* access to central-bank money is priced, we should see an implementation effect even if haircut changes are fully anticipated.

The results in Panel D for haircut harmonization implementation show a statistically significant (1% level) treatment effect on the yields of treated Italian bonds of −2.7 bps and −3.3 bps over the ten- and twenty-day event windows, respectively. This is approximately 50% of the 6.0 bps average difference between the spot curves of Italian rating category 2 and 1 bonds estimated in Section 4.2. For Spain, the corresponding numbers are −1.4 bps and −2.0 bps, both significant at the 5% level. The overall conclusion, therefore, is that changes to central-bank haircuts affect security prices *even when fully anticipated.*

Our finding supports the view that the degree to which a security can be used to extract central-bank money affects its spot price in the market. In particular, a collateral policy revision that increases a security's conversion rate into central-bank money also increases its market price.

[28]Model (4) (parallel shifts), announcement of haircut harmonization (event 3), twenty-day window.
[29]Model (4) (parallel shifts), harmonization implementation (event 4), twenty-day window.

Broadly put, money matters in asset pricing.

The estimated treatment effect from the harmonization announcement (Panel C) are also significant, but weaker than the implementation effect. For Italy, the announcement treatment effect is -1.1 bps and -2.4 bps over the ten- and twenty-day event windows, respectively (both significant at the 5% level). For Spain, the point estimates for both event windows are close to zero and not statistically significant. In short, for both countries, implementation effects dominate announcement effects.

Given our finding that yield differentials shrink when haircuts are harmonized, we would expect to see the opposite when haircuts diverge. For the first divergence date, Panel A in Table 8 shows a statistically significant treatment effect for Spain of 3.7 bps (5% level) over the ten-day window. For the haircut update event, for Italy, Panel B reports a statistically significant treatment effect (combined announcement and implementation) of 2.3 bps (1% level) and 1.9 bps (5% level) over the ten- and twenty-day windows, respectively. These positive treatment effects are consistent with the negative effect from harmonization because, for the first two events, haircuts on treated bonds rise relative to controls. Thus, overall, the results in Table 8 confirm the basic finding from Section 4 that haircuts in central-bank repos are increasing in yields.

Still, the results are noticeable weaker for the first two events. For instance, for the first divergence date, we do not find a significant treatment effect for Italy. Theoretically, this can reflect a sample bias because, as noted above, the DiD estimator in Specification (4) only captures the average in-sample treatment effect. Moreover, as we have discussed, there is reason to expect long bonds to be less affected by haircuts because they are predominantly held by agents that are not eligible as counterparties in central-bank repos. Hence, the absence of a significant treatment effect under Specification (4) at the first divergence date for Italy may simply reflect that there is skew toward long bonds in the treated sample, as reported in Table 7. Next, we turn to our main analysis of testing for differential treatment effects over the term structure.[30]

5.3.2 Fully flexible specification

The results on the specification with fully flexible yield curves, Equation (5), are in Table 9 and in Figures 5 (Italy) and 6 (Spain). The table shows treatment effects at different maturities for both

[30] Weaker results for some events could also reflect less tight monetary constraints, as per the theory reviewed in Section 7. As regards the first divergence date for Italy, another potential explanation for the insignificant result is that the event went unnoticed. We have not found announcements that relate to it. Furthermore, in the media, reports on haircut implementation errors focused on Spain, where the treatment effect on the first divergence date is strong. The "ignorance" hypothesis implies that we should not observe effects at any maturity.

the ten- and twenty-day estimation windows, with z-statistics in parentheses. Standard errors are calculated by the delta method and clustered at the individual bond level. The figures plot the treatment delta curves, $\Delta_4(x)$, for each event and country, based on ten-day event windows and with 10% confidence bands.

Insert Table 9 and Figures 5 and 6 here.

For both Italy and Spain, the overall treatment effects are negative for the two haircut harmonization events and positive for the first two events. This is in line with the results in Table 8. However, for both countries, Table 9 and the two figures show that treatment effects are heterogeneous across the maturity spectrum. Broadly, for both countries and across all four events, the effect is relatively stronger at shorter maturities and becomes largely insignificant at the longer end. In short, there are habitat effects. Insignificance at longer maturities is consistent with what one would expect when eligible counterparties hold predominantly short-term paper (as discussed in the Introduction). Given the overweight of long-dated treated bonds in the first event for Italy (Table 7), this also helps explain the insignificant average treatment effect for this event under the parallel-shifts model for Italy.

Next, we discuss the four events in more detail. For the first event (divergence), Figures 5 and 6 show that there is a statistically significant positive treatment effect out to a maturity of 4.05 years for Italy and 2.44 years for Spain, respectively. Effects are insignificant at longer maturities. In terms of magnitudes, for Italy, at a residual maturity of one year, the yields of treated bonds experience an abnormal increase of 1.9 bps and 2.7 bps over the ten- and twenty-day event windows, respectively (Panel A, Table 9). For Spain, the corresponding numbers are 3.9 bps and 3.4 bps.

For the second event (haircut update), the figures report statistically significant positive treatments effects out to a maturity of 3.53 years for Italy and after 1.74 years for Spain (where the longest bond has a maturity of around four years). In terms of magnitudes, the point estimate of the DiD effect for the one-year Italian yield is 6.2 bps and 2.8 bps for the ten- and twenty-day estimation windows, respectively, dropping to 4.1 bps and 2.5 bps, respectively, at two years.[31] The corresponding numbers for Spain at a maturity of two years are 1.4 bps and 2.1 bps.

The two haircut harmonization events exhibit the same overall pattern, with significant treatment effects at relatively shorter maturities. For Italy, there is a statistically significant negative

[31] The model also produces a smaller, but statistically significant positive treatment effect in the Italian sample for maturities larger than 17.16 years (Figure 5). However, this apparent effect vanishes under the Diebold and Li (2006) yield-curve specification (see Section 6).

treatment effect up to 4.74 years at the announcement of haircut harmonization. At implementation, significance extends up to 5.72 years. There is also a significant negative treatment effect at harmonization for Spain at short maturities and beyond 1.76 years at implementation.

Consistent with the results under the parallel shifts model (Table 8), the treatment effect is larger in magnitude at harmonization implementation than at the announcement. For one- and two-year spot rates for Italy, the estimated harmonization implementation treatment effects over the ten-day windows are −4.3 bps and −3.6 bps, respectively. The corresponding numbers for the announcement are −1.5 bps and −1.3 bps, respectively.

To estimate the full impact of harmonization, we also need to take into account the interim period, between announcement and implementation. Doing this, the full harmonization treatment effect on one year spot rates is estimated as −10.1 bps, or −1.8 bps per percentage point reduction in haircut.[32] The estimated harmonization treatment effects in Spain are smaller, but move in the same direction as for Italy.

In summary, the eight event studies – four for Italy and four for Spain – tell a consistent story. Government-bond yields are increasing in haircuts in central-bank repos in the short-to-mid range of the term structure. For the first two events, where haircuts of treated bonds increase relative to controls, the estimated treatment effect on the yields of treated bonds is positive. For the last two events, where haircuts of treated bonds decrease relative to controls, the treatment effect is negative. The results for Italy show that the effect is significant up to around five years of residual maturity. Insignificance at the long end is consistent with eligible counterparties in Eurosystem repos (banks) typically holding shorter duration bonds. Our findings show that economically significant effects can be achieved with sufficiently large changes in haircuts. However, policy is likely to have the most significant impact in habitats where players that have access to central-bank repos are active.

6. Yield curve specifications with exponential decay

In this section, we repeat the analysis in Section 5 with differential treatment effects using the Nelson and Siegel (1987) yield-curve specification. This model and its extensions, e.g., Svensson (1994), are characterized by exponential decay of the impact of slope and curvature factors. Thus, these models do not "blow up" at long maturities, as polynomial specifications

[32] Over the interim period, $[\text{announcement} + 5, \text{implementation} - 6]$, the one-year spot rate of treated bonds falls by 4.3 bps relative to control bonds.

do. Models with exponential decay are, therefore, better suited to extrapolation beyond the range of maturities observed in the data. However, in this paper, our main concern lies with fit within the sample range of maturities, and as seen above, the cubic specification fits very well. Still, employing the Nelson-Siegel/Diebold-Li (NSDL) model offers a solid robustness check to our results in Section 5.

The analysis in this section focuses on Italy. The reason is that the short maturity range in the Spanish sample leads to situations where, over long periods, the yield curve is strictly upward sloping and convex. Hence, fitting a curve where the slope forcibly decays with time to maturity does not work well. With respect to estimating the decay parameter, λ, we do not achieve convergence on a large fraction of days in the Spanish sample.

6.1 Specification

We employ the Diebold-Li (2006) factorization of the Nelson-Siegel (1987) model so that the spot curve at time t can be written as[33]

$$y_t(x;\lambda_t) = \beta_{0,t} + \beta_{1,t}\; l_{1,t}(x;\lambda_t) + \beta_{2,t}\; l_{2,t}(x;\lambda_t), \tag{8}$$

where

$$l_{1,t}(x;\lambda_t) = \left(\frac{1-e^{-\lambda_t x}}{\lambda_t x}\right) \quad \textit{and} \quad l_{2,t}(x;\lambda_t) = \left(\frac{1-e^{-\lambda_t x}}{\lambda_t x} - e^{-\lambda_t x}\right), \tag{9}$$

x is time to maturity, $\beta_{0,t}$ is a level (or long-term) factor, $\beta_{1,t}$ is a slope (or short-term) factor, $\beta_{2,t}$ is a curvature (or medium term) factor, and λ_t is the decay parameter.

The four parameters in Equation (8) can be estimated on day t using nonlinear least squares (NLS). However, as emphasized by Diebold and Li (2006), if λ_t is given, the three remaining parameters can be estimated simply by OLS. Fixing the decay parameter at some reasonable, time-invariant value is common in practice. To get a sense of what may be sensible, note that the decay parameter determines the point where the loading on the curvature factor, $\beta_{2,t}$, obtains its maximum (Diebold and Li, 2006). Based on practice, Diebold and Li pick this to be at a maturity of 30 months. The "Diebold-Li lambda" is then $\lambda_t = \lambda = 0.0609$ for all t, which translates into $\lambda = 0.7308$ when maturity is given in years (as in our case). We run the model below with both the Diebold-Li lambda and event-specific lambdas that are estimated in sample.

[33] As explained by Diebold and Li (2006), their factorization reduces the multicollinearity inherent in the original Nelson and Siegel (1987) specification.

Our DiD model under the Diebold and Li (2006) yield curve specification with a constant decay parameter, λ, over the event window is

$$yield_{it} = \mathbf{B}_1' \, \mathbf{L}_{it} + \mathbf{B}_2' \, \mathbf{L}_{it} \, \mathbb{1}_{Treated,i} + \mathbf{B}_3' \, \mathbf{L}_{it} \, \mathbb{1}_{Post,t} + \mathbf{B}_4' \, \mathbf{L}_{it} \, \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} \; + \; \varepsilon_{it}, \qquad (10)$$

where $\mathbf{L}_{it}$ is a three-dimensional vector of regressors with elements 1, $l_1(x_{it};\lambda)$, and $l_2(x_{it};\lambda)$, and $\mathbf{B}_j$ is the corresponding vector of coefficients, with individual elements $\beta_{k,j}$, $k = 0, \ldots, 2$. The rest of the notation is as before. The model is estimated over ten- and twenty-day event windows, as above.

The estimated spot curve for controls over the pre-event estimation period is

$$s^{dl}(x;\lambda) = \widehat{\beta}_{0,1} + \widehat{\beta}_{1,1} \; l_1(x;\lambda) + \widehat{\beta}_{2,1} \; l_2(x;\lambda), \qquad (11)$$

where $\{\widehat{\beta}_{k,1}\}_{k=0}^{2}$ are the estimated regression coefficients and x is residual maturity. Incremental differences for treated bonds ($j = 2$), the post-event estimation period ($j = 3$), and treated bonds over the post-event estimation period ($j = 4$) are given by

$$\Delta_j^{dl}(x;\lambda) = \widehat{\beta}_{0,j} + \widehat{\beta}_{1,j} \; l_1(x;\lambda) + \widehat{\beta}_{2,j} \; l_2(x;\lambda), \qquad (12)$$

where $\{\widehat{\beta}_{k,j}\}_{k=0}^{2}$ are the estimated regression coefficients, $j = 2, \ldots, 4$. The DiD estimator is given by the vector $\widehat{\mathbf{B}}_4$, and the corresponding delta curve is $\Delta_4^{dl}(x)$.

6.2 Results

We use the same data as for Italy in Section 5. For each event and time-window combination, we run Equation (10) using OLS with two values for λ. The first is the Diebold-Li lambda, $\lambda = 0.7308$. The second is estimated in sample for each event and window using NLS. In particular, for each day in the relevant event window, we estimate Equation (10) with NLS separately for treated and control bonds. The value for λ is then set as the average of the resulting daily estimates.

The motivation for estimating λ in sample is twofold. First, the Diebold-Li lambda is an educated guess based on US Treasury data. There is no reason to expect this to be the same across countries and time. For example, λ may vary because of dynamic and country-specific clientele effects in different parts of the term structure. Second, as will be discussed, the fit using the Diebold-Li lambda is worse than when using the cubic spot-curve specification. Using the in-sample λ improves fit.

Table 10 provides estimated treatment effects of the yields on treated bonds at selected maturities. z-statistics (in parentheses) use standard errors calculated by the delta method and clustered at the individual bond level. The results using the Diebold-Li lambda are on the left, while those using the in-sample λ are on the right. In addition, for each event, the treatment delta curve, $\Delta_4^{dl}(x)$, is plotted in Figure 7 with 10% confidence bands. The figures are based on ten-day event windows and the in-sample, event-specific λ's.[34]

Insert Table 10 and Figure 7 here.

We start with the results for haircut harmonization (Panels C and D). For conciseness, we focus on the ten-day window. Note first that the in-sample λ's are quite different from the Diebold-Li lambda. Over the ten-day announcement and implementation windows, the estimated in-sample λ's are 0.3929 and 0.2655, respectively. As a result, using the "canned" Diebold-Li lambda of 0.7308 produces a relatively poor fit. Adjusted R^2's are 97.63% and 95.84% for the announcement and implementation events, respectively. The corresponding numbers when employing the in-sample λ's are 99.64% and 99.62%, respectively, which is approximately the same as under the cubic specification. Precision is important because the treatment effect on spot rates is measured in single-digit basis points. Hence, we focus on the results under the in-sample λ's in the discussion below.

