The Price of Money: The Reserves Convertibility Premium over the Term Structure[1]

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Abstract

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Central bank money provides utility by serving as means of exchange for virtually all transactions in the economy. Central banks issue reserves (money) to banks in exchange for assets such as government bonds. If additional reserves have value to a bank, an asset's degree of convertibility into reserves can affect its price. We show the existence of a government bond reserves convertibility premium, which tapers off at longer maturities. The degree of convertibility is priced, but heterogeneously so. Our findings have implications for our understanding of reserves, liquidity premia, the term structure of interest rates, and central bank collateral policy.

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The rate of interest on these securities is a measure of their imperfection—of their imperfect 'moneyness.' The nature of money and the nature of interest are therefore very nearly the same problem. —Hicks (1939)

1. Introduction

This paper addresses monetary effects in asset prices, in particular, the idea that the utility of money as a means of exchange should be reflected in asset prices (Hicks, 1939). While the architecture of money has evolved over time, the basic maxim that money provides utility, especially as a medium of exchange, is commonly viewed as more or less immutable (Pigou, 1917; Clower, 1967; Duffie, 1990; Dubey and Geanakoplos, 1992; Kiyotaki and Moore, 2003, 2019; Lagos and Wright, 2005; Lagos and Zhang, 2022; Goldstein, Yang, Zeng, 2025). Our focus is on the ultimate medium of exchange in modern monetary systems, namely, central bank reserves. Examining government bond yields over the maturity spectrum, we find evidence that is broadly consistent with, but also expands on, the Hicksian idea that the utility of money, in this case, reserves, affects bond yields. Methodologically, we use a novel differences-in-differences (DiD) approach in curves that resolves a misspecification problem inherent in the classical DiD approach that arises from term structure effects (Nyborg and Woschitz, 2025). This also allows us to estimate monetary effects in bond yields over the term structure, which is of primary interest.

To place the paper in the literature, note first that Hicks (1939) argues that instruments that can be converted into money with low transactions costs (and vice versa), are safe in the sense of having low duration or credit risk, or have a high level of what he refers to as "moneyness," should normally trade at a premium (have relatively low yields) because of the utility of money as a medium of exchange. Although rarely attributed to Hicks, these ideas have propagated through the literature and have a strong presence in modern works on liquidity premia (Amihud and Mendelson, 1986; Krishnamurthy and Vissing-Jorgensen, 2012; Greenwood, Hanson, and Stein, 2015; Nagel, 2016; Van Binsbergen, Diamond, and Grotteria, 2022). Our paper is differentiated from this literature by our institutional focus, specifically, on reserves and the effects over the maturity spectrum of the convertibility of bonds into this institutionally fundamental form of money. We make use of the monetary policy implementation framework in the euro area to precisely measure a security's "moneyness" in the Hicksian sense as its rate of convertibility into reserves straight from the central bank, as determined by central bank collateral policy. Utilizing policy changes that affect convertibility differentials between same-country government bonds, we show that an increase in the reserves convertibility rate reduces yields, ceteris paribus, at short-to-mid durations. The effect tapers off at longer maturities. As will become clear, the government bonds we study are not riskfree assets. The existence of reserves convertibility premia in risky bonds stand in some contrast to Hicks (1939) and the liquidity premium literature which to a large extent emphasize safe securities. Our findings have implications with respect to our understanding of liquidity premia, the term structure of interest rates, the price impact of central bank collateral policy, and the role of reserves.

Insert Figure 1 here.

Reserves matter in modern two-tier monetary systems because they function as the ultimate medium of exchange; nearly all transactions ultimately have to settle in them (or banknotes, the other current form of central bank money). This is illustrated in Figure 1. For instance, a purchase made with a debit card or a bank transfer triggers a transfer of reserves from the bank of the buyer to the bank of the seller, if these are different, regardless of whether the payment is for groceries or a financial asset. Although the buyer sees her purchase as being made with her bank deposits, the transaction is ultimately settled in reserves, that is, in deposits her bank holds with the central bank. The daily turnovers of dollar and euro reserves measure in the trillions. Because there is no substitute, having sufficient reserves is a hard constraint for banks with respect to payment-system obligations, reserve requirements (if any), and settling claims when liabilities are not rolled over, for example, as in the case of customer withdrawals.[1] Banks can borrow reserves from other banks in the interbank market, but only the central bank can issue new reserves. It does this in exchange for assets, in accordance with its collateral policy, in repos or outright purchases (Nyborg, 2016). Thus, if additional reserves are valuable to some banks, for example, because of frictions in the interbank market for reserves or a shortage arising from increased demand, an asset's market price can be increasing in its rate of convertibility into reserves in a direct transaction with the central bank. Chapman, Chiu, and Molico (2011) develop a theoretical model in this vein and show that the price of the single asset in their model can increase in its convertibility into reserves. More generically, modern monetarist models show that liquidity premia can be thought of as the shadow costs of binding monetary constraints (Lagos, Rocheteau, and Wright, 2017). Tightness in the interbank market has been shown by Nyborg and Östberg (2014) to have

[1] Withdrawals can also be in banknotes, which banks get from the central bank in exchange for reserves.

spillover effects to equity markets and Li and Li (2024) show that payment-flow volatility affects bank lending. Both findings speak to the importance of reserves.

Our analysis is set within the euro area's monetary policy implementation framework. We study events after the onset of the financial crisis, but before the European Central Bank (ECB) launched the public-sector purchase program (quantitative easing) in March 2015. This is an ideal setting in which to capture potential reserves convertibility premia. First, by most accounts, this was a period of interbank tightness and strong aggregate demand for reserves. Second, prior to its large-scale unsterilized asset purchase programs, the Eurosystem provided reserves almost exclusively through regularly scheduled fixed-term repo (collateralized loan) operations with banks as counterparties. These operations are central to monetary policy implementation. Their primary objectives are to provide banks with sufficient reserves to ensure the smooth running of the payment system, to allow banks to satisfy their liquidity needs and fulfill reserve requirements, and to steer the overnight rate close to the policy target (Bindseil, Nyborg, Strebulaev, 2009; ECB, 2014b). For each eligible security, the central bank determines the quantity of reserves it is willing to provide in its operations or facilities by taking a haircut off the security's price. In this repo-based framework, the rate of convertibility of a security into new reserves straight from the central bank is defined by this haircut. Focusing on government securities, the questions we ask in this paper, therefore, boil down to whether these central bank haircuts for the regular provisioning of reserves affect prices in the first place and to what extent this depends on residual maturity.

To address this, we exploit differential treatment of same-country government bonds by the Eurosystem with respect to haircuts and specific events where this changed. The identification strategy can be utilized in four events and the country with the richest government bond data with respect to these events is Italy (see below), which is why we focus on this specific issuer. When a variable exhibits a term structure, there is no reason to expect that potential treatment effects do not. Furthermore, a well-specified model must allow for term effects (Nyborg and Woschitz, 2025). Thus, we use a DiD in curves approach.

The four events tell the same story: a higher haircut causes a higher spot rate at short-to-mid durations (around five years), after which there is no significant effect. In terms of magnitudes, a one percentage point haircut reduction decreases the one-year spot rate, for example, by approximately two basis points. This represents ten basis points for an observed five percentage point haircut change. The large yield spreads of Italian government bonds over German ones since the financial crisis in 2008 mean that we are not finding reserves convertibility premia in riskfree assets, but in risky ones.

The finding that there is a habitat dimension (Culbertson, 1957; Modigliani and Sutch, 1966 and 1967; Vayanos and Vila, 2021) to the convertibility premium is consistent with the view that the impact of collateral policy depends on the assets held by the players that can access the central bank's operations (Nyborg and Strebulaev, 2001) and the fact that the entities (banks) that can do so hold relatively short term paper (Fecht, Nyborg, Rocholl, and Woschitz, 2016; Koijen, Koulischer, Nguyen, and Yogo, 2021). Our findings are also consistent with a home bias in banks' government bond holdings (Lojsch, Vives, and Slavik, 2011) and, at least some, Italian banks having poor access to the interbank market over the sample period.

We also find that there are significant announcement *and* implementation effects when haircuts are revised. This can be understood as follows. A security that is convertible into reserves is essentially endowed with a valuable option in addition to its promised cash flows. The option value lies in the ability to pledge the security to the central bank in return for reserves that can ease monetary constraints. Thus, when a haircut reduction, say, is announced, the option value of the security increases because it may be optimal to pledge the security at a future date after the haircut reduction is implemented. At the implementation date itself, there can be a further boost in the market price of the security if reserves are sufficiently tight that it is optimal to pledge the security right away. That we find both an announcement and an implementation effect is consistent with tight conditions in the interbank market for reserves and a positive marginal value of reserves.

Our results show the existence of a component to the market prices of some financial assets that derives from their direct convertibility into fresh reserves. The simplest explanation is analogous to Hicks' (1939) argument that the low interest rates on banknotes and bank deposits relative to alternative safe assets reflect the relative convenience value of holding these forms of money for liquidity, or transactional, reasons. The low interest earned on money is just a complement to its relative convenience. Similarly, assets that can be converted directly into reserves also provide agents that can take advantage of this (banks) with a convenience yield. In turn, this puts upward pressure on the prices of these assets. Under this view, reserves convertibility premia are liquidity premia in their most basic, Hicksian form. The value of reserves can be amplified by frictions with respect to the private provisioning of liquidity (Bhattacharya and Gale, 1987; Kiyotaki and Moore, 2003; Holmström and Tirole, 2011; Bolton, Santos, and Scheinkman, 2011), concerns regarding bank runs or crises (Bagehot, 1873;

Diamond and Dybvig, 1983; Allen, Carletti, Gale, 2014; Chen, Goldstein, Huang, Vashishtha, 2024; Lengwiler and Orphanides, 2023), and payment-flow volatility (Li and Li, 2024). Such monetary concerns can give rise to precautionary demand for excess reserves (Bindseil and Papadia, 2006; Acharya and Merrouche, 2013) and contribute to our results.

Remaining structure: Section 2 discusses additional literature. Section 3 provides an overview of the identification strategy. Section 4 discusses the institutional framework and the data. Section 5 describes the DiD events. Section 6 provides preliminary analysis of yields and spot curves. Section 7 contains the main analysis. Section 8 concludes.

2. Additional literature

Our paper relates to several strands of the literature. Longstaff (2004), Krishnamurthy and Vissing-Jorgensen (2012), Greenwood, Hanson, and Stein (2015), Nagel (2016), and Van Binsbergen, Diamond, and Grotteria (2022), among others, study liquidity premia in Treasury securities, defined as spreads relative to yields of other safe instruments. Treasuries typically have relatively low yields, but Treasuries can also trade at discounts to estimates of their intrinsic fair values (Fleckenstein and Longstaff, 2024). Our findings suggest that the preferred status of Treasuries in transactions with the Federal Reserve is one factor that can affect their relative prices. Institutionally, the papers that come closest to ours are Bindseil and Papadia (2006), Corradin and Rodriguez-Moreno (2016), and Pelizzon, Riedel, Simon, and Subrahmanyam (2024) who study eligibility premia in Eurosystem repos using broad cross-sections of non-government bonds. Although most eligible collateral are not actively traded, especially outside the government bond space (Nyborg, 2016), eligibility can potentially increase a security's market price for those securities that do trade for a number of reasons, e.g.: signaling of quality; investor attention; ratings upgrades; new issues; lobbying for inclusion; and the potential for subsequent inclusion in indices, securities lending, and repo general collateral pools. Thus, the concepts of eligibility premium and reserves convertibility premium are different. We are able to isolate the latter because we identify the effects of haircut changes on the prices of assets that are already eligible for use as collateral in central bank repos for reserves. Our paper is also differentiated from the literature by our DiD in curves approach, which both controls for idiosyncratic term effects and allows for the estimation of treatment effects over the maturity spectrum (Nyborg and Woschitz, 2025).

The Hicksian idea that an asset's degree of convertibility into means of exchange can affect its value has a parallel in the idea that the degree of collateralizability of an asset with respect to obtaining credit can affects its value (Veblen, 1904; Geanakoplos, 1997; Kiyotaki and Moore, 1997). Just as collateral can have value for a bank whose reserves position is tight, it can also have value for a constrained agent who seeks leverage for investment purposes. The general principle is that if an asset can help alleviate a constraint, an agent may be willing to pay a premium for it. Haircuts in central bank repos for reserves bear some resemblance to investment margins. Gârleanu and Pedersen (2011) develop a margin CAPM, where a lower margin requirement (haircut) on an asset can enhance utility to less risk averse, but constrained, investors by allowing them to invest in more efficient portfolios. In turn, this increases the price of said asset. This logic can be relevant when a central bank takes action to ease borrowing constraints to end-investors in specific assets (Ashcraft, Gârleanu, and Pedersen, 2010). However, in our case, the absence of a haircut effect at long durations is difficult to reconcile with the margin CAPM perspective. This supports the notion that since reserves have a specific transactional role at the core of the monetary system, economically, reserves provisioning is not equivalent to investment-leverage provisioning.