For the ten-day window, Figure 7 shows a statistically significant negative harmonization announcement effect out to 10.05 years. This is longer than under the cubic specification (4.74 years). Point estimates are also slightly larger in absolute value under the NSDL yield curve specification. For example, for a time-to-maturity of one year, the treatment effect is -1.8 bps, versus -1.5 bps under the cubic specification.

For harmonization implementation, Figure 7 shows that the "significance boundary" is at 5.46 years. This is similar to under the cubic specification (5.72 years). Treatment effect point estimates are also similar. For a residual maturity of one year, it is -4.0 bps under the NSDL yield curve specification versus -4.3 bps under the cubic specification.

As discussed above, to capture the full harmonization effect, we also need to consider potential changes in spot rates over the interim period between announcement and implementation. We

[34]As an alternative to estimating daily λ's using NLS and then taking the average within each event window to get our in-sample λ's, we have also run (10) using NLS over each event window. The results, which are in Table A.3 in the Internet Appendix, are practically indistinguishable from those in Table 10.

would expect to see a time-value effect over this period if implementation leads to an increase in monetary convenience yield. At a maturity of one year, the difference between the two curves shrinks by 3.6 bps. Taking this into account, the total treatment effect of haircut harmonization under the NSDL specification can be approximated as −9.4 bps, or −1.7 bps per pp reduction in haircut. Again, this is almost the same as under the cubic specification (−1.8 bps).

The haircut-harmonization findings can be summarized as follows: Goodness of fit and estimated treatment effects are similar under the NSDL and cubic yield-curve specifications. Quantitatively, both models offer superb fit and show consistently significant treatment effects out to approximately five years. Under either specification, the implementation effect exceeds the announcement effect, and at a maturity of one year, the combined treatment effect from announcement through implementation is close to two bps per percentage point change in haircut.

As regards the first two events, for brevity, we focus on the results under the in-sample λ's and the ten-day windows. Figure 7 shows a statistically significant treatment effect out to 2.78 years and 1.93 years for the first and second events, respectively. These significance boundaries are smaller than under the cubic specification, but the R^2's are also lower. At a maturity of one year, the point estimates of the treatment effects are 1.2 bps and 4.3 bps for the first divergence date and the haircut update, respectively.

Overall, results using the NSDL curve specification are similar to those under the cubic specification in the previous section. All four event studies tell the same story, namely that spot rates in the short- to mid-range of the maturity spectrum are increasing in haircuts, ceteris paribus. Magnitudes of the treatment effect are economically meaningful and suggest that collateral policy can be used to affect the yield curve by adjusting haircuts in central-bank repos.

7. The economics of the haircut effect

There are several strands of thought as to why haircuts in central-bank repos should affect asset prices and what, specifically, the convenience yield, or premium, in low-haircut bonds represents. The idea that liquidity provided by the central bank has value has been recognized since Bagehot (1873). While Bagehot's dictum is in terms of emergency injections of liquidity to individual, stressed banks, our study is in the context of the regular operational framework of the Eurosystem. In this context, any bank in the euro area can bring eligible collateral to the central bank and exchange it for reserves at its regularly scheduled operations or by tapping the marginal lending facility at any time.

Emergency liquidity or funding aside, the literature offers two broad perspectives on the haircut premium. The first of these, what we can refer to as the "monetary perspective," is based on the idea that central-bank money has intrinsic value. Hence, securities that can be exchanged for a relatively higher amount of central-bank money trade at a premium, ceteris paribus. There are several potential factors that can give rise to such value. First, most transactions must ultimately settle in central-bank money and there is no substitute for it so that "monetary constraints" may be binding. Chapman, Chiu, and Molico (2011) develop a model in this vein where a haircut reduction increases the price of the eligible asset. The transactional importance of money is also emphasized by Stein (2012) and in the new monetarist literature (Lagos, Rocheteau, and Wright, 2017). Second, banks need central-bank money to satisfy reserve requirements and may have additional precautionary demand for reserves, as emphasized by Bindseil and Papadia (2006). Empirically, this can put upward pressure on interbank rates (Acharya and Merrouche, 2013), and tightness in the market for liquidity spills over to security markets (Nyborg and Östberg, 2014). In a constrained-arbitrage model of liquidity-driven repos, Nyborg (2019) shows that elevated haircuts put downward pressure on asset prices when unsecured liquidity is tight and relatively expensive. Third, moral hazard can reduce the effectiveness of inside money and, thereby, impart value to outside money from a central bank (Kiyotaki and Moore, 2003; Holmström and Tirole, 2011). The same conclusion can be drawn from the observation that liquidity is a public good and is, therefore, subject to a private-sector underprovisioning problem (Bhattacharya and Gale, 1987). In short, the monetary perspective emphasizes that what is provided in central-bank repos is central-bank money, which plays a unique role in the economy to settle trades and as the ultimate liquidity backstop.

The alternative "finance perspective" says that central-bank liquidity injections can be viewed as leverage provisioning by the central bank (Ashcraft, Gârleanu, and Pedersen, 2010; Gârleanu and Pedersen, 2011). Thus, low-haircut assets can trade at a premium if leverage constraints are binding.[35] The institutional setting of our paper suggests that the haircut premium we document relates to plain liquidity provisioning, and, therefore, that the monetary perspective is most relevant. However, we cannot categorically rule out that there is also a leverage-constraint element to our findings.

[35] Singh (2020) describes the structure of leverage and the use of collateral in the financial system.

8. Concluding remarks

In this paper, we have shown that collateral policy, specifically, haircuts in regular liquidity-injecting central-bank repos, has significant impact on government-bond yields. Using DiD analyses on four separate events and employing different specifications for the yield curve for robustness, the basic finding is that an increase in haircuts in central-bank repos causes spot rates to increase. However, the magnitude of the haircut effect is heterogeneous across the term structure, tapering off at the long end. The DiD analysis also shows that yields respond to the implementation of haircut revisions, even when this has been announced months in advance. Our findings suggest that central-bank money is priced in the market.

Our analytical approach contributes to the literature by (i) developing clean identification of changes in central-bank haircuts and (ii) employing methodology that allows us to identify heterogeneity in the effect of haircuts across the term structure. The starting point is the existence of differential treatment of same-country government bonds by collateral policy in the euro area. We show that the haircut rules within the Eurosystem's collateral framework imply that bonds can be categorized into two classes based on haircuts. The identification itself comes from four specific events where the haircuts of the two classes of bonds changed differentially. In terms of methodology, we combine DiD regressions with flexible yield-curve modeling, as a first in the literature. We are able to address potential heterogeneity in haircut effects over the term structure because relative haircuts in the two classes of bonds change over the whole maturity spectrum in all four events.

The vanishing term effect we document squares with the fact that banks, who are the counterparties in Eurosystem repos, hold paper with relatively short duration. Thus, even though long-term bonds experience the largest haircut changes in our DiD events, their yields do not react. The existence of habitat effects has policy implications. For example, to make haircuts effective at longer maturities, it may be necessary to encourage banks to hold paper with longer durations or to expand the set of eligible counterparties. Further research is needed to assess the potential costs and benefits of this. As another example, introducing a haircut gap between green and brown bonds to stimulate green investment (Villeroy de Galhau, 2019) may be ineffective if eligible counterparties are not active in the targeted segments of the bond market. An interesting question for further research that relates to these issues is how much influence haircuts in central-bank repos have on the security-portfolios of eligible counterparties.

On a conceptual level, our findings imply that central-bank money has value; habitat effects aside, securities that can be converted into relatively more central-bank money trade at a premium. This can be thought of as deriving from the convenience that central-bank money provides as, for example, a medium of exchange. But it could also reflect demand for leverage that is not fully met in private markets. An interesting avenue for further research would be to try to disentangle the different fundamental forces, e.g., monetary or financial, that give rise to the haircut premium.

The idea that the haircut premium relates to binding constraints and a monetary convenience yield has implications for our understanding of the formation of asset prices. An application that is close to our setting is that of differential government-bond yields in the euro area. Jiang, Lustig, Van Nieuwerburgh, and Xialoan (2021) show that yield spreads relative to Germany are not fully explained by default risk and that the resulting difference, the overall convenience yield, correlates with fiscal conditions. Given a home bias in government-bond holdings and segmentation in the euro area, our findings suggest that country-specific monetary constraints affect government-bond yields and, thus, contribute to the overall convenience yields observed in the data. Investigating this would be another interesting avenue for future research.

Along similar lines, our finding that there is a yield differential between same-country government bonds with different haircuts, and that at least some of this is due to the haircut difference itself, suggests that differences in central-bank haircuts between government bonds and other assets may contribute to observed yield spreads. Theoretically, the haircut premium depends on the tightness of constraints, which may fluctuate over time (for example as discussed by Gârleanu and Pedersen, 2011, in their leverage-constraint driven model). This may be relevant, for example, with respect to the liquidity premium in US Treasury securities (Longstaff, 2004), which is typically viewed as relating to the "moneyness" of these securities in the sense that they are very safe and highly liquid (Krishnamurthy and Vissing-Jorgensen, 2012; Greenwood, Hanson, Stein; 2015; and Nagel, 2016). Our findings raise the possibility that the premium could also relate to Treasury securities having a favored status with respect to convertibility into reserves.

While our focus in this paper is on government bonds, banks can also use covered and unsecured bonds issued by banks, corporate bonds, and asset-backed securities in Eurosystem repos. To more fully understand the scope of collateral policy to affect asset prices, an important agenda for further research is to expand the analysis in this paper to other asset classes and settings.

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Table 1: Haircuts on zero- and fixed-coupon central-government bonds.

This table details the mapping between rating categories and Eurosystem haircuts given security-specific information such as coupon type and residual maturity for eligible zero- and fixed-coupon central-government securities on the public list of eligible collateral over the period April 9, 2010 to May 25, 2017. All ratings in this table are given on the S&P long-term rating scale. Bonds assigned a rating below BBB− are not eligible, unless specifically exempt (see Panel B). Panel A shows regular haircuts by rating category. Bonds in rating category 1 (2) have a rating in the AAA to A− (BBB+ to BBB−) range and receive lower (higher) haircuts, ceteris paribus. Panel B provides extraordinary haircuts applied to securities temporarily exempt from Eurosystem minimum rating rule requirements (no rating at BBB− or higher, relevant for Greece and Cyprus). Panel C provides additional haircuts for securities denominated in foreign currency, which also received temporary eligibility status. Notes: (1)Rating rules exemptions were also in place in Portugal and Ireland but not with extraordinary haircuts. For Greece and Cyprus rating rules exemptions were temporarily suspended at various points in time (Nyborg, 2017, Subsections 5.4, 6.2, and A.5, and references therein). (2)From Jan. 1, 2011 to Nov. 8, 2012 assets denominated in yen, pound sterling, and US dollars are not eligible. Sources: Nyborg (2017, Subsections 5.3, 5.4, and A.3, and, in particular, Tables 5.2, 5.3, 5.4, 5.5, and A.2) and ECB collateral framework references therein, as well as ECB (2016a, 2016b, and 2016c).

	Coupon type	Residual maturity (years)						Residual maturity (years)					
		0-1	1-3	3-5	5-7	7-10	>10	0-1	1-3	3-5	5-7	7-10	>10
Panel A: Regular haircuts													
Rating		**Apr. 8, 2010 – Sep. 30, 2013**						**Oct. 1, 2013 – May 25, 2017**					
AAA to A−	Fixed	0.5	1.5	2.5	3.0	4.0	5.5	0.5	1.0	1.5	2.0	3.0	5.0
(Category 1)	Zero	0.5	1.5	3.0	3.5	4.5	8.5	0.5	2.0	2.5	3.0	4.0	7.0
BBB+ to BBB−	Fixed	5.5	6.5	7.5	8.0	9.0	10.5	6.0	7.0	9.0	10.0	11.5	13.0
(Category 2)	Zero	5.5	6.5	8.0	8.5	9.5	13.5	6.0	8.0	10.0	11.5	13.0	16.0
Panel B: Extraordinary haircuts applied to securities exempt from minimum rating rule requirements													
Exempted country		**Dec. 21, 2012 – Dec. 14, 2014(1)** **Jun. 29, 2016 – May 25, 2017(1)**						**Dec. 15, 2014 – Feb. 10, 2015(1)**					
Greece	Fixed	15.0	33.0	45.0	54.0	56.0	57.0	6.5	11.0	16.5	23.0	34.0	40.0
	Zero	15.0	35.5	48.5	58.5	62.0	71.0	6.5	12.0	18.0	26.0	39.5	52.5
		May 9, 2013 – Mar. 31, 2016(1)											
Cyprus	Fixed	14.5	27.5	37.5	41.0	47.5	57.0						
	Zero	14.5	29.5	40.0	45.0	52.5	71.0						
Panel C: Additional haircuts applied to assets denominated in foreign currency													
		Apr. 8, 2010 – Dec. 31, 2010(2)						**Nov. 9, 2012 – May 25, 2017**					
Currency		Add additional haircut to regular (or extraordinary) haircut						Apply additional haircut as valuation markdown before regular (or extra-ordinary) haircut					
GBP and USD		8.0						16.0					
JPY		8.0						26.0					

Table 2: Agency rating scales and Eurosystem rating categories.

This table shows the correspondence between ratings from the four official rating agencies, namely, Moody's, Standard&Poors' (S&P), Fitch, and DBRS, and their relation to Eurosystem rating categories. The horizontal dashed line that starts in the DBRS column beneath DBRS' rating BBB refers to an ECB collateral framework update on April 1, 2014 (Nyborg, 2017, Sections 6.1 and 6.2, and, in particular, Table 6.1, Panel E, and ECB collateral framework references therein). Previously, the eligibility threshold based on DBRS ratings was BBB. On April 1, 2014, the eligibility threshold for DBRS ratings moved one notch down to BBBL. Sources: S&P, Moody's, Fitch, and DBRS webpages and Nyborg (2017, Subsections 5.3, 5.4, and A.3, and, in particular, Tables 5.2, 5.3, 5.4, 5.5, and A.2) and ECB collateral framework references therein, as well as ECB (2016a, 2016b, and 2016c).

Long-term rating scales			Eurosystem	Eurosystem
Moody's	S&P and Fitch	DBRS	rating category	haircut
Aaa	AAA	AAA		
Aa1	AA+	AAH		
Aa2	AA	AA		
Aa3	AA−	AAL	1	low
A1	A+	AH		
A2	A	A		
A3	A−	AL		
Baa1	BBB+	BBBH		
Baa2	BBB	BBB	2	high
Baa3	BBB−	BBBL		
Ba1	BB+	BBH		
Ba2	BB	BB		
Ba3	BB−	BBL		
B1	B+	BH		
B2	B	B		
B3	B−	BL	not	
Caa1	CCC+	CCCH	eligible	−
Caa2	CCC	CCC		
Caa3	CCC−	CCCL		
Ca	CC	CC		
C	C	C		
−	D	D		

Table 3: Haircut inconsistencies and yield differentials: Two examples.

This table shows two pairs of eligible Spanish zero-coupon government bonds that mature on the same date, but have different haircuts, as seen in the public list of eligible collateral for June 16, 2014. The table also provides the following information valid on this date (from Bloomberg): (1) the ratings from all four official rating agencies for all four securities (issue ratings) as well as for Spain (country rating), and (2) the securities' end-of-day yields. In Example 1, both securities mature on January 31, 2015, and in Example 2 they mature on January 31, 2018. The ratings rule in place on June 16, 2014 for government bonds is as follows: Each security is assigned a "collateral framework rating" (for the purpose of determining the haircut) equal to the highest issue rating, alternatively, if there is no issue rating, the highest country rating is chosen. For each security, the resulting rating is indicated in boldface. The rating categories in Column 4 are given in terms of the S&P scale. Data sources: Bond maturities and haircuts are from the public list of eligible collateral published on Friday, June 13, 2014, applying on Monday, June 16, 2014. Rating and yield data is from Bloomberg.

ISIN	Maturity	Haircut (in %)	Rating category	Yield (in %)	Rating agency	Issue rating	Country rating
Panel A: Example 1							
ES00000120C3	Jan. 31, 2015	0.5	1	0.205	S&P	–	BBB
			(AAA to A–)		Fitch	–	BBB+
					Moody's	–	Baa2
					DBRS	**AL**	AL
ES0000011892	Jan. 31, 2015	6.0	2	0.284	S&P	–	BBB
			(BBB+ to BBB–)		Fitch	**BBB+**	BBB+
					Moody's	–	Baa2
					DBRS	–	AL
Panel B: Example 2							
ES00000123V7	Jan. 31, 2018	2.5	1	1.108	S&P	–	BBB
			(AAA to A–)		Fitch	–	BBB+
					Moody's	–	Baa2
					DBRS	–	**AL**
ES0000011926	Jan. 31, 2018	10.0	2	1.283	S&P	–	BBB
			(BBB+ to BBB–)		Fitch	**BBB+**	BBB+
					Moody's	–	Baa2
					DBRS	–	AL

Table 4: Incidence of haircut inconsistencies across countries.

This table provides an overview of the incidence of haircut inconsistencies across countries. A haircut inconsistency occurs if, on a given day, there are same-country central-government bonds in different rating categories. Rating category 1 (2) refers to securities with a rating in the AAA to A− (BBB+ to BBB−) range (on the S&P scale). This table counts all days and securities involved in haircut inconsistencies. Panel A does this for the full sample, and Panel B does it for the sub-sample of securities with market prices. The first column shows, by country, the number of sample days with haircut inconsistencies. The second column provides, by country, the total number of involved securities across those days. The three blocks to the right provide summary statistics of the involved securities across haircut-inconsistency days in both rating categories, combined and separately.

Country	Days	Securities	Distribution of securites over haircut-inconsistency days								
			Rating categories 1 and 2			Rating category 1			Rating category 2		
			Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Panel A: Full Sample											
Cyprus	40	55	54.5	54	55	9.9	1	52	44.6	2	54
Greece	46	77	70.5	67	74	67.2	4	72	3.3	2	63
Hungary	97	13	12.3	12	13	1.0	1	1	11.3	11	12
Ireland	198	35	18.2	12	22	16.5	11	20	1.7	1	3
Italy	351	537	408.8	367	465	293.8	255	343	115.0	105	124
Latvia	16	30	28.3	27	29	8.4	4	10	19.9	19	24
Portugal	1	28	28.0	28	28	16.0	16	16	12.0	12	12
Slovenia	423	89	34.8	23	42	21.9	17	28	12.9	1	19
Spain	449	277	175.7	153	210	159.2	137	188	16.5	1	25
TOTAL	1,621	1,141									
Panel B: Sub-sample with market prices											
Cyprus	33	5	4.1	3	5	1.5	1	4	2.6	1	4
Greece	1	13	13.0	13	13	1.0	1	1	12.0	12	12
Hungary	97	13	12.0	9	13	1.0	1	1	11.0	8	12
Ireland	194	23	10.7	9	12	9.0	8	9	1.7	1	3
Italy	345	250	172.0	159	192	103.3	91	116	68.8	53	78
Latvia	16	23	19.9	7	23	6.7	3	7	13.3	1	17
Portugal	1	24	24.0	24	24	15.0	15	15	9.0	9	9
Slovenia	14	18	13.4	11	16	11.4	9	14	2.0	2	2
Spain	441	220	142.5	58	154	126.4	49	149	16.1	1	25
TOTAL	1,142	589									

Table 5: Summary statistics.

This table shows summary statistics on the final samples of zero-coupon bonds with market prices for Italy (Panel A) and Spain (Panel B) for two subperiods, namely, (i) first mass correction date to the day before the second mass correction date, and (ii) the second mass correction date to the last day before the implementation of haircut harmonization. For each country and subperiod, statistics are reported on the following variables for each rating category across days (bond-days with stale prices are dropped): Number of bonds, average residual maturity, shortest residual maturity, longest residual maturity, and maturity range. In addition, the table also reports statistics on the population of daily differences in average yields between rating category 1 and category 2 bonds in two different ways, namely, (1) unadjusted: the raw difference between average yields of rating category 2 and 1 bonds, and (2) adjusted for Eurosystem maturity buckets: first, for each day, average yields of bonds in each rating category within each maturity bucket (see Table 1), second, for each rating category, average across these maturity-bucket means, and, third, take the difference between the resulting rating category 2 and category 1 mean yields. For the yield differences, the table provides two-sided t-tests with a, b, and c indicating significance at the levels of 1%, 5%, and 10%, respectively.

		Mean	Med	SD	SE	Min	Max	Mean	Med	SD	SE	Min	Max
Panel A: Italy		August 9, 2013 to March 31, 2014						April 1, 2014 to December 12, 2014					
Number of bonds	Rating category 1	46.81	47.00	1.81	0.14	41.00	51.00	31.61	30.00	4.90	0.36	28.00	52.00
	2	60.42	61.00	2.19	0.17	53.00	63.00	74.37	75.00	1.76	0.13	70.00	78.00
Yield diff. (RC2−RC1) [pps]	Unadjusted	2.006^a	2.017	0.114	0.009	1.726	2.190	0.491^a	0.558	0.230	0.017	-0.359	0.744
	Maturity adjusted	0.084^a	0.062	0.052	0.004	0.012	0.193	0.028^a	0.028	0.030	0.002	-0.034	0.076
Average resid. mat. [years]	Rating category 1	5.12	5.13	0.13	0.01	4.59	5.49	7.71	7.35	1.23	0.09	6.95	12.44
	2	12.12	12.14	0.15	0.01	11.70	12.57	9.53	9.52	0.20	0.01	9.11	10.11
Shortest resid. mat. [years]	Rating category 1	0.05	0.05	0.02	0.00	0.03	0.12	0.13	0.13	0.07	0.01	0.03	0.44
	2	0.17	0.16	0.11	0.01	0.03	0.72	0.07	0.06	0.03	0.00	0.03	0.16
Longest resid. mat. [years]	Rating category 1	25.61	25.66	0.40	0.03	23.04	25.98	26.05	25.13	1.97	0.15	24.64	29.96
	2	25.16	25.17	0.19	0.01	24.84	25.48	24.48	24.48	0.20	0.02	24.06	24.84
Maturity range	Rating category 1	25.56	25.63	0.40	0.03	23.00	25.92	25.92	25.00	1.97	0.15	24.58	29.92
(longest−shortest)	2	24.99	25.00	0.23	0.02	24.25	25.25	24.41	24.39	0.21	0.02	24.00	24.80
Number of days		164						181					
Panel B: Spain		June 3, 2013 to March 31, 2014						April 1, 2014 to December 12, 2014					
Number of bonds	Rating category 1	31.83	33.00	3.28	0.23	23.00	37.00	19.93	20.00	1.74	0.13	15.00	24.00
	2	8.68	9.00	0.94	0.06	6.00	10.00	16.56	17.00	1.20	0.09	13.00	19.00
Yield diff. (RC2−RC1) [pps]	Unadjusted	0.521^a	0.532	0.120	0.008	0.115	0.722	-0.136^a	-0.136	0.049	0.004	-0.253	-0.049
	Maturity adjusted	0.186^a	0.165	0.128	0.009	-0.365	0.378	0.055^a	0.052	0.042	0.003	-0.196	0.110
Average resid. mat. [years]	Rating category 1	1.45	1.47	0.14	0.01	1.12	1.68	1.72	1.71	0.09	0.01	1.49	2.00
	2	2.08	2.10	0.16	0.01	1.33	2.36	1.00	0.99	0.08	0.01	0.60	1.16
Shortest resid. mat. [years]	Rating category 1	0.07	0.07	0.03	0.00	0.03	0.18	0.14	0.13	0.08	0.01	0.03	0.39
	2	0.30	0.33	0.17	0.01	0.03	0.99	0.10	0.09	0.05	0.00	0.03	0.27
Longest resid. mat. [years]	Rating category 1	4.03	4.00	0.22	0.01	3.50	4.41	3.48	3.48	0.21	0.02	2.89	3.84
	2	4.22	4.25	0.33	0.02	2.58	4.66	3.46	3.47	0.28	0.02	1.64	3.84
Maturity range	Rating category 1	3.96	3.94	0.22	0.02	3.44	4.36	3.34	3.25	0.25	0.02	2.75	3.79
(longest−shortest)	2	3.92	4.00	0.38	0.03	2.49	4.51	3.36	3.37	0.28	0.02	1.52	3.71
Number of days		211						181					

Table 6: Average spot curve difference between rating categories 1 and 2.

This table shows the results from the following specification, run using the Fama-MacBeth procedure on the final samples of 177 Italian and 72 Spanish zero-coupon bonds with market prices, individually for each country: $yield_{it} = \mathbf{\Gamma}_1' \ \mathbf{Mat}_{it} + \mathbf{\Gamma}_2' \ \mathbf{Mat}_{it} \ \mathbb{1}_{RC2,it} + \varepsilon_{it}$, where $\mathbf{Mat}_{it}' = [1 \quad x_{it} \quad x_{it}^2 \quad x_{it}^3]$, x_{it} is the residual time-to-maturity of bond i on day t, and $\mathbb{1}_{RC2,it}$ is an indicator variable that is one if bond i is in rating category 2 on day t and zero otherwise. $\mathbf{\Gamma}_j$, $i = 1, 2$ are vectors of coefficients, with $\mathbf{\Gamma}_2$ being the main vector of interest. "RC" stands for rating category. Panels A and B provide results for the Italian and Spanish samples, respectively, over the respective haircut inconsistency periods from August 9 and June 3, 2013 to December 12, 2014 (bond-dates with stale prices are excluded). t-statistics are in parentheses underneath the coefficients and are based on Newey-West standard errors with five lags (the fourth root of the number of sample days, rounded up to the nearest integer, Greene, 2008). a, b, and c denote significance (two-sided) at the levels of 1%, 5%, and 10%, respectively. Coefficients that are statistically significant at the 10%-level or better are marked in bold. The adjusted R^2 is provided as an average of the individual cross-sectional regressions in step 1 of the Fama-MacBeth procedure. The average, minimum, and maximum number of bonds across sample days are included as well as the number of bond-day observations.

	Fama-MacBeth regressions					
	Panel A: Italy			*Panel B: Spain*		
	August 9, 2013 to December 12, 2014			June 3, 2013 to December 12, 2014		
Constant	**0.152**^{a}			**0.180**^{a}		
	(10.20)			(14.35)		
Maturity	**0.475**^{a}			**0.592**^{a}		
	(22.76)			(10.73)		
Maturity^2	**-0.017**^{a}			**-0.085**^{a}		
	(-10.05)			(-5.42)		
Maturity^3	**0.000**^{a}			**0.014**^{a}		
	(4.92)			(6.79)		
$\mathbb{1}_{RC2}$	**0.060**^{a}			**0.103**^{a}		
	(4.75)			(6.49)		
$\mathbb{1}_{RC2}$×Maturity	0.002			**-0.081**^{a}		
	(0.30)			(-3.65)		
$\mathbb{1}_{RC2}$×Maturity^2	-0.000			**0.052**^{a}		
	(-0.35)			(4.85)		
$\mathbb{1}_{RC2}$×Maturity^3	0.000			**-0.007**^{a}		
	(0.30)			(-4.25)		
Number of days	345			392		
Average adjusted R-squared	0.9959			0.9727		
Number of bonds and observations	All	RC 1	RC 2	All	RC 1	RC 2
Mean number of bonds	106.58	38.84	67.74	38.66	26.33	12.32
Min number of bonds	98	28	53	30	15	6
Max number of bonds	126	52	78	47	37	19
Number of observations	36,769	13,399	23,370	15,153	10,323	4,830

Table 7: Overview on the number of bonds by country and event in the DiD analysis.

This table provides an overview on the number of control and treated bonds in the DiD analysis for each country and each event date. Panel A is for Italy and Panel B for Spain. Each panel provides the number and percentage of control and treated bonds by maturity bucket for the ten-day event window for each of the four events and the change when going to the twenty-day window. All bonds are zero-coupon and have non-stale market prices each day in the respective event windows. For the second event (haircut update), we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013).