This paper also relates to the vast literature on bond pricing and the term structure (see Dai and Singleton, 2003; Gürkaynak and Wright, 2012; and Duffee, 2013, for overviews). The prices of Treasury securities are known to be affected by conventional monetary policy[2] and correlate with market liquidity and measures of funding conditions.[3] Large-scale asset purchase programs also affect yields (D'Amico and King, 2013; Eser and Schwaab, 2016; Todorov, 2020; Lentner, 2025b). With respect to collateral frameworks, Nyborg (2016), Van Bekkum, Gabarro, and Irani (2018), Cassola and Koulischer (2019), and Lentner (2025a) discuss how collateral policy can influence banks' lending, pledging, and debt issuance behavior. Koulischer and Struyven (2014) suggest that a loose collateral policy can be welfare improving, while Nyborg and Strebulaev (2001) argue that the outcome of easing depends on which players hold the assets that benefit. Singh (2020) discusses uses of collateral in the financial system more broadly. We contribute by showing that central bank collateral policy can affect the term structure of interest rates.

[2]Cook and Hahn (1989), Evans and Marshall (1998), Kuttner (2001), Cochrane and Piazzesi (2002), Gürkaynak, Sack, and Swanson (2005a, 2005b), Gertler and Karadi (2015), Hanson and Stein (2015), Nakamura and Steinsson (2018), Leombroni, Vedolin, Venter, and Whelan (2021).

[3]Amihud and Mendelson (1991), Boudoukh and Whitelaw (1993), Boudoukh, Richardson, Smith, and Whitelaw (1999), Fleming and Remolona (1999), Goldreich, Hanke, and Nath (2005), Chordia, Sarkar, and Subrahmanyam (2005), Beber, Brandt, and Kavajecz (2009), Sundaresan and Wang (2009), Goyenko, Subrahmanyam, and Ukhov (2011), Fontaine and Garcia (2012), Pflueger and Viceira (2016), Andreasen, Christensen, and Riddell (2021).

3. Overview of the identification strategy

Our identification strategy is based on two elements. The first relates to credit rating and haircut differentials between same-country government bonds. The second relates to events that allow us to exploit these differences to identify the effect of haircuts on yields over the maturity spectrum.

As noted by Nyborg (2016), haircut differentials between same-issuer bonds, even with identical maturities and coupons, can arise under the collateral framework of the Eurosystem because of how ratings feed into haircuts. We will provide details below, but for now just note that eligible bonds can be classified into two rating categories, 1 and 2, with the former being associated with better ratings. Thus, rating category 1 bonds also have lower haircuts, ceteris paribus. The first element of our identification strategy is based on the fact that there are days where we can observe same-country government bonds in different rating categories. We refer to this as a *haircut inconsistency*. As a first step, we comprehensively document these inconsistencies over the period April 8, 2010 to December 15, 2014, when the ECB implemented a rule change to eliminate them. We show below that a large number of bonds from several countries are involved. However, over time, haircut inconsistencies are especially prevalent in Italy and Spain, with Italy having substantially better coverage over the maturity spectrum, which is why we focus on this country.

Nyborg (2016) provides examples with couplets of same-country zero-coupon bonds that mature on the same day, yet are in different rating categories. In these examples, the bond with the lower haircut has the lower yield. However, such perfectly matched couplets are rare. The basic building block of our empirical design is the spot-curve differential, the delta curve, between same-country government bonds in rating categories 2 and 1. Our main focus is on the change in the delta curve around events with exogenous shocks to the haircut differentials between these two groups of bonds.

The identified events share a common backdrop, namely, collateral policy implementation mistakes by the Eurosystem itself.[4] A story broke on Reuters on November 4, 2012 that "[t]he 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."[5] In a press conference on November 8, 2012, Mario Draghi, President of the ECB at

[4] In the Eurosystem, the ECB formulates rules and policy and the national central banks (NCBs) implement.

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

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 ..."[6] 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 the same rating category based on individual country ratings. 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 haircuts on the market prices of bonds. This is sketched below, with details provided in Section 5.

The first event date corrects the mistake. On August 9, 2013, several Italian, 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 control bonds. This is also what we find, with a term effect that vanishes at longer maturities.

The second event is a haircut update on October 1, 2013.[7] Historically, the ECB revises haircuts only every three to four years (Nyborg, 2016), 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 and 2. Thus, we would expect to see the post-event yield curve of category 2 bonds to shift up relative to that of category 1 bonds. This is what we find, with, again, a declining and vanishing 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, thus eliminating haircut inconsistencies. Reflecting their country ratings, on December 15, 2014, all Italian government bonds in rating category 2 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 the effects of anticipated versus actual haircut changes. Consistent with the findings for the first two events, we find that the overall effect of harmonization is a decrease in the relative yields of treated bonds (for which haircuts

[6] 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`.

[7] 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.

decrease). There are both announcement *and* implementation effects, but the latter dominates.

4. 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. Recall that a "haircut inconsistency" refers to same-country government bonds in different rating categories on the same day. The section ends with a comprehensive overview of the incidence of haircut inconsistencies across countries, which helps motivate our focus on Italy.

4.1 Data

The underlying data are the public lists of Eurosystem eligible collateral from April 8, 2010 to January 6, 2015, inclusive. The start date represents the first date for which these lists are publicly available, and the end date is about three weeks after the ECB implemented government bond haircut harmonization. There are 1,232 eligible-collateral lists over this time period. The lists are updated every business day and posted on the ECB's website the evening before they apply. They contain data on individual eligible collateral such as ISIN, maturity, coupon type, issuer, type of security ("liquidity category"), and haircut in Eurosystem repos. 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 ("government bonds") are in what is labeled Liquidity Category 1, along with paper issued by national central banks.[8] This category comprises approximately 5.4 percent of securities on average. Across lists, the number of unique ISINs that appear in Liquidity Category 1 at least once is 6,000. From these, we drop 214 floating-rate securities, 78 securities that sometimes appear under a different liquidity category and/or change coupon type, and four national central bank securities. This leaves 5,704 central-government bonds, all with either a fixed or zero coupon, for a total of 2,246,390 security-day observations. Across lists, the number of ISINs in this basic dataset fluctuates between 1,588 and 2,201.

[8] The terminology "liquidity category" was replaced with the terminology "haircut category" in September/October 2013 (see Nyborg, 2016). ISIN is short for "International Securities Identification Number."

The 5,704 ISINs were fed into Bloomberg to get historical price data. 830 securities were not in Bloomberg and 1,456 securities were in Bloomberg but without price data. Of the remaining 3,418 securities, 605 had theoretical (model) prices only, leaving 2,813 ISINs with market prices.[9] Of these we drop 359 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 do not match or changes over time, or the data is not good in some other way.[10] The resulting dataset consists of 2,454 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,[11] the total number of security-day observations is 1,202,586, and the average number of securities per daily public list over the sample period is 993.1.

4.2 Ratings and haircut rules

Eurosystem haircuts are a function of asset type, maturity, coupon type, and credit ratings. The official collateral framework acts and decisions lay this out in tables that, historically, are updated every three to four years (Nyborg, 2016). Government bonds have the lowest haircuts, ceteris paribus. For fixed- and zero-coupon bonds, there are six residual maturity buckets over the sample period, namely, 0–1, 1–3, 3–5, 5–7, 7–10, 10+ years. Haircuts are increasing in maturity, ceteris paribus, but constant within each bucket and with a markup for zeros. From October 2008, the ECB operated with its own definition of two rating categories, with lower-rated bonds receiving higher haircuts, ceteris paribus.

Insert Table 1 here.

The exact mapping from government bond characteristics, for fixed- and zero-coupon bonds, to haircuts for each day in the sample period is laid out in Table 1.[12] Panel A contains the ordinary haircut rules for euro-denominated government bonds. Panel B provides extraordinary haircuts applied to the government bonds of Greece and Cyprus, who received

[9]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, 98.04% are flagged as BGN, which gives bid, ask, and mid-point market quotes.

[10]See the Internet Appendix for details.

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

[12]Table 1 is based on the complete set of collateral framework documents relevant for the sample period, available on the ECB's webpage. This work is from Nyborg (2016), 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 Tables 5.2, 5.3, 5.4, and 5.5, and the ECB collateral framework references therein.

temporary exemptions from regular minimum ratings requirement (at least the equivalent of BBB− on the S&P scale).[13] 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 on each sample day.

The reason same-country government bonds could be assigned to different rating groups is that they may be rated by different rating agencies, with different credit assessment, or not rated at all. Over the sample period, the Eurosystem recognized four rating agencies for securities on the public list, namely, S&P, Moody's, Fitch, and DBRS. The two rating categories in Table 1, Panel A can be described in terms of long-term ratings from the four official rating agencies.[14] 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.[15] 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.

Insert Table 2 here.

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

[13] During the euro crisis, Portugal and Ireland were also exempted, but continued to receive ordinary haircuts. Greece and Cyprus occasionally experienced suspensions of their exemptions (for details see Nyborg, 2016, Subsections 5.4 and 6.2, and the references therein).

[14] After April 30, 2015, short-term ratings may, in some cases, serve as a substitute for long-term ratings. The terminology "rating category" follows Nyborg (2016). The ECB operates with the terminology "credit quality steps," which are defined in terms of long- and short-term ratings. See Nyborg (2016) and the references therein for details and a comprehensive presentation of the rules.

[15] Full details of the priority rules over time are in Nyborg (2016), Chapter 6, and the references therein.

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.

4.3 Two examples of haircut inconsistencies

Table 3 provides two examples of haircut inconsistencies and how they can arise. Each example comprises a pair of zero-coupon Italian government bonds with the same or very close maturity dates. All bonds are in the 0–1 year maturity bucket. Haircuts are from the public list. Individual bond and country ratings are from Bloomberg. Rating categories are commensurate with Table 1. The illustrated haircut inconsistencies persisted until the implementation of haircut harmonization on December 15, 2014.

Insert Table 3 here.

In Example 1 (Panel A), the two bonds mature on the same date. 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%. The haircut inconsistency arises because the first bond 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) rating for the second security is BBB+ from Fitch, which earns it a higher haircut.

In Example 2 (Panel B), the two bonds mature within two days of each other. The first security has no individual issue rating and, therefore, has a rating category 1 haircut of 0.5% due to Italy's AL country rating by DBRS. The second bond is rated BBB+ by Fitch and has a rating category 2 haircut of 6.0% since it has no other (or higher) rating.

With haircut harmonization, only country ratings matter. Thus, the two rating category 2 bonds were moved to category 1 and saw their haircuts drop by 5.5%. Panel C shows that the resulting DiD in yields (high haircut minus low haircut bond) is −3.50 basis points (bps) in Example 1 and −10.12 bps in Example 2.[16] Thus, the yields of the two treated bonds experience an average decrease of 1.2 bps, relative to their matched counterparts, per percentage point decrease in haircut. Because perfect matches are rare, in the formal analysis below, we employ DiD in curves.

[16] $DiD = \Delta_{Post} - \Delta_{Pre}$, where Δ is the yield of the second bond (high haircut before harmonization) minus the first bond. Yields are five-day averages before and after harmonization. All bonds have market prices in Bloomberg.

4.4 Incidence of haircut inconsistencies

We now use the mapping in Table 1 and security-specific information in the public lists of eligible collateral to report on the incidence of haircut inconsistencies across countries. The daily aggregate distribution of bonds with market prices across rating categories is shown in Figure 2, and statistics on haircut inconsistencies per country are in Table 4.[17]

Insert Figure 2 and Table 4 here.

Table 4, Panel A shows the incidence of haircut inconsistencies across countries in the dataset of 2,454 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. There are a total of 1,142 country-days with haircut inconsistencies and 593 securities involved. Italy and Spain combine for 68.8% of these days and 79.3% of the securities. Table B shows that coverage across the maturity spectrum is especially good for Italy, which is why we focus on this country.

5. Event dates and treated and control bonds

In this section, we discuss the events that form the basis of the identification in the DiD analysis in Section 7 and specify the sets of treated and control bonds.

5.1 Event dates

To help see the events and the data, Figure 3a plots the daily number of Italian government bonds with market prices in rating categories 1 and 2. The occurrence of bonds in both rating categories on the same day implies a haircut inconsistency.

Insert Figure 3 here.

Two features are immediately obvious from the figure. First, 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 above. Second, haircut inconsistencies vanish on December 15, 2014, when the ECB implemented the rule change designed for this exact purpose (Nyborg, 2016, Table 6.1). Vertical bars in the figure represent these and other

[17]The Internet Appendix includes a similar figure for the full dataset, which includes bonds without market prices.

key event dates that affect haircuts differentially across bonds.[18] In chronological order:

- August 9, 2013, (mint-green solid line). First mass correction of Italian government bond collateral framework implementation errors. Haircuts diverged, with sixty-three bonds moved from rating category 1 to category 2. We refer to this as *Divergence date 1*.
  - There was a second, smaller mass correction of collateral framework implementation errors on April 1, 2014 (blue longdash-dotted line in Figure 3a). This involved sixteen Italian bonds with less than one year to maturity. Because of the small number of bonds and the short range of residual maturities, this event (*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 end of the sample period of this study (January 2015), the ECB updated haircuts on sovereign bonds only once (October 1, 2013), as seen 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 Eurosystem repo 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 on same-country government bonds by changing the rating priority rule for these 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 3a, Italian government bonds in rating category 2 shift

[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.

[19] See Nyborg (2016, Subsections 5.3, 5.4, and, in particular, Tables 5.2, 5.3, 5.4, and 5.5) and the Eurosystem collateral framework references therein.

back to category 1 on this date (ECB, 2014a). This occurs because Italy had a country rating of AL from DBRS.

5.2 Treated and control bonds

Henceforth, we set the sample period as being fifteen business days before the first divergence date to fifteen business days after harmonization (July 19, 2013 to January 7, 2015). We label bonds that were moved into rating category 2 and received higher haircuts on the first divergence date as treated. For the next two events, we continue to label rating category 2 bonds as treated. For the fourth and final event, treated bonds are those that switch from rating category 2 to 1. The haircut update event differs from other events in that haircuts change for both groups of bonds. However, it is still relevant to ask to what extent yield differentials change as a result of the change in haircut differentials.

It turns out that all rating category 2 securities, and thus all treated bonds, are zeros. 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. Finally, we exclude security-day observations with less than ten calendar days to maturity. We are left with 177 zero-coupon bonds for a total of 40,527 security-day observations on 375 sample days. The total number of bonds that at some point in time are in rating category 2 are 96, comprising 23,554 security-day observations. Figure 3b plots the number of bonds in each rating category over time in this sample of zeros. As seen, there are bonds in each category every day from the first divergence date until haircut harmonization.

6. Preliminary analysis: High versus low haircut bonds

Using the sample of 177 zero-coupon bond just described, in this section we take a preliminary look at yield differentials between bonds in the two rating categories. All securities have the BGN pricing source (see Footnote 9), and we take the mid-point of the end-of-day bid and ask prices, expressed in terms of yield. We drop 550 security-day observations with stale prices. These are defined as cases where the bid, ask, and mid-prices are unchanged from the previous day. All securities are euro-denominated. We first report on unconditional differences in yields between the two groups. We then introduce a simple term-structure control using Eurosystem haircut maturity buckets (see Table 1). Finally, we estimate daily spot and delta curves (spot curve differentials between bonds in rating categories 2 and 1) and report statistics on these.[20]

6.1 Overview and summary statistics

Figure 4 provides time-series plots of average residual maturities and average yields from the first divergence date (August 9, 2013) to the last business day before haircut harmonization (December 12, 2014). Table 5 provides summary statistics across sample days, including on yield spreads between rating categories. Because Figure 4 shows that average residual maturities and relative yields in the two rating groups 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.

Figure 4a plots the average spot rate within each rating category over time. High-haircut bonds have higher yields. In the subperiod prior to the second divergence date, the difference in yields (rating category 2 less category 1) is 2.006 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). However, these plain differences do not correct for term structure effects. This matters because of the large differences in residual maturities between rating category 1 and 2 bonds, as seen in Figure 4b and Table 5. 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.

Figure 4c presents a simple term-structure correction using the six Eurosystem maturity buckets in Table 1. For each rating group, we first average yields across all bonds in the same maturity bucket and then across buckets. This gives us two time series with simple maturity-controlled average yields on a daily basis. Figure 4c 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. The average differences across

[20]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. However, this simply 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).

days are now 8.4 bps and 2.8 bps in the first and second subperiods, respectively (both significant at the 1% level).

Table 5 also includes information on the ranges of residual maturities across days. These maturity ranges never fall below 23.00 and 24.00 years for rating category 1 and 2 bonds, respectively. Time series plots of residual maturities are in Figure A.2 in the Internet Appendix.

6.2 Average daily spot and delta curves

To control more precisely for term-structure effects, in this subsection, we estimate daily delta curves, that is, the difference between the spot curve of rating category 2 and 1 bonds. Before the introduction of curves with exponential decay by Nelson and Siegel (1987), researchers and policymakers often fitted yield curves as cubics. As emphasized by Nelson and Siegel (1987), cubics have the same number of parameters as their own curve and often provide better fits. Cubics have the drawbacks, however, in that they blow up at long maturities and can impute excessive curvature to parts of the maturity spectrum. A prominent example of a "pre-Nelson-Siegel" curve is that of Fisher (1966), who adds a log term to a cubic specification. Given that our data consists entirely of zero coupon bonds, cubics and their extensions can be fitted with OLS by regressing yields on residual maturity. This means that they are also amenable to Fama-MacBeth style regressions, whereas fitting curves in the Nelson and Siegel (1987) tradition requires nonlinear least squares (NLS). Thus, in this section, we employ simple cubic and Fisher (1966) curves (which turn out to fit extremely well). In the DiD analysis below, we introduce curves with exponential decay.

Estimation is carried out on a day-by-day basis, and we report the averages of these daily runs. Specifically, we employ the Fama-MacBeth procedure with the following specification:

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

where $yield_{it}$ is the yield-to-maturity of bond i on day t 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. In the case of a simple cubic specification, $\mathbf{Mat}_{it}$ is the 4×1 dimensional vector $[1 \quad x_{it} \quad x_{it}^2 \quad x_{it}^3]'$, where x_{it} is the residual time-to-maturity; $\mathbf{\Gamma}_j$, $j = 1, 2$, is a vector of coefficients with individual elements $\gamma_{k,j}^c$, $k = 0, \ldots, 3$. The Fisher (1966) specification just adds an $\ln(x)$ term.[21]

[21] Under the Fisher (1966) specification, $\mathbf{Mat}_{it}$ is a 5×1 vector $[1 \quad x_{it} \quad x_{it}^2 \quad x_{it}^3 \quad \ln(x_{it})]'$, and the vectors $\mathbf{\Gamma}_j$, $j = 1, 2$, of coefficients have elements $\gamma_{k,j}^f$, $k = 0, \ldots, 4$.

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

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

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

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

where $\{\widehat{\gamma}_{k,2}^c\}_{k=0}^3$ are the estimated regression coefficients. This is the main object of interest. The Fisher (1966) delta curve is defined analogously.[22] Estimation is over a 345-day period, involving 39 bonds in rating category 1 and 68 in category 2 on average across days (Table 6, Panel A).

Insert Table 6 here.

Table 6, Panel B reports the results. The letters *a*, *b*, and *c* denote statistical significance (two-sided) at the 1%, 5%, and 10% levels, respectively, based on Newey-West standard errors with five lags.[23] The average adjusted R^2 of the individual cross-sectional regressions (in step 1 of the Fama-MacBeth procedure) is 99.59% under the plain cubic and 99.72% under Fisher (1966), showing that either of these specifications fit the data exceptionally well.

The first column in Panel B shows the results for the plain cubic specification. The coefficient vector of interest is $\mathbf{\Gamma}_2$, that is, the interaction coefficients that describe $\Delta^c(x)$. The intercept coefficient is 6.0 bps and statistically significant at the 1% level. The point estimates of the slope and curvature coefficients (of $\Delta^c(x)$) are neither economically nor statistically significantly different from zero. In other words, on average over sample days, the spot curve

[22]Under the Fisher (1966) specification, the estimated average spot curve for rating category 1 is

$$s_1^f(x) = \widehat{\gamma}_{0,1}^f + \widehat{\gamma}_{1,1}^f x + \widehat{\gamma}_{2,1}^f x^2 + \widehat{\gamma}_{3,1}^f x^3 + \widehat{\gamma}_{4,1}^f \ln(x), \tag{4}$$

where $\{\widehat{\gamma}_{k,1}^f\}_{k=0}^4$ are the estimated regression coefficients, and the estimated average delta curve is

$$\Delta^f(x) = \widehat{\gamma}_{0,2}^f + \widehat{\gamma}_{1,2}^f x + \widehat{\gamma}_{2,2}^f x^2 + \widehat{\gamma}_{3,2}^f x^3 + \widehat{\gamma}_{4,2}^f \ln(x), \tag{5}$$

where $\{\widehat{\gamma}_{k,2}^f\}_{k=0}^4$ are the estimated regression coefficients.

[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).

of the high-haircut bonds (rating category 2) lies a level 6.0 bps over that of the low-haircut bonds (category 1). Results under the Fisher (1966) specification (column 2) are practically identical, with a level 5.6 bps difference between high- and low haircut bonds. In short, regardless of the fine details of the curve specification, the high-haircut spot curve is estimated to lie above the low-haircut curve over the full sample range of maturities.

7. Main analysis: Difference-in-differences

The finding above that Italian government bonds with relatively high haircuts have higher yields controls for residual maturity. Nevertheless, we cannot conclude that this necessarily results from differences in haircuts because we cannot rule out that there are other, unknown differences between bonds in the two rating categories. Our main analysis, therefore, uses a DiD approach with identification coming from exogenous haircut shocks.

As discussed in Section 5, the first two events involve a divergence of haircuts between treated and control bonds, while the last two events involve haircut convergence. 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 update on October 1, 2013, haircut differences between rating categories 1 and 2 increase (see 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. By comparing harmonization announcement and implementation treatment effects, we can examine the relative importance of anticipated versus current haircuts in the data.

The question as to whether anticipated haircut changes affect yields is also relevant for the first two events. It is unclear to what extent market participants anticipated the first mass corrections of collateral framework implementation mistakes of Italian 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 yields should also react to the mass-correction and haircut update events if reserves are tight.

7.1 Filtering the data for the event studies

We use ten day windows around each event, from −5 to +4.[24] The underlying data is the cleaned sample of zero-coupon bonds discussed in Section 5.2 and used in Section 6. 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 in a twenty-day window around the event. In addition, for each event, we filter out bonds that do not have fresh (non-stale) market prices every day within the ten-day window. This ensures equal consideration of sample bonds with respect to the estimation of yield curves and treatment effects.

Insert Table 7 here.

For each event, Table 7 reports on the number and percentage of treated and control bonds by ECB maturity bucket. For the first event, thirty-nine control and sixty-one treated bonds pass the filters. 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. Bonds are more evenly distributed for the last two events, but are still not matched on residual maturity.

7.2 Methodology: DiD in curves

As discussed by Nyborg and Woschitz (2025), if an outcome variable exhibits a term structure, there is little reason to believe that treatment effects have no term structure. Furthermore, because term structures are not constant over time, a well specified econometric model needs to separate idiosyncratic movements, that are unrelated to treatment, from changes in the term structure that are caused by treatment. This is especially critical when treated units and controls do not match on residual maturity, as is the case in our data. As shown by Nyborg and Woschitz (2025), the classical DiD specification with bond fixed effects commonly used in the fixed-income literature is misspecified, regardless of whether the control vector includes variables that are functions of residual maturity.[25] Therefore, we use a DiD in curves as

[24]For the second event (haircut update), we form the window 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.

[25] The classical DiD specification is:

$$y_{it} = \alpha_i + \delta_t + \beta_{DiD}\, \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} + \mathbf{\Gamma}'\mathbf{Z}_{it} + \varepsilon_{it}, \qquad (6)$$

follows:

$$yield_{it} = \mathbf{B}_1' \ \mathbf{L}_{it} + \mathbf{B}_2' \ \mathbf{L}_{it} \ \mathbb{1}_{Treated,i} + \mathbf{B}_3' \ \mathbf{L}_{it} \ \mathbb{1}_{Post,t} + \mathbf{B}_4' \ \mathbf{L}_{it} \ \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} \ + \ \varepsilon_{it}, \tag{7}$$

where $\mathbf{L}_{it}$ is a vector of regressors that depend on the yield curve functional form and $\mathbf{B}_j$ is the corresponding vector of coefficients; $\mathbb{1}_{Treated,i}$ and $\mathbb{1}_{Post,t}$ are treatment and post-event indicator variables, respectively; and ε_{it} is an error term. We do not include controls since all bonds are Italian government zeros. Equation (7) is distinguished from the classical DiD specification by being in curves rather than at the individual unit level. Instead of a single treatment effect estimate, it generates an estimate of the term structure of the treatment effect as discussed next.

For robustness, we run Equation (7) under two curve specifications; namely, the Diebold and Li (2006) factorization of the Nelson and Siegel (1987) curve, which is designed to mitigate factor collinearity, and, for robustness, a plain cubic. The Nelson and Siegel (1987) yield-curve specification and its extensions, e.g., Svensson (1994), are characterized by exponential decay of the impact of slope and curvature factors. Unlike cubics, these models do not blow up at long maturities and are also somewhat smoother. They are widely used in the literature and in practice to estimate curves for a wide range of bonds, see, e.g., Elton, Gruber, Agrawal, and Mann (2001), Beber, Brandt, and Kavajecz (2009), Buraschi, Menguturk, and Sener (2015).

The Diebold-Li spot curve at time t is given by

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

where

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

where the α_i's and δ_t's are individual unit and time fixed effects, respectively; y_{it} is the outcome variable; $\mathbf{Z}_{it}$ and $\mathbf{\Gamma}_{it}$ are vectors of control variables and coefficients, respectively; β_{DiD} is the treatment effect; and ε_{it} is an error term. Nyborg and Woschitz (2025) show that for variables with a term structure, Equation (6) is misspecified because it cannot separate out idiosyncratic and true treatment effects in the term structure. It leads to a problem of false treatment effects mixed with garbled true treatment effect, the latter because it incorporates true treatment effects as an average across treated sample bonds. Unless there is perfect matching on residual maturities between treated units and controls and the treatment effect is homogeneous over the term structure, this is problematic on many levels (Nyborg and Woschitz, 2025), including that it simply does not generate a meaningful treatment effect estimate. A simple way to try to deal with heterogeneous effects over the maturity spectrum would be to run Equation (6) on selected maturity buckets. However, besides the theoretical issue as to how those maturity buckets should be formed, implementation can be problematic because of a paucity of bonds. Furthermore, as explained by Nyborg and Woschitz (2025), this approach just pushes the basic problem down to the maturity-bucket level.

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. As is common in practice, we assume a time-invariant decay parameter, that is, $\lambda_t = \lambda$ for all t. Diebold and Li (2006) also work with a time-invariant decay parameter, which, based on practice, they set equal to $\lambda = 0.0609$. This translates into $\lambda = 0.7308$ when the unit for residual maturity is years (as in our case).[26] In this paper, however, we estimate λ in sample for each event. The motivation is twofold. First, the Diebold-Li lambda is an educated guess based on US Treasury data. There is little reason to expect it to be the same across countries and time. Second, the model fits worse under the Diebold-Li lambda (see Table A.2, Panel A in the Internet Appendix).