	Control			Treated			Control			Treated		
	10d	in %	Δ 20d	10d	in %	Δ 20d	10d	in %	Δ 20d	10d	in %	Δ 20d
Panel A: Italy	Divergence 1: August 9, 2013						Haircut update: October 1, 2013					
By maturity bucket (in years): 0-1	15	38.5	-2	3	4.9		15	36.6	-2	3	4.8	-1
1-3	6	15.4		4	6.6		6	14.6		4	6.5	
3-5	5	12.8		2	3.3		6	14.6		2	3.2	
5-7	2	5.1		5	8.2		2	4.9		6	9.7	
7-10	2	5.1		9	14.8		3	7.3		9	14.5	
10-15	3	7.7		16	26.2		3	7.3		16	25.8	
15-20	3	7.7		13	21.3		3	7.3		13	21.0	
>20	3	7.7		9	14.8		3	7.3		9	14.5	-1
Total	39	100.0	-2	61	100.0	0	41	100.0	-2	62	100.0	-2
	Harmon. announcement: September 1, 2014						Harmon. implementation: December 15, 2014					
By maturity bucket (in years): 0-1	5	17.2	-1	11	16.4	-2	4	14.3	-1	14	20.3	-5
1-3	7	24.1		3	4.5		8	28.6		3	4.3	-1
3-5	4	13.8		4	6.0		3	10.7		5	7.2	-1
5-7	2	6.9		6	9.0		2	7.1		6	8.7	
7-10	3	10.3		7	10.4		3	10.7		7	10.1	-2
10-15	2	6.9		18	26.9		3	10.7		16	23.2	-2
15-20	4	13.8		10	14.9		3	10.7		10	14.5	
>20	2	6.9		8	11.9		2	7.1		8	11.6	-1
Total	29	100.0	-1	67	100.0	-2	28	100.0	-1	69	100.0	-12
Panel B: Spain	Divergence 1: June 3, 2013						Haircut update: October 1, 2013					
By maturity bucket (in years): 0-1	17	50.0	-4	2	25.0		11	39.3	-1	2	22.2	
1-3	11	32.4		5	62.5		10	35.7		5	55.6	
3-5	6	17.6	-1	1	12.5		7	25.0		2	22.2	
Total	34	100.0	-5	8	100.0	0	28	100.0	-1	9	100.0	0
	Harmon. announcement: September 1, 2014						Harmon. implementation: December 15, 2014					
By maturity bucket (in years): 0-1	5	27.8		9	69.2		7	33.3		11	73.3	-1
1-3	11	61.1		3	23.1		13	61.9	-1	3	20.0	
3-5	2	11.1		1	7.7		1	4.8		1	6.7	
Total	18	100.0	0	13	100.0	0	21	100.0	-1	15	100.0	-1

Table 8: Estimated treatment effects using the cubic, parallel-shift yield-curve specification.

This table provides estimated treatment effects (in pps) for each event and country using the following DiD specification: $yield_{it} = \mathbf{\Gamma}'\ \mathbf{Mat}_{it} + \alpha\ \mathbb{1}_{Treated,i} + \delta\ \mathbb{1}_{Post,t} + \beta_{DiD}\ \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} + \varepsilon_{it}$, where $\mathbb{1}_{Treated,i}$ is an indicator variable that is one for treated bonds and zero otherwise, and $\mathbb{1}_{Post,t}$ is an indicator variable that is one for the event and post-event dates and zero otherwise. α and δ are the corresponding coefficients. β_{DiD} is the DiD estimator. The rest of the notation is as in Table 6 so that $\mathbf{\Gamma}'\mathbf{Mat}_{it}$ represents a polynomial of degree three. The specification is run with OLS individually for Italy and Spain for each event date using the samples of zero-coupon bonds with non-stale market prices each day in the respective event windows discussed in Table 7. Panels A to D show, in that order, the results for the first divergence dates in Italy (August 9, 2013) and Spain (June 3, 2013), the haircut update on October 1, 2013, haircut harmonization announcement on September 1, 2014, and harmonization implementation on December 15, 2014. In Panel B, we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013). t-statistics, shown below the DiD coefficients, are based on standard errors clustered at the individual bond level. a, b, and c denote significance (two-sided) at the levels of 1%, 5%, and 10%, respectively. Coefficients that are statistically significant at the 10%-level or better are marked in bold.

	Italy		Spain	
	Window (business days)		Window (business days)	
	10 days	20 days	10 days	20 days
Panel A: First divergence (August 9, 2013 in Italy; June 3, 2013 in Spain)				
DiD	-0.003	-0.006	$\mathbf{0.037^b}$	0.044
	(-0.54)	(-0.85)	(2.45)	(1.54)
Num. treated bonds/obs.	61/610	61/1,220	8/80	8/160
Num. control bonds/obs.	39/390	37/740	34/340	29/580
Adjusted R-squared	0.9955	0.9945	0.9894	0.9800
Panel B: Haircut update (October 1, 2013)				
DiD	$\mathbf{0.023^a}$	$\mathbf{0.019^b}$	0.021	0.013
	(3.36)	(2.35)	(1.06)	(0.61)
Num. treated bonds/obs.	62/620	60/1,200	9/90	9/180
Num. control bonds/obs.	41/410	39/780	28/280	27/540
Adjusted R-squared	0.9957	0.9940	0.9835	0.9791
Panel C: Harmonization announcement (September 1, 2014)				
DiD	$\mathbf{-0.011^b}$	$\mathbf{-0.024^b}$	-0.003	-0.007
	(-2.01)	(-2.39)	(-0.69)	(-1.30)
Num. treated bonds/obs.	67/670	65/1,300	13/130	13/260
Num. control bonds/obs.	29/290	28/560	18/180	18/360
Adjusted R-squared	0.9932	0.9918	0.9188	0.9297
Panel D: Harmonization implementation (December 15, 2014)				
DiD	$\mathbf{-0.027^a}$	$\mathbf{-0.033^a}$	$\mathbf{-0.014^b}$	$\mathbf{-0.020^b}$
	(-2.95)	(-2.83)	(-2.11)	(-2.58)
Num. treated bonds/obs.	69/690	57/1,140	15/150	14/280
Num. control bonds/obs.	28/280	27/540	21/210	20/400
Adjusted R-squared	0.9955	0.9947	0.8993	0.8608

Table 9: Estimated treatment effects at selected maturities under cubic yield-curve specifications.

This table provides estimated treatment effects (in pps) at selected maturities for each event and country using the following fully-flexible DiD specification: $yield_{it} = \mathbf{\Gamma}_1' \ \mathbf{Mat}_{it} + \mathbf{\Gamma}_2' \ \mathbf{Mat}_{it} \ \mathbb{1}_{Treated,i} + \mathbf{\Gamma}_3' \ \mathbf{Mat}_{it} \ \mathbb{1}_{Post,t} + \mathbf{\Gamma}_4' \ \mathbf{Mat}_{it} \ \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} \ + \ \varepsilon_{it}$. The notation follows that in Table 8. The DiD estimator is given by the vector $\mathbf{\Gamma}_4$. The specification is run with OLS individually for Italy and Spain over the ten- and twenty-day event windows for each event date using the samples of zero-coupon bonds with non-stale market prices each day in the respective windows discussed in Table 7. Panels A to D show, in that order, the results for the first divergence dates in Italy (August 9, 2013) and Spain (June 3, 2013), the haircut update on October 1, 2013, haircut harmonization announcement on September 1, 2014, and harmonization implementation on December 15, 2014. In Panel B, we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013). Each panel provides the estimated treatment effect at selected maturities for each event window, with z-statistics (in parentheses) calculated using the delta method (with standard errors clustered on the bond-level). a, b, and c denote significance (two-sided) at the levels of 1%, 5%, and 10%, respectively. Coefficients that are statistically significant at the 10%-level or better are marked in bold. For each event, the DiD in haircuts is provided (in pps) in the column to the far right for all selected maturities. For residual maturity, x, equaling 1, 3, and 5 years, we have taken the haircut at x minus one day.

	Panel A: First divergence					*Panel B: Haircut update (Oct. 1, 2013)*				
Maturity	Italy (Aug. 9, 2013)		Spain (Jun. 3, 2013)		Haircut	Italy		Spain		Haircut
(in years)	10 days	20 days	10 days	20 days	DiD (pps)	10 days	20 days	10 days	20 days	DiD (pps)
0.5	**0.020**^{b}	**0.031**^{a}	**0.025**^{a}	**0.036**^{a}	5.0	**0.074**^{a}	**0.029**^{c}	-0.005	0.000	0.5
	(2.04)	(3.10)	(3.36)	(3.75)		(4.58)	(1.83)	(-0.39)	(0.00)	
1	**0.019**^{b}	**0.027**^{a}	**0.039**^{a}	**0.034**^{a}	5.0	**0.062**^{a}	**0.028**^{b}	0.007	0.018	0.5
	(2.34)	(3.31)	(4.82)	(4.66)		(4.49)	(2.09)	(0.64)	(1.11)	
2	**0.017**^{b}	**0.019**^{a}	**0.026**^{a}	**0.028**^{b}	5.0	**0.041**^{a}	**0.025**^{b}	**0.014**^{b}	**0.021**^{b}	1.0
	(2.58)	(3.01)	(2.76)	(2.36)		(3.85)	(2.54)	(2.16)	(2.16)	
3	**0.016**^{b}	**0.013**^{c}	0.010	-0.003	5.0	**0.024**^{b}	**0.023**^{b}	0.009	0.005	1.0
	(2.18)	(1.78)	(1.26)	(-0.28)		(2.48)	(2.51)	(1.68)	(0.62)	
5	0.013	0.002	-	-	5.0	-0.001	0.018	-	-	2.5
	(1.31)	(0.24)	-	-		(-0.07)	(1.64)	-	-	
8	0.007	-0.006	-	-	5.0	-0.016	0.012	-	-	4.0
	(0.63)	(-0.50)	-	-		(-1.30)	(0.88)	-	-	
12	-0.000	-0.010	-	-	5.0	-0.009	0.004	-	-	4.0
	(-0.04)	(-0.58)	-	-		(-0.73)	(0.40)	-	-	
16	-0.008	-0.008	-	-	5.0	0.013	0.001	-	-	4.0
	(-0.56)	(-0.39)	-	-		(1.11)	(0.18)	-	-	
20	-0.016	-0.007	-	-	5.0	**0.029**^{b}	0.005	-	-	4.0
	(-1.19)	(-0.35)	-	-		(2.57)	(0.70)	-	-	
No. treat. sec./obs.	61/610	61/1,220	8/80	8/160	Not	62/620	60/1,200	9/90	9/180	Not
No. contr. sec./obs.	39/390	37/740	34/340	29/580	applic.	41/410	39/780	28/280	27/540	applic.
Adj. R-squared	0.9962	0.9953	0.9897	0.9816		0.9962	0.9948	0.9844	0.9801	

Table 9 – *continued*

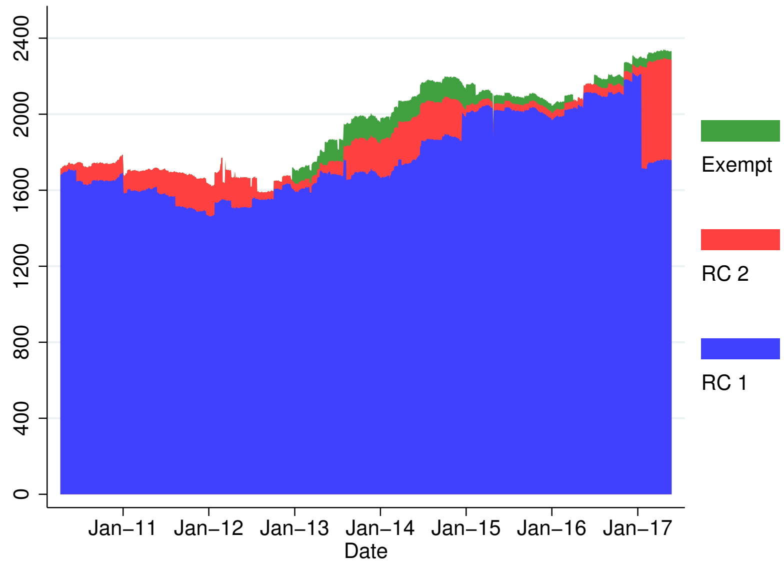
Maturity (in years)	*Panel C: Harmon. announcement (Sep. 1, 2014)* Italy 10 days	Italy 20 days	Spain 10 days	Spain 20 days	Haircut DiD (pps)	*Panel D: Harmon. implementation (Dec. 15, 2014)* Italy 10 days	Italy 20 days	Spain 10 days	Spain 20 days	Haircut DiD (pps)
0.5	**-0.016**^{a}	-0.011	**-0.013**^{b}	**-0.019**^{b}	0.0	**-0.048**^{a}	**-0.052**^{a}	0.002	-0.004	−5.5
	(-2.80)	(-1.36)	(-2.23)	(-2.14)		(-2.70)	(-2.77)	(0.27)	(-0.49)	
1	**-0.015**^{a}	-0.009	-0.002	-0.006	0.0	**-0.043**^{a}	**-0.047**^{a}	0.010	0.008	−5.5
	(-3.21)	(-1.52)	(-0.31)	(-0.68)		(-2.94)	(-2.93)	(1.19)	(0.77)	
2	**-0.013**^{a}	-0.007	-0.004	-0.003	0.0	**-0.036**^{a}	**-0.037**^{a}	**-0.020**^{b}	**-0.028**^{b}	−6.0
	(-3.56)	(-1.64)	(-0.59)	(-0.50)		(-3.42)	(-3.20)	(-2.68)	(-2.09)	
3	**-0.012**^{a}	-0.005	-0.008	-0.004	0.0	**-0.029**^{a}	**-0.028**^{a}	**-0.010**^{c}	-0.010	−6.0
	(-2.85)	(-1.11)	(-0.92)	(-0.66)		(-3.55)	(-3.16)	(-2.02)	(-1.60)	
5	-0.009	-0.003	-	-	0.0	**-0.017**^{b}	**-0.016**^{c}	-	-	−7.5
	(-1.55)	(-0.39)	-	-		(-2.16)	(-1.89)	-	-	
8	-0.006	-0.002	-	-	0.0	-0.006	-0.005	-	-	−9.0
	(-0.87)	(-0.18)	-	-		(-0.64)	(-0.54)	-	-	
12	-0.004	-0.003	-	-	0.0	0.003	0.000	-	-	−9.0
	(-0.56)	(-0.27)	-	-		(0.35)	(0.04)	-	-	
16	-0.003	-0.005	-	-	0.0	0.006	0.002	-	-	−9.0
	(-0.40)	(-0.46)	-	-		(0.61)	(0.16)	-	-	
20	-0.002	-0.006	-	-	0.0	0.008	0.008	-	-	−9.0
	(-0.28)	(-0.59)	-	-		(0.79)	(0.62)	-	-	
No. treat. sec./obs.	67/670	65/1,300	13/130	13/260	Not	69/690	57/1,140	15/150	14/280	Not
No. contr. sec./obs.	29/290	28/560	18/180	18/360	applic.	28/280	27/540	21/210	20/400	applic.
Adj. R-squared	0.9933	0.9921	0.9257	0.9388		0.9960	0.9953	0.9146	0.8774	