Under Diebold-Li curves, $\mathbf{L}_{it}$ in Equation (7) is a three-dimensional vector of regressors, $(1, l_1(x_{it};\lambda), l_2(x_{it};\lambda))$, and $\mathbf{B}_j$ is the corresponding vector of coefficients, with elements $\beta^{dl}_{k,j}$, $k = 0, \ldots, 2$. We estimate all parameters, including λ, jointly using NLS, and standard errors are clustered at the bond level using the Delta method.

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

$$s^{dl}(x;\lambda) = \widehat{\beta}^{dl}_{0,1} + \widehat{\beta}^{dl}_{1,1}\ l_1(x;\lambda) + \widehat{\beta}^{dl}_{2,1}\ l_2(x;\lambda), \tag{10}$$

where $\{\widehat{\beta}^{dl}_{k,1}\}^2_{k=0}$ 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

$$\Delta^{dl}_j(x;\lambda) = \widehat{\beta}^{dl}_{0,j} + \widehat{\beta}^{dl}_{1,j}\ l_1(x;\lambda) + \widehat{\beta}^{dl}_{2,j}\ l_2(x;\lambda), \tag{11}$$

where $\{\widehat{\beta}^{dl}_{k,j}\}^2_{k=0}$ 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 $\Delta^{dl}_4(x)$, which is the object of interest.

Under cubic curves, $\mathbf{L}_{it}$ in Equation (7) is a four-dimensional vector $(1, x_{it}, x^2_{it}, x^3_{it})$, and $\mathbf{B}_j$ is the corresponding vector of coefficients, with elements $\beta^c_{k,j}$, $k = 0, \ldots, 3$. In this case, estimation is with OLS. Standard errors are clustered at the bond level. The estimated spot

[26] 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 for all t. The "Diebold-Li lambda" is then $\lambda = 0.0609$, equivalent to 0.7308 when the residual maturity is in years. When λ is fixed "in advance," the three remaining parameters in Equation (8) can be estimated by OLS.

curve for controls over the pre-event period is

$$s^c(x) = \widehat{\beta}^c_{0,1} + \widehat{\beta}^c_{1,1}x + \widehat{\beta}^c_{2,1}x^2 + \widehat{\beta}^c_{3,1}x^3, \tag{12}$$

where $\{\widehat{\beta}^c_{k,1}\}^3_{k=0}$ are the estimated regression coefficients. Similarly to before, the three delta curves are given by

$$\Delta^c_j(x) = \widehat{\beta}^c_{0,j} + \widehat{\beta}^c_{1,j}x + \widehat{\beta}^c_{2,j}x^2 + \widehat{\beta}^c_{3,j}x^3, \tag{13}$$

where $\{\widehat{\beta}^c_{k,j}\}^3_{k=0}$ are the estimated regression coefficients, $j = 2, \ldots, 4$. The DiD estimator is given by the vector $\widehat{\mathbf{B}}_4$, and the delta curve of interest is $\Delta^c_4(x)$.

In the DiD in curves model, the estimated treatment effect depends on, and controls for, maturity in a fully flexible way. The DiD delta curve, Δ_4, captures the treatment effect at each maturity, which is also what is economically interesting.

7.3 Results

The results are in Table 8 and Figure 5. The table shows treatment effects at selected maturities, with z-statistics in parentheses. Panel A uses the Diebold-Li curve specification and Panel B the cubic functional form.[27] Standard errors are clustered at the individual bond level. Statistical significance at the 1%, 5%, or 10% levels are denoted by superscripts a, b, or c. The figures plot the treatment delta curves, $\Delta_4(x)$, for each event under the two curve specifications and with 10% confidence bands.

Insert Table 8 and Figure 5 here.

We first discuss the results under Diebold-Li curves. Note first that goodness of fit is exceptional, with adjusted R^2 ranging from 99.41% (first divergence) to 99.64% (harmonization announcement). This excellent fit is the result of a well specified model that separates out the curves of rating category 2 and 1 bonds. A contributing factor may be that practitioners use curves to price bonds in practice.

In terms of treatment effects, there are two key qualitative takeaways. First, the treatment effect is heterogeneous over the maturity spectrum, being significant only at short-to-mid durations (roughly five years). This is consistent with banks being the only counterparties in

[27] We have also run estimation under Diebold-Li curves with OLS using in-sample lambdas calculated as the average of daily estimates, with the latter coming from estimating Equation (8) with NLS separately for treated and control bonds on each day in each event window. The results, which are in the Internet Appendix (Table A.2, Panel B), are practically indistinguishable from those in Table 8, Panel A.

Eurosystem repos and the fact that banks hold predominantly short-term paper. Second, the treatment effect is positive when haircuts between the two rating categories diverge; and it is negative when haircuts converge. In other words, the results are qualitatively the same in each of the four event studies: at short-to-mid durations, yields increase in haircuts; equivalently, they fall in a bond's rate of convertibility into reserves.

To discuss the results in more detail, we start in reverse chronological order by first discussing events 3 and 4; that is, the announcement and implementation of haircut harmonization. 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.

With respect to the implementation of haircut harmonization, Figure 5 shows a significant (10% level) negative treatment effect out to 5.47 years. Table 8, Panel A shows that the effect is significant at the 1% level out to at least three years, where the estimated effect is -2.5 bps. At one year maturity, the treatment effect is -4.0 bps, which is two thirds of the 6.0 bps average difference between the spot curves of Italian rating category 2 and 1 bonds estimated in Section 6.2. It is noteworthy that we find these strong results *even though this event was fully anticipated* over a period of more than two months. This is consistent with a positive marginal value to reserves by holders of Italian government bonds, since it is only when the haircut change is implemented that it is possible to get more reserves from the central bank with the bonds.

For the harmonization announcement, the magnitude of the treatment effect is slightly smaller, being -2.0 bps at three years and -1.8 bps at the one-year maturity (both significant at the 1% level). Figure 5 shows an estimated significance boundary for this event of 10.03 years.

To capture the full harmonization effect, we need to consider potential changes in spot rates over the interim period between announcement and implementation. As the date at which the haircut actually changes approaches, the time value of an anticipated value increase should increase. In the data, over the interim period, $[\text{announcement}+5, \text{implementation}-6]$, the one-year spot rate of treated bonds falls by 3.63 bps relative to control bonds (under Diebold-Li curves). Thus, the total effect of haircut harmonization at the one-year maturity is -9.4 bps, or -1.7 bps per percentage point reduction in haircut.

Given our finding that yield differentials shrink when haircuts are harmonized, we would expect to see the opposite when haircuts diverge. This is also what we find. At the one-year maturity, the estimated treatment effects are 1.2 bps (significant at the 5% level) for the first divergence date and 4.3 bps (significant at the 1% level) for the haircut update. The latter is especially large because the increase in haircut for one-year bonds is only 0.5 percentage points at this event. Figure 5 shows significance up to 2.76 years for the first divergence date and 1.90 years for the haircut update.

The results under cubic curves are qualitatively concordant with the results under Diebold-Li. Goodness of fit remains excellent, with the lowest adjusted R^2 being 99.33% (harmonization implementation). The results for haircut harmonization are almost the same as under Diebold-Li. Figure 5 shows an estimated significance boundary for the implementation event of 5.72 years, dropping to 4.74 years at announcement. With respect to treatment effect magnitudes, at the one-year maturity, the estimated effect is -1.5 bps at the harmonization announcement and -4.3 bps at implementation (both significant at the 1% level). Over the interim period, the difference between rating category 2 and 1 curves shrinks by 4.3 bps under the cubic specification. These numbers imply a total estimated harmonization effect under the cubic specification of -10.1 bps, or -1.8 bps per percentage point reduction in haircut which is almost identical to the -1.7 bps number estimated under Diebold-Li.

In summary, for the harmonization events, both curve specifications offer superb fit and show consistently significant treatment effects out to around 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 basis points per percentage point change in haircut.

The results for the first two events are slightly stronger under the cubic specification than under Diebold-Li. For example, the treatment effect at the one-year maturity is estimated as 1.9 bps (significant at the 5% level) for the first divergence date and 6.2 bps (significant at the 1% level) for the haircut update.

Overall, results using the two curve specifications are similar and 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. In other words, short- to mid-range bond yields are decreasing in their degree of convertibility into new reserves provided directly by the central bank. Insignificance at the long end is consistent with eligible counterparties in Eurosystem repos (banks) typically holding shorter duration bonds. Magnitudes of the treatment effect are economically meaningful and show that government bond yields can be affected by central bank collateral policy. While our findings show that economically significant effects can be achieved with sufficiently large changes in central-bank haircuts, they also suggest that policy is likely to have the most significant impact in habitats where players with access to central bank repos are active.

7.4 Exclusion restriction

With respect to the question as to whether our findings can be driven by something other than relative changes in haircuts between treated and control bonds, it bears emphasis that our findings across the four events are consistent with each other. That we have used four events, and these are also the complete set of feasible events that exploit haircut inconsistencies (as we have shown), means that we have set the bar high. Furthermore, unlike the classical DiD specification (Equation (6), Footnote 25), the DiD in curves is well specified with respect to idiosyncratic, non-treatment related movements in the term structure. The results are similar under the two curve specifications. Thus, the only issue with respect to the exclusion restriction is whether treated and control bonds are subject to systematic changes in their pricing around our events that are not related to relative changes in central-bank haircuts.

With respect to this: First, we are not aware of other, contemporaneous events that could change bond yields systematically and differentially between the two rating categories. Second, over the event windows, none of the bonds experience ratings changes or move across ECB maturity buckets. Third, there are no coupon payments. Fourth, by virtue of being on the public list of eligible collateral, none of the bonds have option features. Fifth, government bonds do not change characteristics after issuance. Sixth, we have perfect issuer control. Seventh, we have used short event windows. Finally, unconditionally, spot rates of Italian government bonds in the two rating categories have a very high degree of comovement. In Figure 4c, the correlation between the two rating category series is 99.72%.

Insert Figure 6 here.

To assess the parallel trends condition for outcome variables that exhibit a term structure, it is necessary to adjust for residual maturities when treated and control units differ on this dimension (Nyborg and Woschitz, 2025). Our approach is to calculate average treated and control bond yields in five-day increments around each event, going from -15 to $+10$, as follows: for each group and five-day period, we first average yields within Eurosystem maturity buckets and then across these maturity-bucket averages. Figure 6 plots the resulting trend lines for treated and control bond yields (red crosses and blue circles, respectively). There is no visible difference in the pre-event trends of the treated and control bonds in any of the four subplots of Figure 6. This supports that the exclusion restriction is satisfied in all four events. Furthermore, consistent with the view that higher haircuts lead to higher yields, for the first two (last two) events, where treated bonds experience a relative increase (decrease) in haircuts, the relative yields of treated bonds visibly increase (decrease).

8. Concluding remarks

This paper shows the existence of a reserves convertibility premium in government bonds, which tapers off and becomes insignificant at longer maturities. A higher rate of convertibility into new reserves from the central bank leads to a higher market price, ceteris paribus, for bonds with up to around five years of residual maturity. Our analysis is motivated by Hicks (1939), who argues that reduced costs of converting bills and bonds into money for transactional purposes increases their "moneyness" and should put downward pressure on their yields. We expand on this by placing the emphasis on reserves and the rate of convertibility of securities into reserves in direct dealings with the central bank. By focusing on changes in central bank haircuts and using a DiD in curves specification that takes account of term effects, we capture a pure reserves convertibility effect over the maturity spectrum. Our findings show that reserves can be priced in government bonds, with habitat effects.

The analysis is carried out in the context of the monetary policy implementation framework of the Eurosystem before the introduction of the public sector purchase program (QE). Under this framework, the central bank employs repo operations (and facilities) to provide banks with sufficient reserves to ensure the smooth running of the payment system, to allow banks to fulfill reserve requirements, and to steer the overnight rate close to the policy target. Rates of convertibility into reserves are defined by haircuts in these repos, which are set by the central bank in its collateral framework. Identification is based on differential treatment of same-country government bonds with respect to these haircuts and several events where this changed. The large yield spreads of the Italian government bonds we study over German ones mean that we are not studying safe securities, but risky ones. Thus, our results stand in contrast to the common notion that liquidity premia necessarily reflect safety, since the convertibility premium is a liquidity premium in its most fundamental, Hicksian form. By exploiting details of the Eurosystem's collateral framework, we show that the central bank can have the power to affect an asset's moneyness and price by adjusting its exchangeability into reserves, which banks need to settle transactions and obligations, even if the market perceives the asset to be quite risky.

However, our finding that the convertibility premium is insignificant at longer maturities also shows that there is a limit to the ability of a central bank to endow securities with moneyness. As suggested by Nyborg and Strebulaev (2001), collateral policy would be expected to be most effective on assets actually held by eligible counterparties. In the Eurosystem, these are banks, and banks are known to hold relatively short duration assets. It may well be that the relatively low haircuts on low duration assets contribute to banks holding these in the first place. Examining the drivers of banks' security holdings and, in turn, the impact on convertibility premia would be an interesting direction for future research. Richer theoretical models could help provide a deeper understanding as to why some assets have a convertibility premium while others do not.