Table 10: Estimated treatment effects at selected maturities under Diebold-Li (2006) yield-curve specifications. This table provides estimated treatment effects (in pps) at selected maturities for each event and country using the following fully-flexible DiD specification: $yield_{it} = \mathbf{B}_1' \, \mathbf{L}_{it} + \mathbf{B}_2' \, \mathbf{L}_{it} \, \mathbb{1}_{Treated,i} + \mathbf{B}_3' \, \mathbf{L}_{it} \, \mathbb{1}_{Post,t} + \mathbf{B}_4' \, \mathbf{L}_{it} \, \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} + \varepsilon_{it}$, where $\mathbf{L}_{it}$ is a three dimensional vector of regressors with elements: 1, $l_1(x_{it};\lambda)$, and $l_2(x_{it};\lambda)$, where $l_{1,t}(x_{it};\lambda) = \left(1 - e^{-\lambda x_{it}}\right)/(\lambda x_{it})$ and $l_{2,t}(x_{it};\lambda) = \left(1 - e^{-\lambda x_{it}}\right)/(\lambda x_{it}) - e^{-\lambda x_{it}}$, x_{it} is the residual time-to-maturity of bond i at date t, and λ is the decay parameter. $\mathbf{B}_j$, $j = 1, \ldots 4$, are the corresponding three-dimensional vectors of coefficients. The DiD estimator is given by the vector $\mathbf{B}_4$. The rest of the notation follows that in Table 8. For each event, the model is estimated with OLS over ten- and twenty-day event-windows on the Italian sample of zero-coupon bonds with non-stale market prices each day over the respective windows discussed in Table 7 and for two separate values of λ. These are, first, $\lambda = 0.7308$ (the "Diebold-Li lambda") and, second, estimated individually for each event and window as an average across daily estimates, using nonlinear least squares, for both rating categories. Panels A to D show, in that order, the results for the first divergence dates in Italy (August 9, 2013) and Spain (June 3, 2013), the haircut update on October 1, 2013, haircut harmonization announcement on September 1, 2014, and harmonization implementation on December 15, 2014. In Panel B, we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013). Each panel provides the estimated treatment effect at selected maturities for each event window and value for λ, with z-statistics (in parentheses) calculated using the delta method (with standard errors clustered on the bond-level). a, b, and c denote significance (two-sided) at the levels of 1%, 5%, and 10%, respectively. Coefficients that are statistically significant at the 10%-level or better are marked in bold. Values for λ are shown at the bottom of each panel. For each event, the DiD in haircuts is provided (in pps) in the column to the far right for all selected maturities. For residual maturity, x, equaling 1, 3, and 5 years, we have taken the haircut at x minus one day.

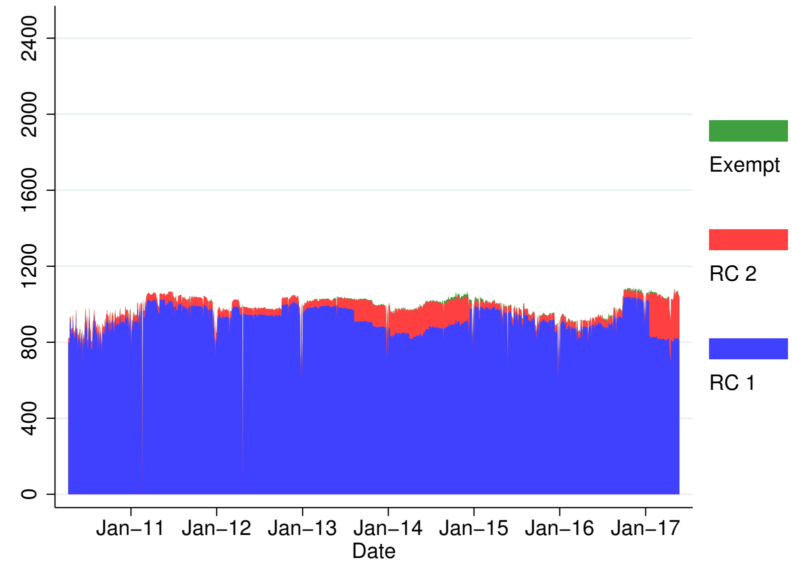
	Panel A: First divergence in Italy (Aug. 9, 2013)					*Panel B: Haircut update (Oct. 1, 2013)*				
Maturity	DL's $\lambda = 0.7308$		In-sample λ		Haircut	DL's $\lambda = 0.7308$		In-sample λ		Haircut
(in years)	10 days	20 days	10 days	20 days	DiD (pps)	10 days	20 days	10 days	20 days	DiD (pps)
0.5	0.006	**0.018**^{b}	0.008	**0.022**^{a}	5.0	**0.062**^{a}	0.025	**0.067**^{a}	0.033	0.5
	(0.75)	(2.23)	(1.02)	(2.58)		(3.91)	(0.90)	(4.17)	(1.24)	
1	**0.011**^{c}	**0.010**^{c}	**0.012**^{b}	**0.013**^{b}	5.0	**0.039**^{a}	0.018	**0.043**^{a}	0.025	0.5
	(1.77)	(1.71)	(2.11)	(2.38)		(3.33)	(1.08)	(3.64)	(1.41)	
2	**0.013**^{c}	-0.000	**0.014**^{b}	0.002	5.0	0.013	0.011	0.014	0.014	1.0
	(1.66)	(-0.01)	(1.96)	(0.32)		(1.31)	(0.98)	(1.51)	(1.33)	
3	0.011	-0.005	0.013	-0.004	5.0	0.004	0.008	0.002	0.009	1.0
	(1.37)	(-0.64)	(1.57)	(-0.48)		(0.36)	(0.67)	(0.17)	(0.83)	
5	0.005	-0.008	0.007	-0.009	5.0	0.001	0.005	-0.004	0.004	2.5
	(0.62)	(-1.11)	(0.87)	(-1.10)		(0.08)	(0.49)	(-0.47)	(0.42)	
8	-0.003	-0.009	-0.002	-0.010	5.0	0.004	0.004	0.001	0.003	4.0
	(-0.32)	(-0.85)	(-0.18)	(-0.97)		(0.66)	(0.43)	(0.12)	(0.34)	
12	-0.008	-0.009	-0.008	-0.010	5.0	0.008	0.004	0.007	0.003	4.0
	(-0.71)	(-0.64)	(-0.77)	(-0.71)		(1.10)	(0.35)	(0.97)	(0.33)	
16	-0.011	-0.009	-0.012	-0.010	5.0	0.011	0.004	0.011	0.004	4.0
	(-0.84)	(-0.56)	(-0.96)	(-0.60)		(1.23)	(0.30)	(1.31)	(0.31)	
20	-0.013	-0.009	-0.015	-0.010	5.0	0.012	0.004	0.014	0.004	4.0
	(-0.90)	(-0.52)	(-1.04)	(-0.54)		(1.28)	(0.28)	(1.46)	(0.30)	
No. treat. sec./obs.	61/610	61/1,220	61/610	61/1,220		62/620	60/1,200	62/620	60/1,200	
No. contr. sec./obs.	39/390	37/740	39/390	37/740	Not	41/410	39/780	41/410	39/780	Not
Adj. R-squared	0.9936	0.9926	0.9941	0.9929	applic.	0.9935	0.9920	0.9940	0.9925	applic.
λ	0.7308	0.7308	0.5804	0.6071		0.7308	0.7308	0.5932	0.5873	

Table 10 – *continued*

Maturity (in years)	*Panel C: Harmon. announcement (Sep. 1, 2014)* DL's $\lambda = 0.7308$ 10 days	20 days	In-sample λ 10 days	20 days	Haircut DiD (pps)	*Panel D: Harmon. implementation (Dec. 15, 2014)* DL's $\lambda = 0.7308$ 10 days	20 days	In-sample λ 10 days	20 days	Haircut DiD (pps)
0.5	**-0.021**^{b}	-0.017	**-0.016**^{b}	-0.012	0.0	**-0.032**^{a}	-0.023	**-0.044**^{a}	**-0.045**^{a}	−5.5
	(-2.50)	(-1.52)	(-2.27)	(-0.99)		(-4.06)	(-1.64)	(-2.61)	(-2.71)	
1	**-0.022**^{a}	**-0.020**^{b}	**-0.018**^{a}	**-0.016**^{c}	0.0	**-0.018**^{a}	-0.013	**-0.040**^{a}	**-0.040**^{a}	−5.5
	(-3.11)	(-2.20)	(-3.40)	(-1.93)		(-3.22)	(-1.35)	(-3.01)	(-3.06)	
2	**-0.022**^{a}	**-0.023**^{b}	**-0.021**^{a}	**-0.020**^{b}	0.0	-0.003	-0.002	**-0.032**^{a}	**-0.032**^{a}	−6.0
	(-2.66)	(-1.97)	(-3.03)	(-2.20)		(-0.54)	(-0.21)	(-3.68)	(-3.53)	
3	**-0.020**^{b}	**-0.022**^{b}	**-0.021**^{a}	**-0.022**^{c}	0.0	0.003	0.003	**-0.025**^{a}	**-0.025**^{a}	−6.0
	(-2.56)	(-2.00)	(-2.59)	(-1.90)		(0.46)	(0.40)	(-3.39)	(-3.18)	
5	**-0.016**^{b}	**-0.019**^{b}	**-0.020**^{b}	**-0.022**^{c}	0.0	0.006	0.005	**-0.016**^{c}	**-0.015**^{c}	−7.5
	(-2.52)	(-2.06)	(-2.43)	(-1.83)		(1.20)	(0.93)	(-1.88)	(-1.85)	
8	-0.012	-0.015	**-0.016**^{b}	**-0.019**^{c}	0.0	0.005	0.004	-0.007	-0.006	−9.0
	(-1.48)	(-1.21)	(-2.22)	(-1.75)		(1.41)	(1.08)	(-0.82)	(-0.82)	
12	-0.009	-0.012	-0.011	-0.014	0.0	0.004	0.003	0.000	0.000	−9.0
	(-0.84)	(-0.70)	(-1.16)	(-1.02)		(0.93)	(0.71)	(0.03)	(0.01)	
16	-0.008	-0.010	-0.008	-0.011	0.0	0.003	0.003	0.004	0.003	−9.0
	(-0.61)	(-0.52)	(-0.62)	(-0.61)		(0.62)	(0.50)	(0.64)	(0.46)	
20	-0.007	-0.009	-0.006	-0.009	0.0	0.002	0.002	0.006	0.005	−9.0
	(-0.50)	(-0.44)	(-0.38)	(-0.43)		(0.46)	(0.40)	(0.79)	(0.59)	
No. treat. sec./obs.	67/670	65/1,300	67/670	65/1,300		69/690	57/1,140	69/690	57/1,140	
No. contr. sec./obs.	29/290	28/560	29/290	28/560	Not	28/280	27/540	28/280	27/540	Not
Adj. R-squared	0.9763	0.9769	0.9964	0.9955	applicable	0.9584	0.9631	0.9962	0.9960	applicable
λ	0.7308	0.7308	0.3929	0.4060		0.7308	0.7308	0.2655	0.2857	



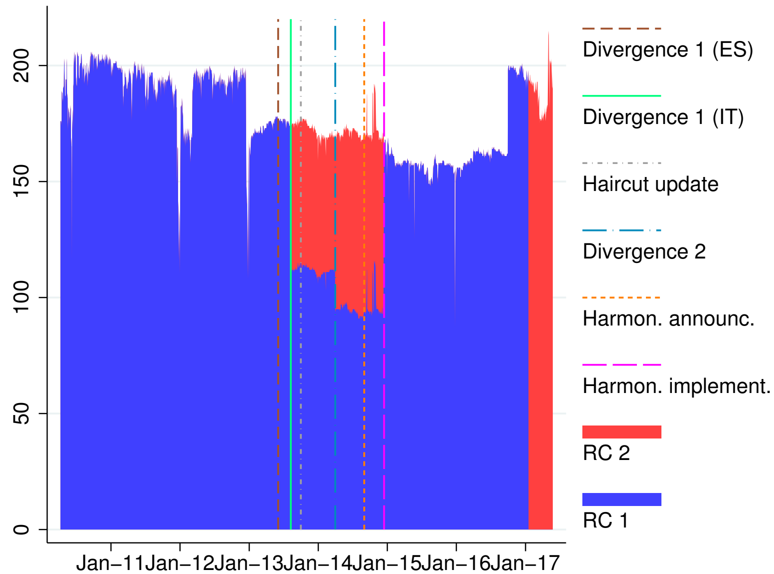
(a) Full sample. Number of bonds by rating category.



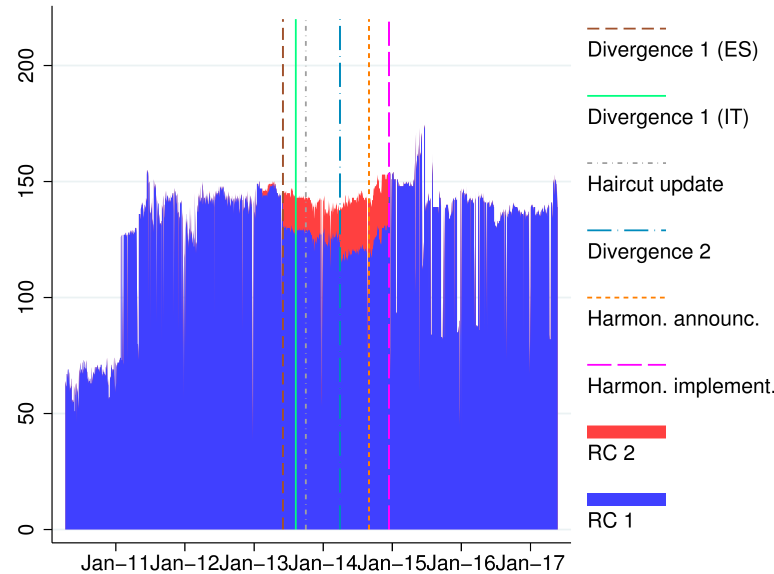
(b) Bonds with market prices. Number by rating category.

Figure 1: Daily distributions of rating categories over time for government bonds.

This figure shows the number of fixed- and zero-coupon central-government bonds by rating category over the sample period April 9, 2010 to May 25, 2017, inclusive. Subplot (a) provides these daily distributions for the full sample and Subplot (b) for the subset of securities with market prices. "RC" stands for rating category. Rating category 1 (2) refers to securities with a rating in the AAA to A− (BBB+ to BBB−) range (on the S&P scale). "Exempt" refers to securities that are exempt from standard minimum rating requirements and, at the same time, receive extraordinary haircuts (for details see Table 1, Panel B, and references there).

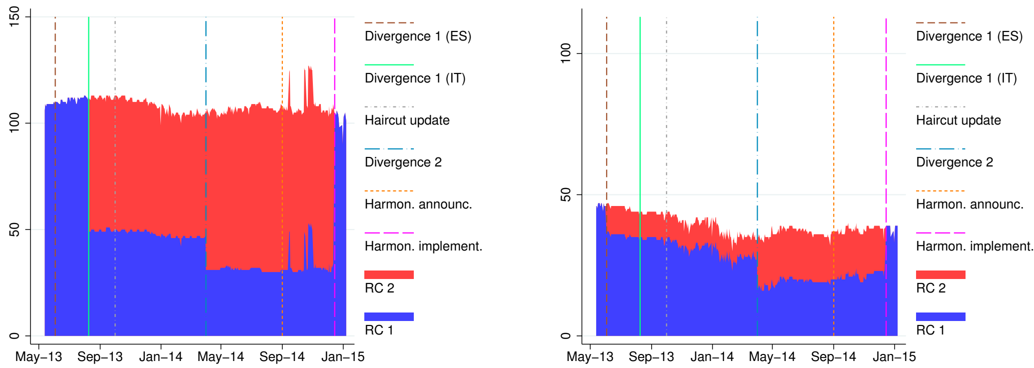


(a) Italy. Number of bonds by rating category.



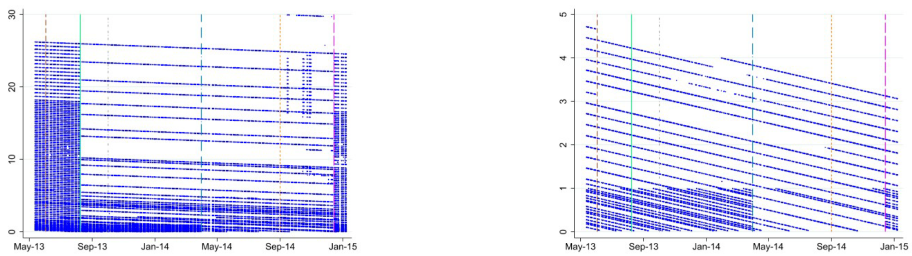
(b) Spain. Number of bonds by rating category.

Figure 2: Italy and Spain: Daily distributions of rating categories over time for government bonds with market prices. This figure shows the number of fixed- and zero-coupon central-government bonds by rating category individually for Italy and Spain over the sample period April 9, 2010 to May 25, 2017, inclusive, for the subset of central-government bonds with market prices. "RC" stands for rating category. Rating category 1 (2) refers to securities with a rating in the AAA to A− (BBB+ to BBB−) range (on the S&P scale). The vertical lines in each subplot mark the following dates (from left to right): the (brown) dashed line marks the first divergence date in Spain on June 3, 2013, the (mint-green) solid line the first divergence date in Italy on August 9, 2013, the (grey) dash-dotted line the ECB's haircut update on October 1, 2013, the (blue) longdash-dotted line the second divergence date on April 1, 2014, the (orange) shortdashed line the rating and haircut harmonization announcement on September 1, 2014, and the (magenta-colored) longdashed line the implementation of harmonization on December 15, 2014.



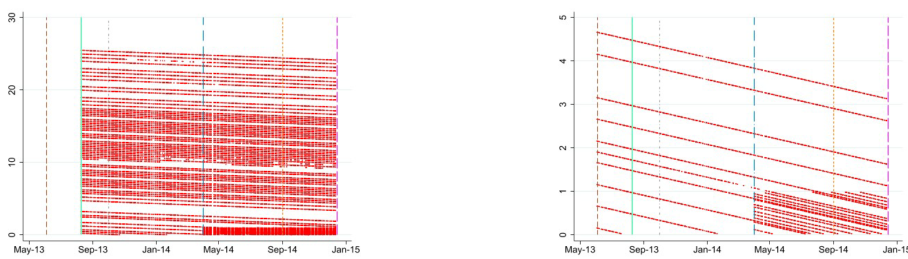
Italy Spain

(a) Number of zero-coupon bonds by rating category



Italy Spain

(b) Residual maturities for bonds in rating category 1

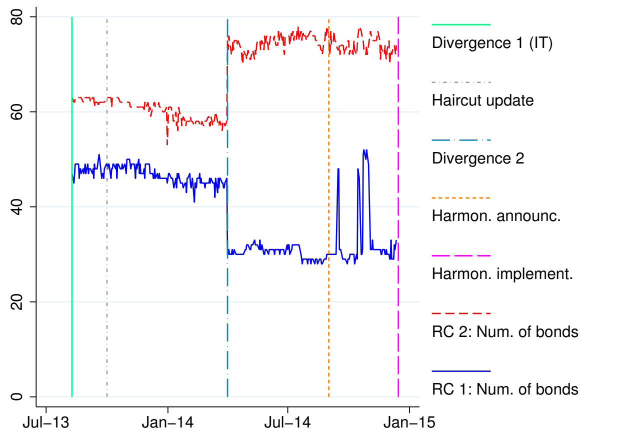


Italy Spain

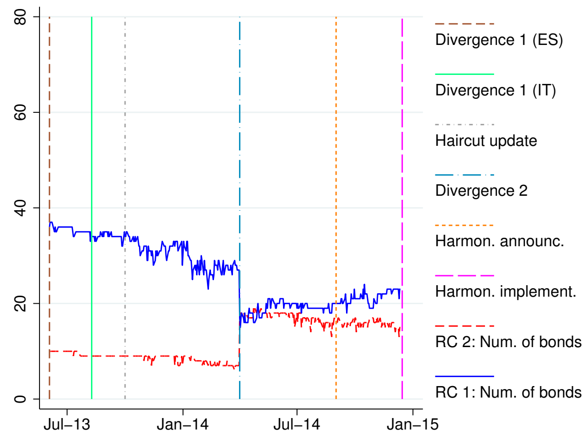
(c) Residual maturities for bonds in rating category 2

Figure 3: Italy and Spain: Daily distributions of rating categories and residual maturities over time in the final sample of zero-coupon bonds with market prices.

This figure plots the number of bonds [(a)] and residual maturities by rating category [(b) and (c)] in the final samples of Italian and Spanish zero-coupon bonds with market prices for the sample period May 13, 2013 to January 7, 2015, inclusive. "RC" stands for rating category. Rating category 1 (2) refers to securities with a rating in the AAA to A− (BBB+ to BBB−) range (on the S&P scale). The vertical lines in each subplot mark the following dates (from left to right): the (brown) dashed line marks the first divergence date in Spain on June 3, 2013, the (mint-green) solid line the first divergence date in Italy on August 9, 2013, the (grey) dash-dotted line the ECB's haircut update on October 1, 2013, the (blue) longdash-dotted line the second divergence date on April 1, 2014, the (orange) shortdashed line the rating and haircut harmonization announcement on September 1, 2014, and the (magenta-colored) longdashed line the implementation of harmonization on December 15, 2014.

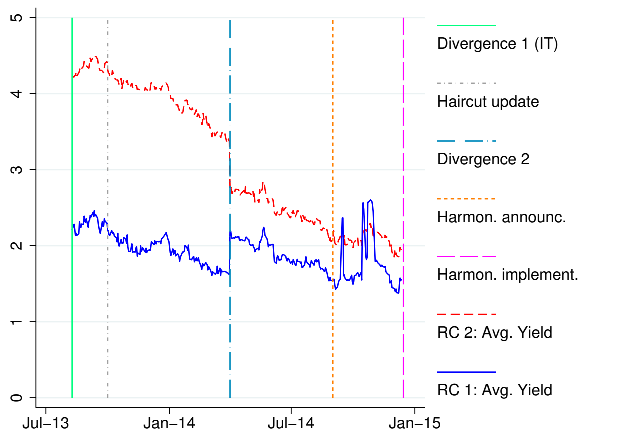


Italy

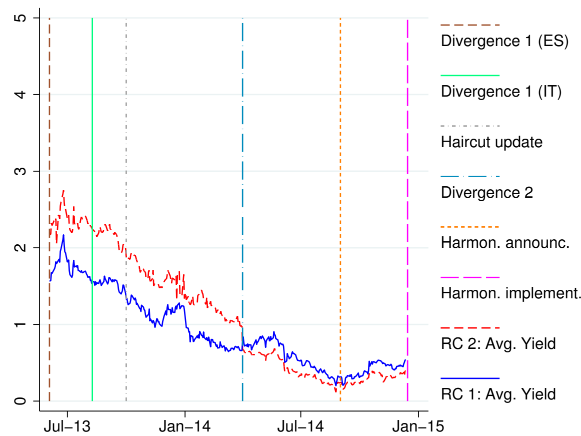


Spain

(a) Number of zero-coupon bonds by rating category

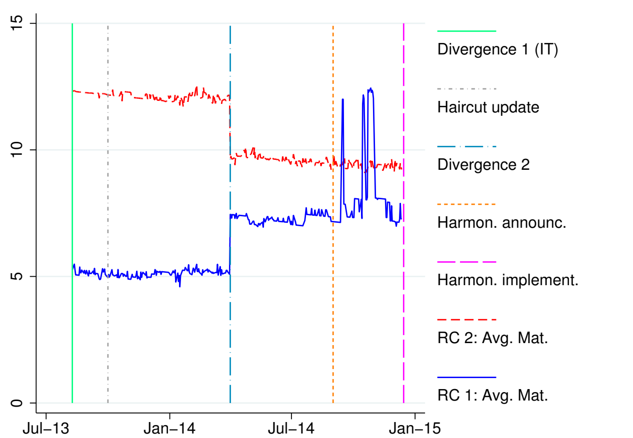


Italy

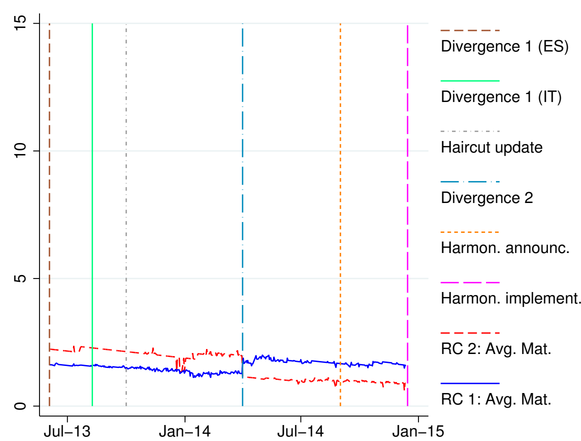


Spain

(b) Average yields (in pps) by rating category

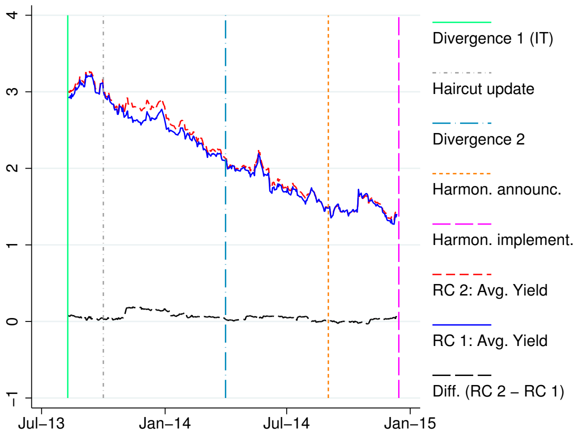


Italy

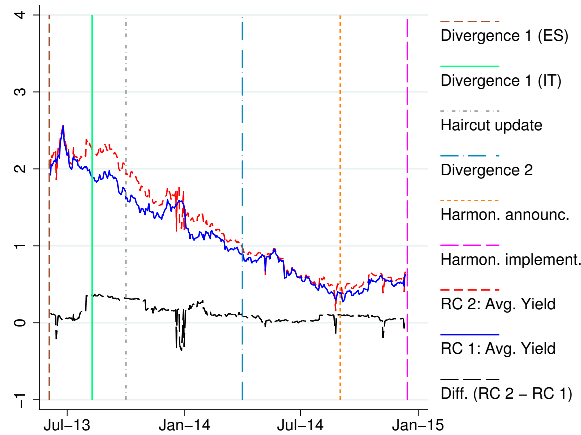


Spain

(c) Average residual maturity (in years) by rating category



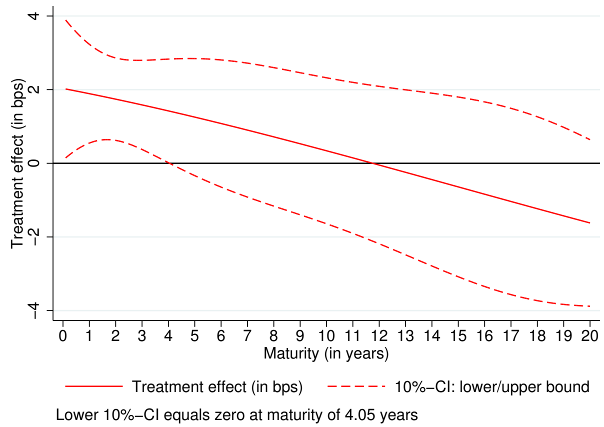
Italy



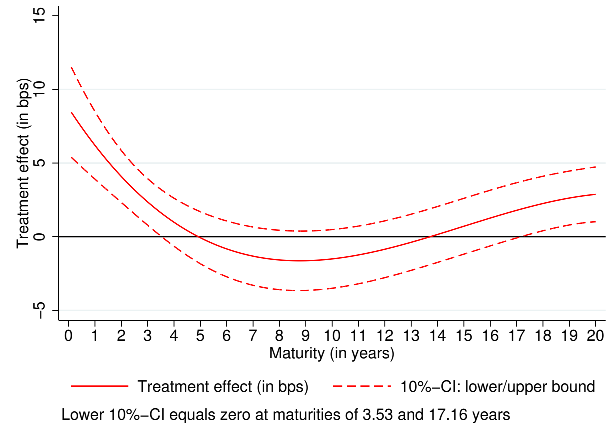
Spain

(d) Average yields (in pps) by rating category controlling for residual maturity

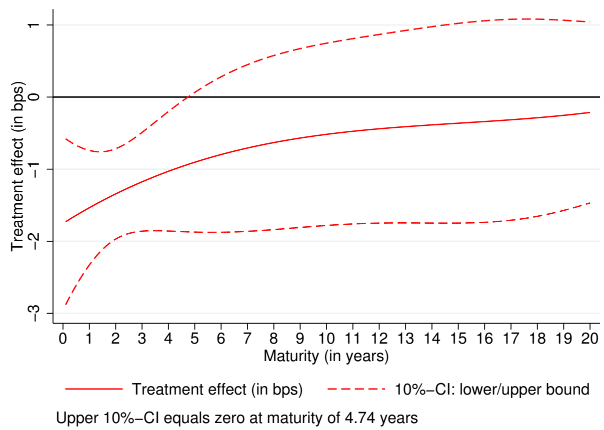
Figure 4: Italy and Spain: Comparison of bonds across rating categories over time. This figure provides time-series plots on the number of bonds in each rating category, average residual maturities, and average yields from the first divergence dates (August 9, 2013 in Italy and June 3, 2013 in Spain) to the last business day before haircut harmonization (December 12, 2014) and is based on the final samples of Italian and Spanish zero-coupon central-government bonds (bond-dates with stale prices are excluded). Plots on the left (right) are for Italy (Spain). Subplots (a) show the number of bonds in each rating category. Subplots (b) and (c) provide daily averages of yields and residual maturity, respectively, across bonds in each rating category. Subplots (d) show average yields calculated as follows: On each day, for each country and each rating category, take yield average within the ECB's maturity buckets, then take average across these maturity-bucket means. "RC" stands for rating category. In each subplot the blue, solid (red, dashed) line represents bonds in rating category 1 (2). Rating category 1 (2) refers to securities with a rating in the AAA to A− (BBB+ to BBB−) range (on the S&P scale). Subplots (d) additionally provide the yield differential between treated and control bonds calculated by subtracting the mean of controls from the mean of treated bonds (black, dotted line). The vertical lines in each subplot mark the following dates (from left to right): the (brown) dashed line marks the first divergence date in Spain on June 3, 2013 (only in the subplots for Spain, on the right), the (mint-green) solid line the first divergence date in Italy on August 9, 2013, the (grey) dash-dotted line the ECB's haircut update on October 1, 2013, the (blue) longdash-dotted line the second divergence date on April 1, 2014, the (orange) shortdashed line the rating and haircut harmonization announcement on September 1, 2014, and the (magenta-colored) longdashed line the implementation of harmonization on December 15, 2014.