With respect to policy, our findings imply that a central bank can potentially influence the difference between short and long term rates through collateral policy. Using collateral policy to target long-term rates specifically, however, may require opening access to central bank reserves and operations to non-banks such as insurance companies or pension funds that hold long duration assets. But this may give rise to its own set of issues. In policy circles, it has been suggested that collateral policy can be used to stimulate green investments by giving relatively low haircuts to green bonds (Villeroy de Galhau, 2019; Schoenmaker, 2021). However, our finding of a habitat effect suggests that the success of such a policy might depend on the extent to which banks (eligible counterparties) hold the targeted assets.

Theoretically, convertibility premia relate to binding monetary constraints as in Chapman, Chiu, and Molico (2011) or along the lines of the models surveyed and synthesized by Lagos, Rocheteau, and Wright (2017). Thus, given time variation in liquidity conditions in the financial system, the convertibility premium would be expected to vary over time. This can contribute to some differences in estimated treatment effects for treated bonds across events. Unfortunately, our identification approach does not generate a sufficient number of events to examine the dynamics of the convertibility premium. Developing alternative identification strategies or other methods to get at this issue would be another important avenue for further research.

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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. While the sample covers the period to January 7, 2015, this table illustrates that the same haircuts are in place until at least 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, 2016, 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 (2016, 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) 0-1	1-3	3-5	5-7	7-10	>10	Residual maturity (years) 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. Credit rating agency 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 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, 2016, Sections 6.1 and 6.2, and, in particular, Table 6.1, Panel E, and ECB collateral framework references therein). Before this, 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 (2016, Subsections 5.3, 5.4, and, in particular, Tables 5.2, 5.3, 5.4, and 5.5) and ECB collateral framework references therein.

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

Table 3. Haircut inconsistencies and difference-in-differences in yields: Two examples. This table shows two pairs of eligible Italian zero-coupon government bonds maturing on the same date (Panel A) or two days apart (Panel B), with different haircuts and ECB rating categories prior to haircut harmonization. Haircuts in the table apply per crossing of the one-year residual maturity threshold or since issuance until (and including) the public eligible collateral list that applies on December 12, 2014 (the last trading day before haircut harmonization on December 15, 2014; intervening days are a weekend). Haircuts are from the public lists; rating categories are inferred using Table 1. To the right the two panels report issue and country ratings from all four official agencies applicable on December 12, 2014. In Example 1, both bonds mature on December 31, 2014; in Example 2, on January 30 and February 1, 2015. The December 12 rating rule assigns the highest issue or, if unavailable, the highest country rating as the "collateral framework rating." 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. From December 15 onward, only the highest country rating applies. Panel C shows the difference-in-differences in yields around haircut harmonization, calculated as $\Delta_{Post} - \Delta_{Pre}$, where Δ is the yield of the second bond (high haircut before harmonization) minus that of the first bond, using five-day averages of non-stale end-of-day yields (all bonds have market prices in Bloomberg). Data sources: Bond maturities and haircuts from the ECB collateral lists (December 12 and 15, 2014) and ratings and yields from Bloomberg.

ISIN	Maturity	Haircut (in %)	Rating category	Rating agency	Issue rating	Country rating
Panel A: Example 1, before haircut harmonization						
IT0004890890	Dec. 31, 2014	0.5	1	S&P	–	BBB–
			(AAA to A–)	Fitch	BBB+	BBB+
				Moody's	Baa2	Baa2
				DBRS	**AL**	AL
IT0005026965	Dec. 31, 2014	6.0	2	S&P	–	BBB–
			(BBB+ to BBB–)	Fitch	**BBB+**	BBB+
				Moody's	–	Baa2
				DBRS	–	AL
Panel B: Example 2, before haircut harmonization						
IT0004848625	Feb. 1, 2015	0.5	1	S&P	–	BBB–
			(AAA to A–)	Fitch	–	BBB+
				Moody's	–	Baa2
				DBRS	–	**AL**
IT0005037251	Jan. 30, 2015	6.0	2	S&P	–	BBB–
			(BBB+ to BBB–)	Fitch	**BBB+**	BBB+
				Moody's	–	Baa2
				DBRS	–	AL
Panel C: DiD in yields, ten-day window around haircut harmonization						
Example 1:	−3.50 bps					
Example 2:	−10.12 bps					

Table 4. Haircut inconsistencies across countries in the sub-sample of securities with market prices.

This table provides an overview of the incidence of haircut inconsistencies across countries for the sub-sample of securities with market prices. 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. In each panel, the first column shows, by country, the number of sample days with haircut inconsistencies. In Panel A, 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. Panel B 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 to the right of 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: Number of securities by country and implied rating category for haircut inconsistency periods

		Number of securites across haircut inconsistency periods									
	Number	RC 1 & 2				RC 1			RC 2		
Country	of days	total	mean	min	max	mean	min	max	mean	min	max
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	24	11.7	10	13	10.0	9	10	1.7	1	3
Italy	345	250	172.0	159	192	103.3	91	116	68.8	53	78
Latvia	16	25	21.8	7	25	6.7	3	7	15.1	1	19
Portugal	1	24	24.0	24	24	15.0	15	15	9.0	9	9
Slovenia	14	19	14.4	12	17	12.4	10	15	2.0	2	2
Spain	441	220	142.5	58	154	126.4	49	149	16.1	1	25
Total	1,142	593									

Panel B: Fraction of days with haircut inconsistencies by maturity bucket (as percentage of total number of haircut inconsistency days)

	Number	Maturity buckets																
Country	of days	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	15-20	20-30
Cyprus	33																	
Greece	1																	
Hungary	97						100											
Ireland	194	99																
Italy	345	100	100	91	64	100	100	100	100	100	99	100	100	100	100	87	100	100
Latvia	16	94	94			94		88										
Portugal	1	100				100												
Slovenia	14				21						50							
Spain	441	89	89	95	88	44	44	89	75	38	6	5					5	88

Table 5. Summary statistics.

This table shows summary statistics on the final samples of zero-coupon bonds with market prices for Italy 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 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
Panel A: Period from August 9, 2013 to March 31, 2014							
Number of bonds	Rating category 1	46.81	47.00	1.81	0.14	41.00	51.00
	2	60.42	61.00	2.19	0.17	53.00	63.00
Yield diff. (RC2−RC1) [pps]	Unadjusted	2.006^a	2.017	0.114	0.009	1.726	2.190
	Maturity adjusted	0.084^a	0.062	0.052	0.004	0.012	0.193
Average resid. mat. [years]	Rating category 1	5.12	5.13	0.13	0.01	4.59	5.49
	2	12.12	12.14	0.15	0.01	11.70	12.57
Shortest resid. mat. [years]	Rating category 1	0.05	0.05	0.02	0.00	0.03	0.12
	2	0.17	0.16	0.11	0.01	0.03	0.72
Longest resid. mat. [years]	Rating category 1	25.61	25.66	0.40	0.03	23.04	25.98
	2	25.16	25.17	0.19	0.01	24.84	25.48
Maturity range	Rating category 1	25.56	25.63	0.40	0.03	23.00	25.92
(longest−shortest)	2	24.99	25.00	0.23	0.02	24.25	25.25
Number of days				164			
Panel B: Period from April 1, 2014 to December 12, 2014							
Number of bonds	Rating category 1	31.61	30.00	4.90	0.36	28.00	52.00
	2	74.37	75.00	1.76	0.13	70.00	78.00
Yield diff. (RC2−RC1) [pps]	Unadjusted	0.491^a	0.558	0.230	0.017	-0.359	0.744
	Maturity adjusted	0.028^a	0.028	0.030	0.002	-0.034	0.076
Average resid. mat. [years]	Rating category 1	7.71	7.35	1.23	0.09	6.95	12.44
	2	9.53	9.52	0.20	0.01	9.11	10.11
Shortest resid. mat. [years]	Rating category 1	0.13	0.13	0.07	0.01	0.03	0.44
	2	0.07	0.06	0.03	0.00	0.03	0.16
Longest resid. mat. [years]	Rating category 1	26.05	25.13	1.97	0.15	24.64	29.96
	2	24.48	24.48	0.20	0.02	24.06	24.84
Maturity range	Rating category 1	25.92	25.00	1.97	0.15	24.58	29.92
(longest−shortest)	2	24.41	24.39	0.21	0.02	24.00	24.80
Number of days				181			

Table 6. Average delta curve coefficients over time.

This table is based on the final sample of 177 Italian zero-coupon bonds with market prices over the period from August 9, 2013 to December 12, 2014 (bond-dates with stale prices are excluded). Panel A shows sample statistics on the number of days and bonds. Panel B shows the results from the following specification, run using the Fama-MacBeth procedure: $yield_{it} = \mathbf{\Gamma}_1' \ \mathbf{Mat}_{it} + \mathbf{\Gamma}_2' \ \mathbf{Mat}_{it} \ \mathbb{1}_{RC2,it} + \varepsilon_{it}$, where $\mathbf{Mat}_{it}'$ is a vector of variables that are functions of residual time-to-maturity x_{it} (with subscripts indicating bond i on day t). $\mathbb{1}_{RC2,it}$ 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 vector of delta curve coefficients. The first column shows results using the cubic version where $\mathbf{Mat}_{it}' = [1 \quad x_{it} \quad x_{it}^2 \quad x_{it}^3]$. The second column shows results with the version of Fisher (1966) where $\mathbf{Mat}_{it}' = [1 \quad x_{it} \quad x_{it}^2 \quad x_{it}^3 \quad \ln(x_{it})]$. 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. "RC" stands for rating category.

Panel A: Sample statistics on number of days and bonds			
Number of days		345	
Number of bonds and observations	All	RC 1	RC 2
Mean number of bonds	106.58	38.84	67.74
Min number of bonds	98	28	53
Max number of bonds	126	52	78
Number of observations	36,769	13,399	23,370

Panel B: Regressions	(1) Cubic	(2) Fisher (1966)
Constant	**0.152**^{a}	**0.066**^{b}
	(8.65)	(2.03)
x	**0.475**^{a}	**0.546**^{a}
	(19.37)	(34.39)
x^2	**-0.017**^{a}	**-0.021**^{a}
	(-8.55)	(-17.06)
x^3	**0.000**^{a}	**0.000**^{a}
	(4.19)	(10.66)
$\ln(x)$		**-0.102**^{a}
		(-5.41)
$\mathbb{1}_{RC2}$	**0.060**^{a}	**0.056**^{a}
	(4.07)	(3.19)
$\mathbb{1}_{RC2} \times x$	0.002	-0.008
	(0.25)	(-0.66)
$\mathbb{1}_{RC2} \times x^2$	-0.000	0.001
	(-0.30)	(0.70)
$\mathbb{1}_{RC2} \times x^3$	0.000	-0.000
	(0.26)	(-0.69)
$\mathbb{1}_{RC2} \times \ln(x)$		0.012
		(0.69)
Average adjusted R-squared	0.9962	0.9972

Table 7. Overview of the number of bonds for each event in the DiD analysis.

This table provides an overview of the number of control and treated bonds in the DiD analysis. Each panel provides the number and percentage of control and treated bonds by maturity bucket for the ten-day event window around each of the four events. 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).

						Harmonization			
		First divergence		Haircut update		announcement		implementation	
	Maturity	August 9, 2013		October 1, 2013		September 1, 2014		December 15, 2014	
	buckets (in years)	Number of securities	in %	Number of securities	in %	Number of securities	in %	Number of securities	in %
Treated bonds	0-1	3	4.9	3	4.8	11	16.4	14	20.3
	1-3	4	6.6	4	6.5	3	4.5	3	4.3
	3-5	2	3.3	2	3.2	4	6.0	5	7.2
	5-7	5	8.2	6	9.7	6	9.0	6	8.7
	7-10	9	14.8	9	14.5	7	10.4	7	10.1
	10-15	16	26.2	16	25.8	18	26.9	16	23.2
	15-20	13	21.3	13	21.0	10	14.9	10	14.5
	>20	9	14.8	9	14.5	8	11.9	8	11.6
Total treated		61	100.0	62	100.0	67	100.0	69	100.0
Control bonds	0-1	15	38.5	15	36.6	5	17.2	4	14.3
	1-3	6	15.4	6	14.6	7	24.1	8	28.6
	3-5	5	12.8	6	14.6	4	13.8	3	10.7
	5-7	2	5.1	2	4.9	2	6.9	2	7.1
	7-10	2	5.1	3	7.3	3	10.3	3	10.7
	10-15	3	7.7	3	7.3	2	6.9	3	10.7
	15-20	3	7.7	3	7.3	4	13.8	3	10.7
	>20	3	7.7	3	7.3	2	6.9	2	7.1
Total controls		39	100.0	41	100.0	29	100.0	28	100.0

Table 8. Treatment effects at selected maturities under the fully flexible specification. This table is based on the Italian sample of zero-coupon bonds with non-stale market prices each day over the ten-day event-windows discussed in Table 7. It provides estimated treatment effects (in pps) of treated bonds at selected maturities for each event using the 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 vector of regressors (that depend on the functional yield curve form), $\mathbf{B}_j$, $j = 1, \ldots 4$, are the corresponding coefficient vectors, and $\mathbb{1}_{Treated,i}$ ($\mathbb{1}_{Post,t}$) is an indicator variable that is one for treated bonds (event and post-event dates) and zero otherwise. $\mathbf{B}_4$ is the DiD estimator. Panel A uses the yield-curve form of Diebold and Li (2006) where $\mathbf{L}_{it} = [1 \quad l_1 \quad l_2]'$ with $l_1(x_{it}; \lambda) = \left(1 - e^{-\lambda x_{it}}\right) / (\lambda x_{it})$ and $l_2(x_{it}; \lambda) = \left(1 - e^{-\lambda x_{it}}\right) / (\lambda x_{it}) - e^{-\lambda x_{it}}$. x_{it} is the residual time-to-maturity of bond i on day t. λ is the decay parameter. For each event, the model is estimated with NLS with a seed value $\lambda = 1$ (the resulting estimates are shown at the bottom of the panel). Panel B uses a cubic yield-curve form where $\mathbf{L}_{it} = [1 \quad x_{it} \quad x_{it}^2 \quad x_{it}^3]'$. For each event, the model is estimated with OLS. For the "haircut update" event, we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013). Underneath the treatment effects, the table provides (in parentheses) z-statistics calculated using the delta method and clustered at 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 second column provides the DiD in haircuts (in pps) for each selected maturity. For maturity x equaling 1, 3, and 5 years, we have taken the haircut at x minus one day.