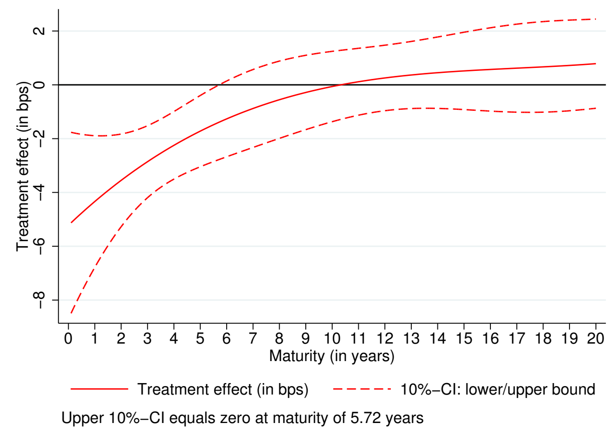
(a) First divergence (Italy)



(b) Haircut update

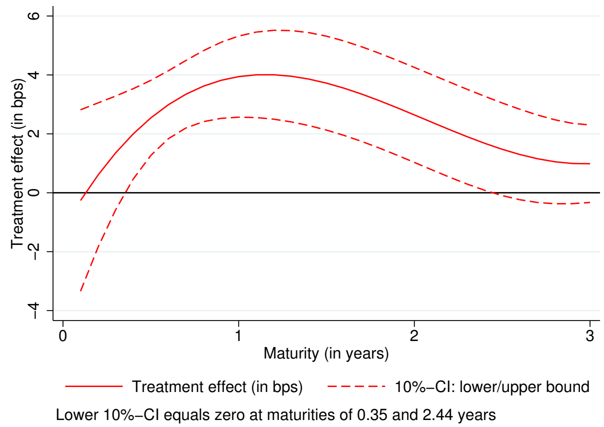


(c) Harmonization announcement

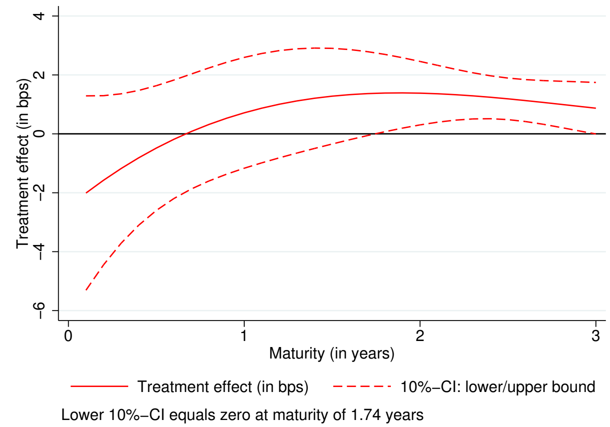


(d) Harmonization implementation

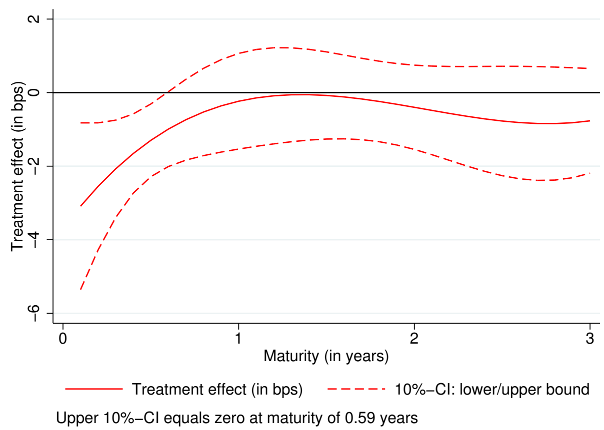
Figure 5: Estimated treatment effects along the term structure in Italy under cubic yield-curve specifications. This figure shows estimated treatment effects (in bps) along the term structure for each of our four events over ten-day windows using the samples of zero-coupon bonds with non-stale market prices for Italy (see Table 7). Estimation is based on the same fully-flexible DiD specification as in Table 9: $yield_{it} = \mathbf{\Gamma}_1' \ \mathbf{Mat}_{it} + \mathbf{\Gamma}_2' \ \mathbf{Mat}_{it} \ \mathbb{1}_{Treated,i} + \mathbf{\Gamma}_3' \ \mathbf{Mat}_{it} \ \mathbb{1}_{Post,t} + \mathbf{\Gamma}_4' \ \mathbf{Mat}_{it} \ \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} \ + \ \varepsilon_{it}$. The DiD estimator is given by the vector $\mathbf{\Gamma}_4$, estimated with OLS as $\widehat{\mathbf{\Gamma}}_4$. The estimated treatment effect at residual maturity, x, is given by the DiD delta curve, $\Delta_4(x) = \widehat{\gamma}_{0,4} + \widehat{\gamma}_{1,4}x + \widehat{\gamma}_{2,4}x^2 + \widehat{\gamma}_{3,4}x^3$, which is plotted as the solid line in each subplot. The dashed lines are 10%-level confidence intervals based on standard errors clustered on the bond-level and calculated using the delta method. Subplots (a) through (d) show, in order, the results for the first divergence date in Italy on August 9, 2013, the haircut update on October 1, 2013, haircut harmonization announcement on September 1, 2014, and harmonization implementation on December 15, 2014. In Subplot (b), we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013).



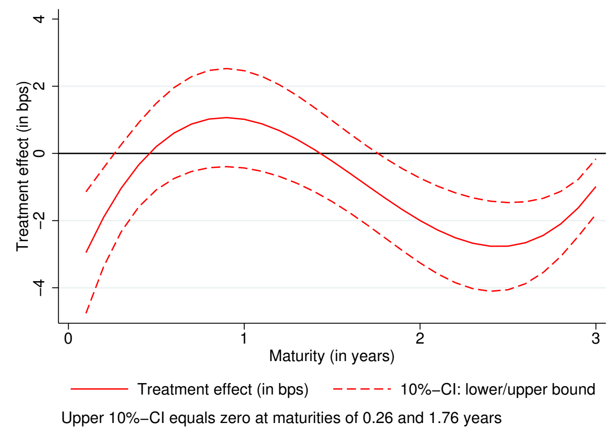
(a) First divergence (Spain)



(b) Haircut update

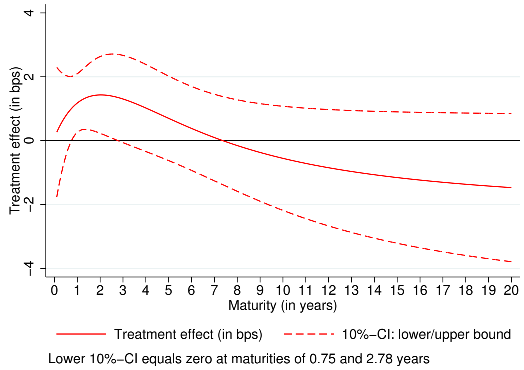


(c) Harmonization announcement

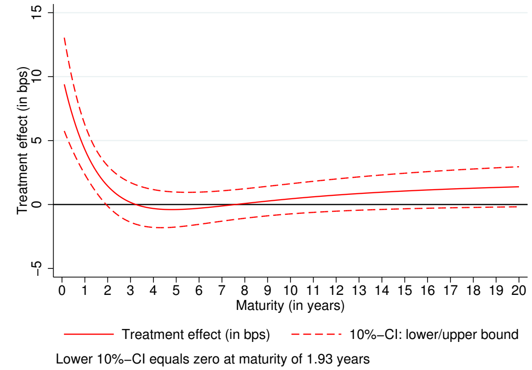


(d) Harmonization implementation

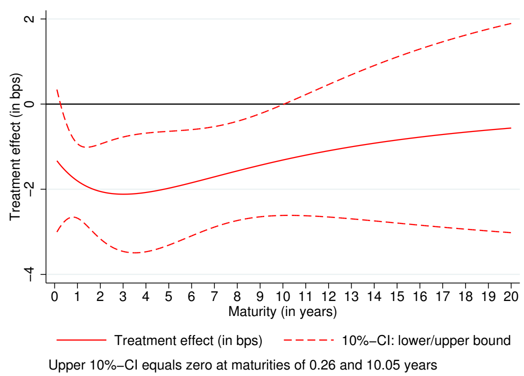
Figure 6: Estimated treatment effects along the term structure in Spain under cubic yield-curve specifications. This figure shows estimated treatment effects (in bps) along the term structure for each of our four events over ten-day windows using the samples of zero-coupon bonds with non-stale market prices for Spain (see Table 7). Estimation is based on the same fully-flexible DiD specification as in Table 9: $yield_{it} = \mathbf{\Gamma}_1' \; \mathbf{Mat}_{it} + \mathbf{\Gamma}_2' \; \mathbf{Mat}_{it} \; \mathbb{1}_{Treated,i} + \mathbf{\Gamma}_3' \; \mathbf{Mat}_{it} \; \mathbb{1}_{Post,t} + \mathbf{\Gamma}_4' \; \mathbf{Mat}_{it} \; \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} \; + \; \varepsilon_{it}$. The DiD estimator is given by the vector $\mathbf{\Gamma}_4$, estimated with OLS as $\widehat{\mathbf{\Gamma}}_4$. The estimated treatment effect at residual maturity, x, is given by the DiD delta curve, $\Delta_4(x) = \widehat{\gamma}_{0,4} + \widehat{\gamma}_{1,4}x + \widehat{\gamma}_{2,4}x^2 + \widehat{\gamma}_{3,4}x^3$, which is plotted as the solid line in each subplot. The dashed lines are 10%-level confidence intervals based on standard errors clustered on the bond-level and calculated using the delta method. Subplots (a) through (d) show, in order, the results for the first divergence date in Spain on June 3, 2013, the haircut update on October 1, 2013, haircut harmonization announcement on September 1, 2014, and harmonization implementation on December 15, 2014. In Subplot (b), we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013).



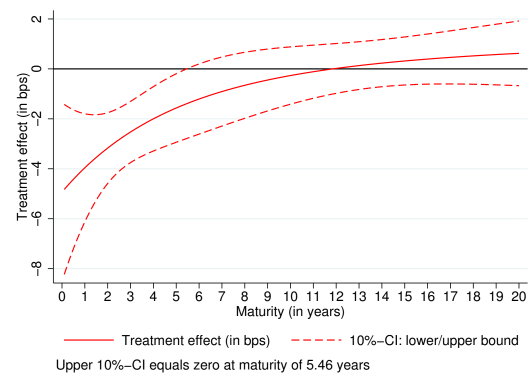
(a) First divergence (Italy)



(b) Haircut update



(c) Harmonization announcement



(d) Harmonization implementation

Figure 7: Estimated treatment effects along the term structure in Italy under Diebold-Li yield-curve specifications. This figure shows estimated treatment effects (in bps) along the term structure for each of our four events over ten-day windows using the samples of zero-coupon bonds with non-stale market prices for Italy (see Table 7). Estimation is based on the same fully-flexible DiD specification as in Table 10: $yield_{it} = \mathbf{B}_1' \ \mathbf{L}_{it} + \mathbf{B}_2' \ \mathbf{L}_{it} \ \mathbb{1}_{Treated,i} + \mathbf{B}_3' \ \mathbf{L}_{it} \ \mathbb{1}_{Post,t} + \mathbf{B}_4' \ \mathbf{L}_{it} \ \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} \ + \ \varepsilon_{it}$, where $\mathbf{L}_{it}$ is a three dimensional vector of regressors with elements: 1, $l_1(x_{it};\lambda)$, and $l_2(x_{it};\lambda)$, where $l_{1,t}(x_{it};\lambda) = \left(1 - e^{-\lambda x_{it}}\right)/(\lambda x_{it})$ and $l_{2,t}(x_{it};\lambda) = \left(1 - e^{-\lambda x_{it}}\right)/(\lambda x_{it}) - e^{-\lambda x_{it}}$, x_{it} is the residual time-to-maturity of bond i at date t, and λ is the decay parameter. $\mathbf{B}_j$, $j = 1, \ldots 4$, are the corresponding three-dimensional parameter vectors. The model is estimated with OLS with λ set equal to the average in-sample λ (as described in Table 10). The DiD estimator is given by the vector $\mathbf{B}_4$, estimated with OLS as $\widehat{\mathbf{B}}_4'$. The estimated treatment effect at residual maturity, x, is given by the DiD delta curve, $\Delta_4^{dl}(x;\lambda) = \widehat{\beta}_{0,4} + \widehat{\beta}_{1,4}\, l_1(x;\lambda) + \widehat{\beta}_{2,4}\, l_2(x;\lambda)$, which is plotted as the solid line in each subplot. The dashed lines are 10%-level confidence intervals based on standard errors clustered on the bond-level and calculated using the delta method. Subplots (a) through (d) show, in order, the results for the first divergence date in Italy on August 9, 2013, the haircut update on October 1, 2013, haircut harmonization announcement on September 1, 2014, and harmonization implementation on December 15, 2014. In Subplot (b), we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013).

Internet Appendix

THE PRICE OF MONEY: HOW COLLATERAL POLICY AFFECTS THE YIELD CURVE[1]

Kjell G. Nyborg

University of Zurich,
Swiss Finance Institute,
and CEPR

Jiri Woschitz

University of Zurich

November 2021

[1]Nyborg: Department of Banking and Finance, University of Zurich, Plattenstrasse 14, CH-8032 Zurich, Switzerland. email: kjell.nyborg@bf.uzh.ch.
Woschitz: Department of Banking and Finance, University of Zurich, Plattenstrasse 14, CH-8032 Zurich, Switzerland. email: jiri.woschitz@bf.uzh.ch.

Footnote 9: The 398 ISINs includes 93 securities where either information on coupon type, coupon rate, maturity date, or currency from Bloomberg is different from information on the Eurosystem's public lists of eligible collateral or where this information is varying over time, 4 perpetual bonds, and 62 securities that are linked to inflation. There are 239 securities on the public lists with data that are not good in some other way. These are comprised of: 4 securities whose principal is not of type "bullet", 1 security with an accrued basis of 18,628 days, 3 securities with a face value other than 100, 1 fixed-coupon security without information on amount issued, and 230 securities where the haircuts on the public lists of eligible collateral are inconsistent with security-specific information.

Additional tables

Table A.1 reports on haircut inconsistencies across the maturity spectrum for the nine countries with inconsistencies. Panel A shows the incidence of haircut inconsistencies across countries in the full dataset of 7,233 securities. Panel B repeats the exercise for the subset of 3,079 securities with market prices. For each day, we assign securities to yearly residual maturity buckets, from 0-1 years to 28-29 years. The table shows that coverage over the maturity spectrum, in terms of haircut inconsistencies, is by far the best for Italy and Spain, in that order.

Table A.1: Incidence of haircut inconsistencies across the maturity spectrum.

This table provides an overview on the incidence of haircut inconsistencies across countries and the maturity spectrum. A haircut inconsistency occurs if, on a given day, there are same-country central-government bonds in different rating categories. Rating category 1 (2) refers to securities with a rating in the AAA to A− (BBB+ to BBB−) range (on the S&P scale). Panel A does this for the full sample, and Panel B does it for the sub-sample of securities with market prices. The first column shows, by country, the number of sample days with at least one haircut inconsistency. To the right of the first column, the table shows the number of days with at least one inconsistency in the respective maturity bucket as a percentage of the total number of days in the first column. For example, 50% means that on half of the sample days in the first column at least two securities in different rating categories mature in that same maturity bucket.

Panel A: Full Sample

Country	Days	Maturity buckets														
		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15
Cyprus	40	20.0	82.5	2.5		20.0				2.5						
Greece	46				2.2		97.8		2.2							
Hungary	97						100.0									
Ireland	198	99.5														
Italy	351	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Latvia	16	100.0	100.0			100.0	56.3	93.8								
Portugal	1	100.0				100.0										
Slovenia	423	100.0	36.4	40.2	56.0					58.6	37.6					
Spain	449	88.9	88.6	94.9	88.6	45.0	44.3	88.6	88.6	38.5	6.2	4.5				
		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	28-29	50+
Italy	351	100	100	100	100	100	100	100	100	100	100	35.9				
Portugal	1															100
Spain	449	4.7											21.6	58.1	8.9	

Panel B: Sub-sample with market prices

Country	Days	Maturity buckets														
		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15
Cyprus	33															
Greece	1															
Hungary	97						100.0									
Ireland	194	99.5														
Italy	345	100.0	100.0	91.3	64.3	100.0	100.0	100.0	100.0	100.0	99.4	100.0	100.0	100.0	100.0	87.2
Latvia	16	93.8	93.8					87.5								
Portugal	1	100.0				100.0										
Slovenia	14				21.4						50.0					
Spain	441	89.1	88.9	94.8	87.5	43.8	44.0	88.7	75.3	37.6	6.3	4.5				
		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	28-29	
Italy	345	87.0	64.3	56.8	64.3	63.5	93.3	28.1	64.3	37.7	27.5	35.7				
Spain	441	4.8											21.5	56.9	9.1	

Table A.2: Estimated treatment effects using Specification (4′) in Footnote 27.

This table provides estimated treatment effects (in pps) for each event and country using the DiD specification in Equation (4′) in the paper, namely: $yield_{it} = \alpha_i + \delta_t + \beta_{DiD}\, \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} + \varepsilon_{it}$, where $\mathbb{1}_{Treated,i}$ is an indicator variable that is one for treated bonds and zero otherwise, $\mathbb{1}_{Post,t}$ is an indicator variable that is one for the event and post-event dates and zero otherwise, and α_i and δ_t are individual unit- and time-fixed effects, respectively. β_{DiD} is the DiD estimator. The specification is run with OLS individually for Italy and Spain for each event date using the samples of zero-coupon bonds with non-stale market prices each day in the respective event windows discussed in Table 7 in the paper. Panels A to D show, in that order, the results for the first divergence dates in Italy (August 9, 2013) and Spain (June 3, 2013), the haircut update on October 1, 2013, haircut harmonization announcement on September 1, 2014, and harmonization implementation on December 15, 2014. In Panel B, we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013). t-statistics, shown below the DiD coefficients, are based on standard errors clustered at the individual bond level. a, b, and c denote significance (two-sided) at the levels of 1%, 5%, and 10%, respectively. Coefficients that are statistically significant at the 10%-level or better are marked in bold.

	Italy		Spain	
	Window (business days)		Window (business days)	
	10 days	20 days	10 days	20 days
Panel A: First divergence (August 9, 2013 in Italy; June 3, 2013 in Spain)				
DiD	0.002	0.004	**0.038**^{b}	0.045
	(0.31)	(0.51)	(2.28)	(1.41)
Num. treated bonds/obs.	61/610	61/1,220	8/80	8/160
Num. control bonds/obs.	39/390	37/740	34/340	29/580
Adjusted R-squared	0.4845	0.7288	0.6091	0.8262
Panel B: Haircut update (October 1, 2013)				
DiD	**0.030**^{a}	**0.031**^{a}	0.023	0.016
	(4.13)	(3.37)	(1.08)	(0.69)
Num. treated bonds/obs.	62/620	60/1,200	9/90	9/180
Num. control bonds/obs.	41/410	39/780	28/280	27/540
Adjusted R-squared	0.6677	0.8107	0.7108	0.8089
Panel C: Harmonization announcement (September 1, 2014)				
DiD	**-0.010**^{c}	**-0.023**^{b}	-0.002	-0.005
	(-1.82)	(-2.27)	(-0.46)	(-0.79)
Num. treated bonds/obs.	67/670	65/1,300	13/130	13/260
Num. control bonds/obs.	29/290	28/560	18/180	18/360
Adjusted R-squared	0.6221	0.7265	0.7945	0.6517
Panel D: Harmonization implementation (December 15, 2014)				
DiD	**-0.026**^{a}	**-0.032**^{a}	**-0.014**^{b}	**-0.022**^{b}
	(-2.97)	(-2.85)	(-2.17)	(-2.52)
Num. treated bonds/obs.	69/690	57/1,140	15/150	14/280
Num. control bonds/obs.	28/280	27/540	21/210	20/400
Adjusted R-squared	0.7384	0.7348	0.5590	0.7773

Table A.3: Treatment effects estimated with nonlinear least squares under Diebold-Li (2006) yield-curve specifications.

This table provides estimated treatment effects (in pps) at selected maturities for each event and country using the following fully-flexible DiD specification: $yield_{it} = \mathbf{B}_1' \mathbf{L}_{it} + \mathbf{B}_2' \mathbf{L}_{it} \mathbb{1}_{Treated,i} + \mathbf{B}_3' \mathbf{L}_{it} \mathbb{1}_{Post,t} + \mathbf{B}_4' \mathbf{L}_{it} \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} + \varepsilon_{it}$, where $\mathbf{L}_{it}$ is a three dimensional vector of regressors with elements: 1, $l_1(x_{it};\lambda)$, and $l_2(x_{it};\lambda)$, where $l_{1,t}(x_{it};\lambda) = \left(1 - e^{-\lambda x_{it}}\right)/(\lambda x_{it})$ and $l_{2,t}(x_{it};\lambda) = \left(1 - e^{-\lambda x_{it}}\right)/(\lambda x_{it}) - e^{-\lambda x_{it}}$, x_{it} is the residual time-to-maturity of bond i at date t, and λ is the decay parameter. $\mathbf{B}_j$, $j = 1, \ldots 4$, are the corresponding three-dimensional vectors of coefficients. The DiD estimator is given by the vector $\mathbf{B}_4$. The rest of the notation follows that in Table 8. For each event, the model is estimated with nonlinear least squares (NLS) over ten- and twenty-day event windows on the Italian sample of zero-coupon bonds with non-stale market prices each day over the respective windows discussed in Table 7 (with the seed value for lambda being the "Diebold-Li lambda," $\lambda = 0.7308$). Estimated lambdas are shown at the bottom of each panel. Panels A to D show, in that order, the results for the first divergence date in Italy on August 9, 2013, the haircut update on October 1, 2013, haircut harmonization announcement on September 1, 2014, and harmonization implementation on December 15, 2014. In Panel B, we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013). Each panel provides the estimated treatment effect at selected maturities for each event window, with z-statistics (in parentheses) calculated using the delta method (with standard errors clustered on the bond-level). a, b, and c denote significance (two-sided) at the levels of 1%, 5%, and 10%, respectively. Coefficients that are statistically significant at the 10%-level or better are marked in bold. For each event, the DiD in haircuts is provided (in pps) in the column to the far right for all selected maturities. For residual maturity, x, equaling 1, 3, and 5 years, we have taken the haircut at x minus one day.

Maturity (in years)	NLS Window (business days) 10 days	20 days	DiD in haircuts (in pps)
Panel A: First divergence in Italy (August 9, 2013)			
0.5	0.008	**0.022**[a]	5.0
	(1.02)	(2.62)	
1	**0.012**[b]	**0.013**[b]	5.0
	(2.11)	(2.33)	
2	**0.014**[c]	0.002	5.0
	(1.95)	(0.30)	
3	0.013	-0.004	5.0
	(1.56)	(-0.46)	
5	0.007	-0.009	5.0
	(0.85)	(-1.08)	
8	-0.002	-0.010	5.0
	(-0.18)	(-0.97)	
12	-0.008	-0.010	5.0
	(-0.76)	(-0.71)	
16	-0.012	-0.010	5.0
	(-0.96)	(-0.60)	
20	-0.015	-0.010	5.0
	(-1.04)	(-0.54)	
Num. treated bonds/obs.	61/610	61/1,220	
Num. control bonds/obs.	39/390	37/740	Not applicable
Adjusted R-squared	0.9941	0.9929	
λ	0.5836	0.6076	

Table A.3 – *continued*

Maturity (in years)	NLS Window (business days) 10 days	20 days	DiD in haircuts (in pps)
Panel B: Haircut update (October 1, 2013)			
0.5	**0.067**^{a}	0.032	0.5
	(4.14)	(1.23)	
1	**0.043**^{a}	0.024	0.5
	(3.56)	(1.41)	
2	0.014	0.014	1.0
	(1.46)	(1.25)	
3	0.002	0.009	1.0
	(0.18)	(0.76)	
5	-0.004	0.004	2.5
	(-0.46)	(0.40)	
8	0.001	0.003	4.0
	(0.14)	(0.34)	
12	0.007	0.003	4.0
	(0.97)	(0.33)	
16	0.011	0.004	4.0
	(1.31)	(0.31)	
20	0.014	0.004	4.0
	(1.45)	(0.30)	
Num. treated bonds/obs.	62/620	60/1,200	
Num. control bonds/obs.	41/410	39/780	Not
Adjusted R-squared	0.9940	0.9925	applicable
λ	0.5979	0.5916	
Panel C: Harmonization announcement (September 1, 2014)			
0.5	**-0.016**^{b}	-0.012	0.0
	(-2.27)	(-0.98)	
1	**-0.018**^{a}	**-0.016**^{c}	0.0
	(-3.39)	(-1.89)	
2	**-0.021**^{a}	**-0.020**^{b}	0.0
	(-3.02)	(-2.17)	
3	**-0.021**^{a}	**-0.022**^{c}	0.0
	(-2.58)	(-1.90)	
5	**-0.020**^{b}	**-0.022**^{c}	0.0
	(-2.43)	(-1.83)	
8	**-0.016**^{b}	**-0.019**^{c}	0.0
	(-2.21)	(-1.75)	
12	-0.011	-0.014	0.0
	(-1.15)	(-1.02)	
16	-0.008	-0.011	0.0
	(-0.62)	(-0.61)	
20	-0.006	-0.009	0.0
	(-0.38)	(-0.42)	
Num. treated bonds/obs.	67/670	65/1,300	
Num. control bonds/obs.	29/290	28/560	Not
Adjusted R-squared	0.9964	0.9955	applicable
λ	0.3948	0.4069	

Table A.3 – *continued*

Maturity (in years)	NLS Window (business days) 10 days	20 days	DiD in haircuts (in pps)
Panel D: Harmonization implementation (December 15, 2014)			
0.5	**-0.044**[a]	**-0.045**[a]	−5.5
	(-2.62)	(-2.70)	
1	**-0.040**[a]	**-0.040**[a]	−5.5
	(-3.02)	(-3.04)	
2	**-0.032**[a]	**-0.032**[a]	−6.0
	(-3.70)	(-3.51)	
3	**-0.025**[a]	**-0.025**[a]	−6.0
	(-3.42)	(-3.18)	
5	**-0.016**[c]	**-0.015**[c]	−7.5
	(-1.89)	(-1.85)	
8	-0.007	-0.006	−9.0
	(-0.82)	(-0.82)	
12	0.000	0.000	−9.0
	(0.03)	(0.01)	
16	0.004	0.003	−9.0
	(0.64)	(0.46)	
20	0.006	0.005	−9.0
	(0.79)	(0.59)	
Num. treated bonds/obs.	69/690	57/1,140	
Num. control bonds/obs.	28/280	27/540	Not
Adjusted R-squared	0.9962	0.9960	applicable
λ	0.2633	0.2842	

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c/o University of Geneva, Bd. Du Pont d'Arve 42, CH-1211 Geneva 4
T +41 22 379 84 71, rps@sfi.ch, www.sfi.ch