Residual maturity (in years)	Haircut differential widens				Haircut differential shrinks			
	First divergence		Haircut update		Harmonization announcement		Harmonization implementation	
	Aug. 9, 2013		Oct. 1, 2013		Sep. 1, 2014		Dec. 15, 2014	
	DiD effects	DiD in hc	DiD effects	DiD in hc	DiD effects	DiD in hc	DiD effects	DiD in hc
Panel A: Using yield-curve specification of Diebold and Li (2006)								
0.5	0.008	5.0	**0.067**^{a}	0.5	**-0.016**^{b}	0.0	**-0.044**^{a}	−5.5
	(1.02)		(4.14)		(-2.27)		(-2.62)	
1	**0.012**^{b}	5.0	**0.043**^{a}	0.5	**-0.018**^{a}	0.0	**-0.040**^{a}	−5.5
	(2.11)		(3.56)		(-3.39)		(-3.02)	
2	**0.014**^{c}	5.0	0.014	1.0	**-0.021**^{a}	0.0	**-0.032**^{a}	−6.0
	(1.95)		(1.46)		(-3.02)		(-3.70)	
3	0.013	5.0	0.002	1.0	**-0.021**^{a}	0.0	**-0.025**^{a}	−6.0
	(1.56)		(0.18)		(-2.58)		(-3.42)	
5	0.007	5.0	-0.004	2.5	**-0.020**^{b}	0.0	**-0.016**^{c}	−7.5
	(0.85)		(-0.46)		(-2.43)		(-1.89)	
8	-0.002	5.0	0.001	4.0	**-0.016**^{b}	0.0	-0.007	−9.0
	(-0.18)		(0.14)		(-2.21)		(-0.82)	
12	-0.008	5.0	0.007	4.0	-0.011	0.0	0.000	−9.0
	(-0.76)		(0.97)		(-1.15)		(0.03)	
16	-0.012	5.0	0.011	4.0	-0.008	0.0	0.004	−9.0
	(-0.96)		(1.31)		(-0.62)		(0.64)	
20	-0.015	5.0	0.014	4.0	-0.006	0.0	0.006	−9.0
	(-1.04)		(1.45)		(-0.38)		(0.79)	
Adj. R-squared	0.9941	–	0.9940	–	0.9964	–	0.9962	–
No. bonds (T/C)	61/39	–	62/41	–	67/29	–	69/28	–
$\widehat{\lambda}$	0.5836	–	0.5979	–	0.3948	–	0.2633	–

Table 8 – *continued*

	Haircut differential widens				Haircut differential shrinks			
	First divergence		Haircut update		Harmonization announcement		Harmonization implementation	
Residual	Aug. 9, 2013		Oct. 1, 2013		Sep. 1, 2014		Dec. 15, 2014	
maturity	DiD		DiD		DiD		DiD	
(in years)	effects	in hc	effects	in hc	effects	in hc	effects	in hc
Panel B: Using a plain cubic yield-curve specification								
0.5	**0.020**[b]	5.0	**0.074**[a]	0.5	**-0.016**[a]	0.0	**-0.048**[a]	−5.5
	(2.04)		(4.58)		(-2.80)		(-2.70)	
1	**0.019**[b]	5.0	**0.062**[a]	0.5	**-0.015**[a]	0.0	**-0.043**[a]	−5.5
	(2.34)		(4.49)		(-3.21)		(-2.94)	
2	**0.017**[b]	5.0	**0.041**[a]	1.0	**-0.013**[a]	0.0	**-0.036**[a]	−6.0
	(2.58)		(3.85)		(-3.56)		(-3.42)	
3	**0.016**[b]	5.0	**0.024**[b]	1.0	**-0.012**[a]	0.0	**-0.029**[a]	−6.0
	(2.18)		(2.48)		(-2.85)		(-3.55)	
5	0.013	5.0	-0.001	2.5	-0.009	0.0	**-0.017**[b]	−7.5
	(1.31)		(-0.07)		(-1.55)		(-2.16)	
8	0.007	5.0	-0.016	4.0	-0.006	0.0	-0.006	−9.0
	(0.63)		(-1.30)		(-0.87)		(-0.64)	
12	-0.000	5.0	-0.009	4.0	-0.004	0.0	0.003	−9.0
	(-0.04)		(-0.73)		(-0.56)		(0.35)	
16	-0.008	5.0	0.013	4.0	-0.003	0.0	0.006	−9.0
	(-0.56)		(1.11)		(-0.40)		(0.61)	
20	-0.016	5.0	**0.029**[b]	4.0	-0.002	0.0	0.008	−9.0
	(-1.19)		(2.57)		(-0.28)		(0.79)	
Adj. R-squared	0.9962	–	0.9962	–	0.9933	–	0.9960	–
No. bonds (T/C)	61/39	–	62/41	–	67/29	–	69/28	–

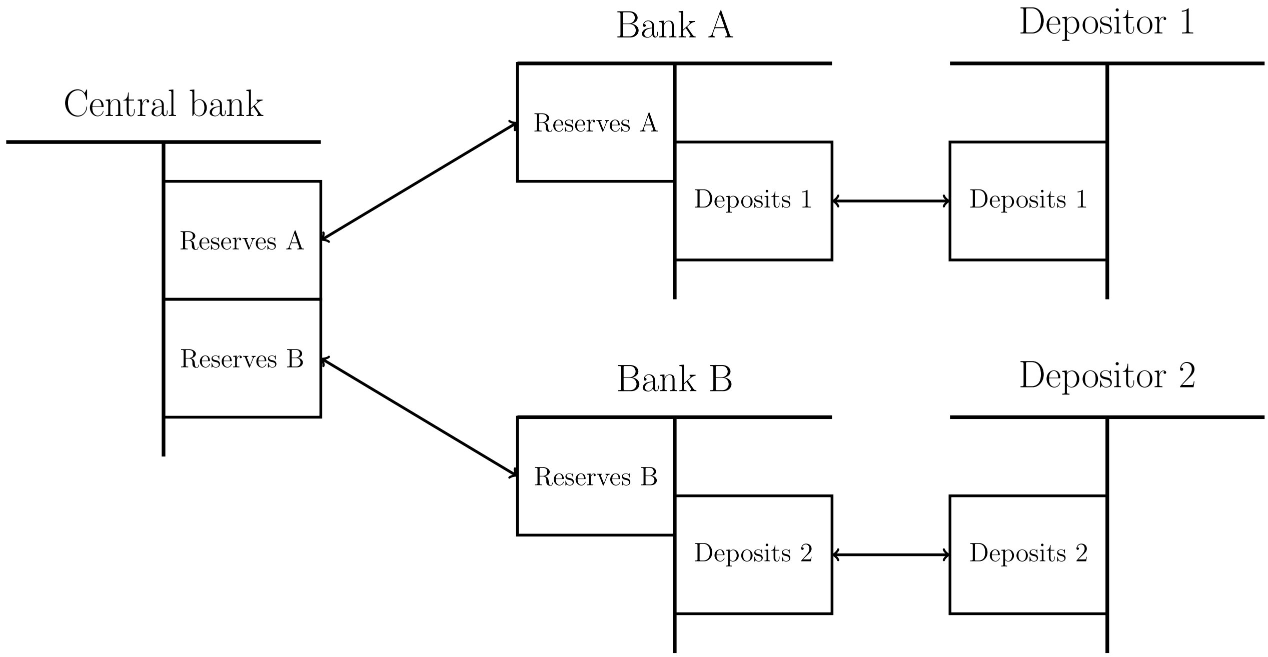


Figure 1. The modern two-tier monetary system.

In the modern two-tier monetary system, transactions ultimately settle in central-bank money (reserves or banknotes). This figure focuses on reserves. In the two-tier system, depositors hold deposits with banks, who, in turn, hold deposits (reserves) with the central bank. Payments between depositors of different banks trigger reserve transfers between the involved banks. For each bank in the system, having sufficient reserves is a hard constraint. Examples:

a. Buy a loaf of bread. If Depositor 1, who is with Bank A, uses her debit card to buy a loaf of bread at the bakery (Depositor 2), which uses Bank B, this triggers a reserves flow from Bank A's central bank account to that of Bank B.

b. Financial assets and leverage. Depositor 1 borrows from Bank A to buy risky assets. The borrowed funds appear as the deposit shown in the figure. Depositor 1 has a corresponding liability toward Bank A (not shown), which is an asset for Bank A (not shown). When Depositor 1 buys the risky securities from Bank B or Customer 2, this triggers a reserves flow from Bank A to Bank B at the level of the central bank.

c. Withdrawals and terminations. The following events trigger a flow of reserves from Bank A to Bank B: (i) Depositor 1 withdraws deposits from Bank A and transfers them to Bank B; (ii) Depositor 2, who banks with Bank B, owns debt issued by Bank A, but refuses to roll this over; (iii) Bank B owns debt issued by Bank A and refuses to roll this over.

d. Banknote withdrawal. Depositor 1 withdraws banknotes from her account with Bank A. To get the banknotes, Bank A exchanges reserves for banknotes with the central bank or Bank B.

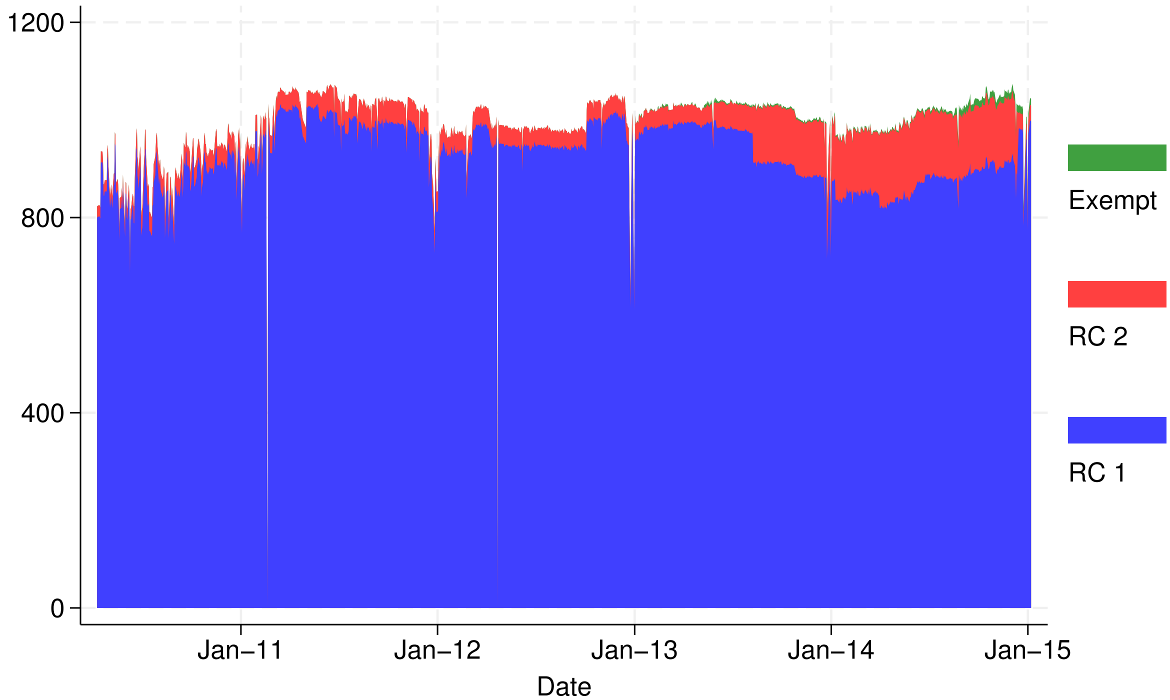
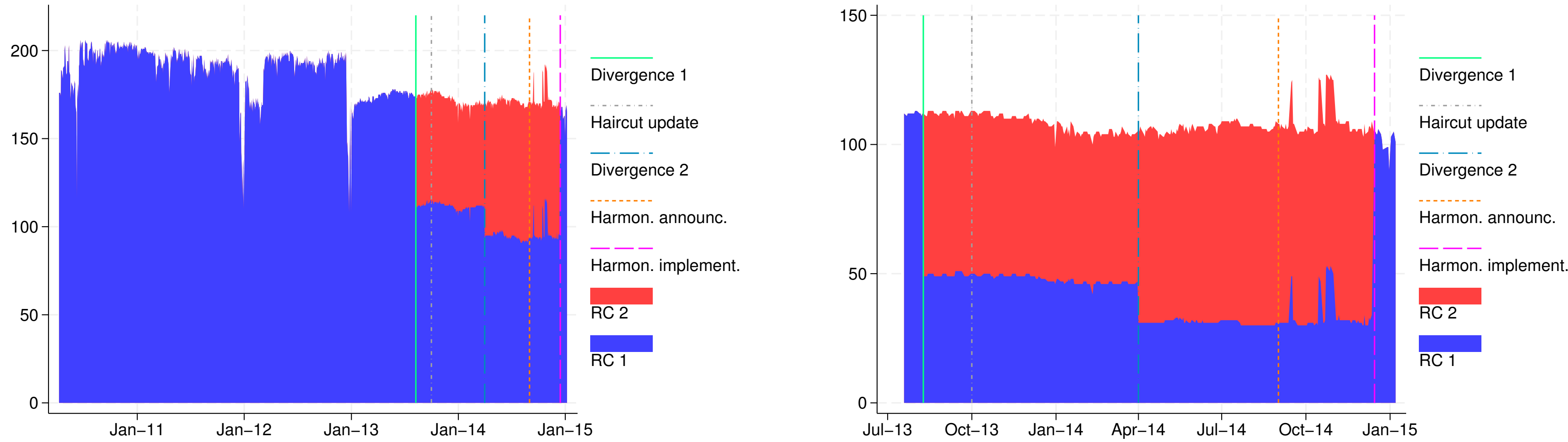


Figure 2. Distributions of government bonds with market prices by rating category (all countries).

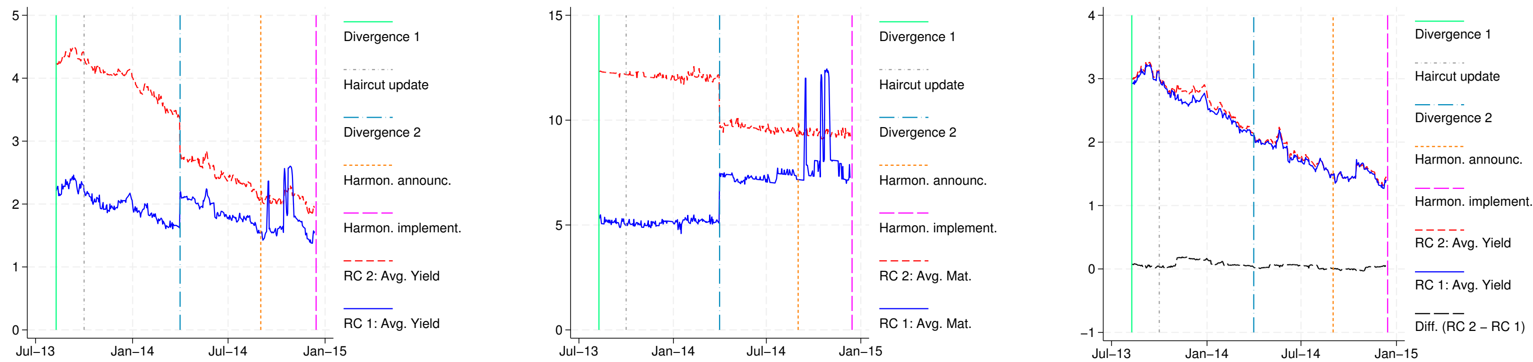
This figure shows the number of fixed- and zero-coupon central-government bonds with market prices by rating category over the time period April 9, 2010 to January 7, 2015, inclusive. "RC" stands for rating category. Rating category 1 (2) refers to securities with a rating in the AAA to A− (BBB+ to BBB−) range (on the S&P scale). "Exempt" refers to securities that are exempt from standard minimum rating requirements and, at the same time, receive extraordinary haircuts (details are in Table 1, Panel B, and references there).



(a) Italian bonds with market prices.

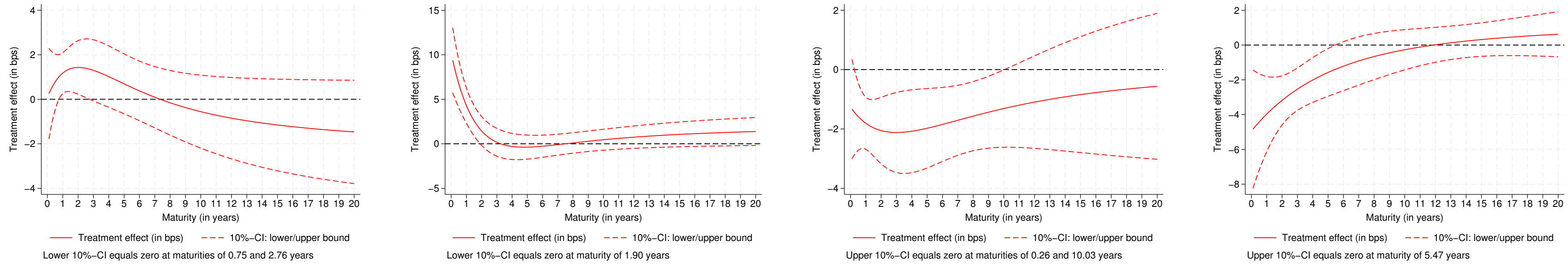
(b) Italian zero-coupon bonds with market prices.

Figure 3. Distributions of Italian government bonds with market prices by rating category.
This figure shows the number of Italian central-government bonds by rating category over time. Subplot (a) includes fixed- and zero-coupon bonds with market prices over the full Italian sample from April 9, 2010 to January 7, 2015, inclusive. Subplot (b) shows the distributions for the final sample of Italian zero-coupon bonds with market prices over the period July 19, 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). "Exempt" refers to securities that are exempt from standard minimum rating requirements and, at the same time, receive extraordinary haircuts (details are in Table 1, Panel B, and references there). The vertical lines (from left to right): the (mint-green) solid line marks 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.

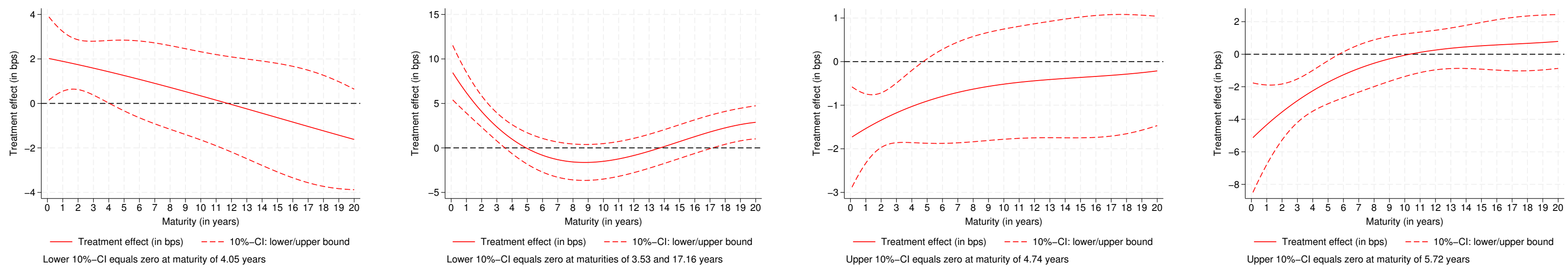


(a) Average yields (in pps) (b) Average maturity (in years) (c) Average yields (in pps) controlling for maturity

Figure 4. Comparison of bond characteristics across rating categories over time (Italy).
This figure provides time-series plots of average yield and average residual maturity from the first divergence date (August 9, 2013) to the last business day before haircut harmonization (December 12, 2014) based on the final sample of Italian zero-coupon central-government bonds (bond-dates with stale prices are excluded). Subplots (a) and (b) provide daily averages of yields and residual maturity, respectively, across bonds in each rating category. Subplot (c) shows average yields calculated as follows: On each day and for 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) representing securities with a rating in the AAA to A− (BBB+ to BBB−) range on the S&P scale. Subplot (c) additionally provides the yield differential between treated and control bonds (mean of treated minus mean of controls; black, dotted line). The vertical lines mark the same dates as described in Figure 3.



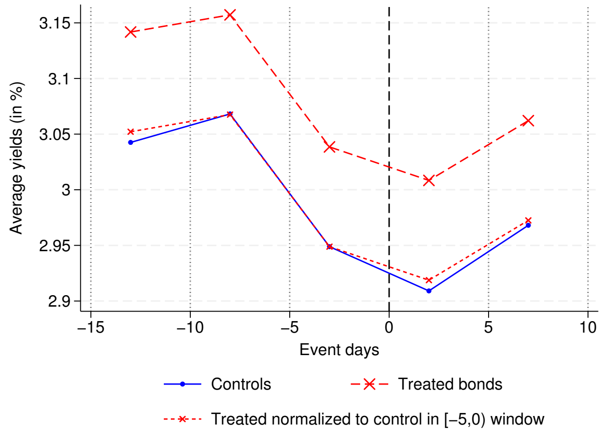
Diebold-Li curves



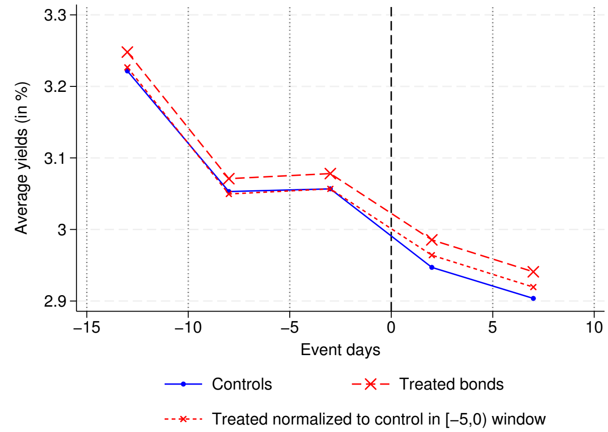
Cubic curves

(a) First divergence August 9, 2013 | (b) Haircut update October 1, 2013 | (c) Harmon. announcement September 1, 2014 | (d) Harmon. implementation December 15, 2014

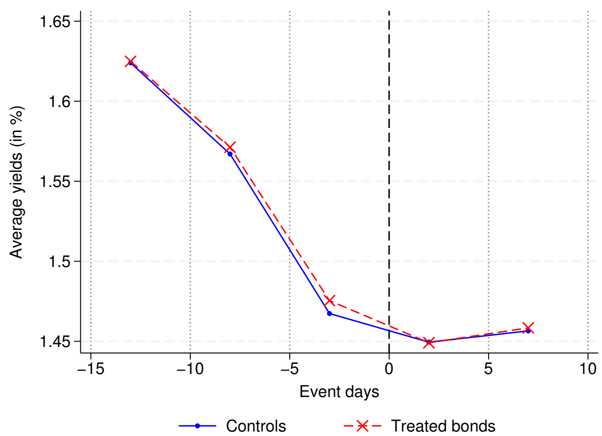
Figure 5. Change in delta curve for each event using Diebold-Li and plain cubic curves. This figure shows the change in the delta curve with two curve specifications over the ten-day windows for each event using the Italian samples of zero-coupon bonds with non-stale market prices (see Table 7). Estimation is based on the same fully flexible DiD specification $yield_{it} = \mathbf{B}_1' \ \mathbf{L}_{it} + \mathbf{B}_2' \ \mathbf{L}_{it} \ \mathbb{1}_{Treated,i} + \mathbf{B}_3' \ \mathbf{L}_{it} \ \mathbb{1}_{Post,t} + \mathbf{B}_4' \ \mathbf{L}_{it} \ \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} \ + \ \varepsilon_{it}$, with notation as in Table 8. For each event, the DiD estimator is given by the vector $\mathbf{B}_4$. The top row of plots use the yield-curve specification of Diebold and Li (2006) where $\mathbf{L}_{it} = [1 \quad l_1 \quad l_2]'$ with $l_1(x_{it};\lambda) = \left(1 - e^{-\lambda x_{it}}\right)/(\lambda x_{it})$ and $l_2(x_{it};\lambda) = \left(1 - e^{-\lambda x_{it}}\right)/(\lambda x_{it}) - e^{-\lambda x_{it}}$. x_{it} is the residual time-to-maturity of bond i on day t. λ is the decay parameter. $\widehat{\mathbf{B}}_4$ is estimated with NLS (using a seed value $\lambda = 1$). The estimated treatment effect of treated bonds at residual maturity, x, is given by the change in the delta curve, $\Delta_4^{dl}(x;\lambda) = \widehat{\beta}_{0,4} + \widehat{\beta}_{1,4} \ l_1(x;\lambda) + \widehat{\beta}_{2,4} \ l_2(x;\lambda)$. The bottom row of plots use a plain cubic yield-curve specification where $\mathbf{L}_{it} = [1 \quad x_{it} \quad x_{it}^2 \quad x_{it}^3]'$. $\widehat{\mathbf{B}}_4$ is estimated with OLS. The change in the delta curve is given by $\Delta_4^c(x) = \widehat{\beta}_{0,4} + \widehat{\beta}_{1,4}x + \widehat{\beta}_{2,4}x^2 + \widehat{\beta}_{3,4}x^3$. In each plot, the solid line is the change in the delta curve and the dashed lines are 10%-level confidence intervals based on standard errors clustered at the bond level calculated using the delta method. In the Subplots (b), we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013).



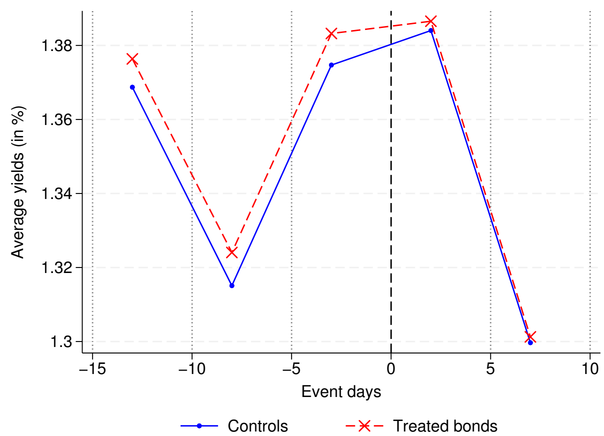
(a) First divergence
August 9, 2013



(b) Haircut update
October 1, 2013



(c) Harmonization announcement
September 1, 2014



(d) Harmonization implementation
December 15, 2014

Figure 6. Parallel trends for each event.

This figure shows average yields separately for treated and control bonds. For each event, we use the samples described in Table 7, extend them to 15 business days before and 10 days after each event making sure that bonds do not move across ECB maturity buckets, do not experience rating changes by one of the four official rating agencies, and have market prices every day in the sample window. The plots show average treated and control bond yields calculated over five-day increments around each event, going from −15 to +10, as follows: for each group and five-day period, we first average yields within Eurosystem maturity buckets and then across these maturity-bucket averages. In each subplot the blue, filled circles (red crosses) represent bonds in rating category 1 (2) with ratings in the AAA to A− (BBB+ to BBB−) range (on the S&P scale). Subplots (a) and (b) also show the average treated yield series normalized to the average control yield series in the subperiod [−5,0) to enable better visual comparison. The vertical solid line shows the event date (0) and the dotted lines the start date of each five-day subperiod (−15, −10, −5, 5).

Internet Appendix

The Price of Money: The Reserves Convertibility Premium over the Term Structure[1]

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June 2025

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Footnote 10: The 359 ISINs includes 65 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 53 securities that are linked to inflation. There are 237 securities on the public lists with data that are not good in some other way. These are comprised of: 3 securities whose principal is not of type "bullet," 4 securities with a face value other than 100, 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 5,704 securities. Panel B repeats the exercise for the subset of 2,454 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 in the full sample (including securities without market prices).

This table provides an overview of the incidence of haircut inconsistencies across countries for the full sample. 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. In each panel, the first column shows, by country, the number of sample days with haircut inconsistencies. In Panel A, 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. Panel B 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 to the right of 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: Number of securities by country and implied rating category for haircut inconsistency periods

		Number of securites across haircut inconsistency periods									
	Number	RC 1 & 2				RC 1			RC 2		
Country	of days	total	mean	min	max	mean	min	max	mean	min	max
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	36	19.2	13	23	17.5	12	21	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	1,142									

Panel B: Fraction of days with haircut inconsistencies by maturity bucket (as percentage of total number of haircut inconsistency days)

	Number	Maturity buckets																	
Country	of days	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	15-20	20-30	30+
Cyprus	40	20	83	3		20				3									
Greece	46				2		98		2								98	2	2
Hungary	97						100												
Ireland	198	99																	
Italy	351	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	88
Latvia	16	100	100			100	56	94											
Portugal	1	100				100													100
Slovenia	423	100	36	40	56					59	38								
Spain	449	89	89	95	89	45	44	89	89	39	6	4					5	89	3

Table A.2. Alternative estimation of fully flexible Diebold-Li specification.

This table is based on the Italian sample of zero-coupon bonds with non-stale market prices each day over the ten-day event-windows discussed in Table 7. It provides estimated treatment effects (in pps) of treated bonds at selected maturities for each event using the 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 $\mathbf{L}_{it} = [1 \quad l_1 \quad l_2]'$ with $l_1(x_{it};\lambda) = \left(1 - e^{-\lambda x_{it}}\right)/(\lambda x_{it})$ and $l_2(x_{it};\lambda) = \left(1 - e^{-\lambda x_{it}}\right)/(\lambda x_{it}) - e^{-\lambda x_{it}}$. x_{it} is the residual time-to-maturity of bond i on day t. λ is the decay parameter. $\mathbf{B}_j$, $j = 1, \ldots 4$, are the corresponding vectors of coefficients, and $\mathbb{1}_{Treated,i}$ ($\mathbb{1}_{Post,t}$) is an indicator variable that is one for treated bonds (event and post-event dates) and zero otherwise. $\mathbf{B}_4$ is the DiD estimator. In Panel A, λ is fixed as $\lambda = 0.7308$ (the "Diebold-Li lambda") and the model is estimated using OLS. In Panel B, λ is estimated individually for each event as an average across daily estimates for both rating categories using NLS. The specification is then estimated with OLS (the $\widehat{\lambda}$s are shown at the bottom of the panel). For the "haircut update" event, we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013). Underneath the coefficients, the table provides (in parentheses) z-statistics calculated using the delta method and clustered at 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 second column provides the DiD in haircuts (in pps) for each selected maturity. For maturity x equaling 1, 3, and 5 years, we have taken the haircut at x minus one day.

	Haircut differential widens				Haircut differential shrinks			
	First divergence		Haircut update		Harmonization announcement		Harmonization implementation	
Residual maturity (in years)	August 9, 2013		October 1, 2013		September 1, 2014		December 15, 2014	
	DiD effects	in hc	DiD effects	in hc	DiD effects	in hc	DiD effects	in hc
Panel A: Estimation using Diebold-Li lambda $\lambda = 0.7308$								
0.5	0.006	5.0	**0.062**^{a}	0.5	**-0.021**^{b}	0.0	**-0.032**^{a}	−5.5
	(0.75)		(3.91)		(-2.50)		(-4.06)	
1	**0.011**^{c}	5.0	**0.039**^{a}	0.5	**-0.022**^{a}	0.0	**-0.018**^{a}	−5.5
	(1.77)		(3.33)		(-3.11)		(-3.22)	
2	**0.013**^{c}	5.0	0.013	1.0	**-0.022**^{a}	0.0	-0.003	−6.0
	(1.66)		(1.31)		(-2.66)		(-0.54)	
3	0.011	5.0	0.004	1.0	**-0.020**^{b}	0.0	0.003	−6.0
	(1.37)		(0.36)		(-2.56)		(0.46)	
5	0.005	5.0	0.001	2.5	**-0.016**^{b}	0.0	0.006	−7.5
	(0.62)		(0.08)		(-2.52)		(1.20)	
8	-0.003	5.0	0.004	4.0	-0.012	0.0	0.005	−9.0
	(-0.32)		(0.66)		(-1.48)		(1.41)	
12	-0.008	5.0	0.008	4.0	-0.009	0.0	0.004	−9.0
	(-0.71)		(1.10)		(-0.84)		(0.93)	
16	-0.011	5.0	0.011	4.0	-0.008	0.0	0.003	−9.0
	(-0.84)		(1.23)		(-0.61)		(0.62)	
20	-0.013	5.0	0.012	4.0	-0.007	0.0	0.002	−9.0
	(-0.90)		(1.28)		(-0.50)		(0.46)	
Adj. R-squared	0.9936	–	0.9935	–	0.9763	–	0.9584	–
No. bonds (T/C)	61/39	–	62/41	–	67/29	–	69/28	–
λ	0.7308	–	0.7308	–	0.7308	–	0.7308	–

Table A.2 – *continued*

Residual maturity (in years)	Haircut differential widens				Haircut differential shrinks			
	First divergence		Haircut update		Harmonization announcement		Harmonization implementation	
	Aug. 9, 2013		Oct. 1, 2013		Sep. 1, 2014		Dec. 15, 2014	
	DiD		DiD		DiD		DiD	
	effects	in hc	effects	in hc	effects	in hc	effects	in hc
Panel B: Estimation using event-specific average in-sample lambda								
0.5	0.008	5.0	**0.067**[a]	0.5	**-0.016**[b]	0.0	**-0.044**[a]	−5.5
	(1.02)		(4.17)		(-2.27)		(-2.61)	
1	**0.012**[b]	5.0	**0.043**[a]	0.5	**-0.018**[a]	0.0	**-0.040**[a]	−5.5
	(2.11)		(3.64)		(-3.40)		(-3.01)	
2	**0.014**[b]	5.0	0.014	1.0	**-0.021**[a]	0.0	**-0.032**[a]	−6.0
	(1.96)		(1.51)		(-3.03)		(-3.68)	
3	0.013	5.0	0.002	1.0	**-0.021**[a]	0.0	**-0.025**[a]	−6.0
	(1.57)		(0.17)		(-2.59)		(-3.39)	
5	0.007	5.0	-0.004	2.5	**-0.020**[b]	0.0	**-0.016**[c]	−7.5
	(0.87)		(-0.47)		(-2.43)		(-1.88)	
8	-0.002	5.0	0.001	4.0	**-0.016**[b]	0.0	-0.007	−9.0
	(-0.18)		(0.12)		(-2.22)		(-0.82)	
12	-0.008	5.0	0.007	4.0	-0.011	0.0	0.000	−9.0
	(-0.77)		(0.97)		(-1.16)		(0.03)	
16	-0.012	5.0	0.011	4.0	-0.008	0.0	0.004	−9.0
	(-0.96)		(1.31)		(-0.62)		(0.64)	
20	-0.015	5.0	0.014	4.0	-0.006	0.0	0.006	−9.0
	(-1.04)		(1.46)		(-0.38)		(0.79)	
Adj. R-squared	0.9941	–	0.9940	–	0.9964	–	0.9962	–
No. bonds (T/C)	61/39	–	62/41	–	67/29	–	69/28	–
$\widehat{\lambda}$	0.5804	–	0.5932	–	0.3929	–	0.2655	–

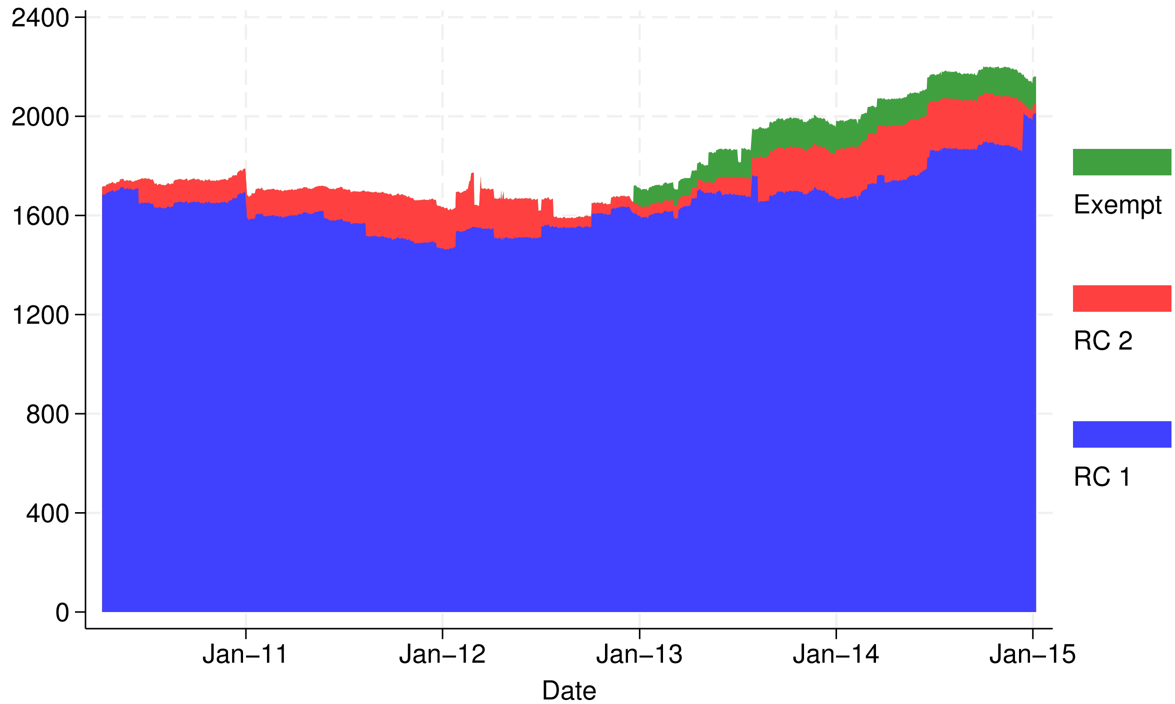
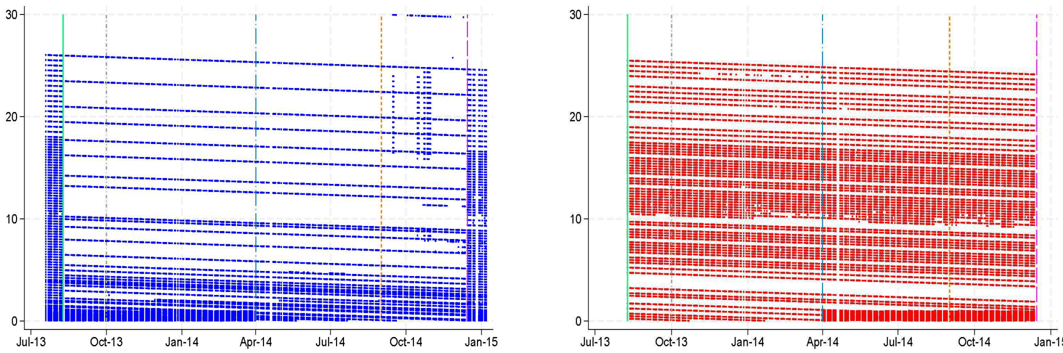


Figure A.1. Distributions of government bonds by rating category (full sample). This figure shows the number of fixed- and zero-coupon central-government bonds by rating category over the time period April 9, 2010 to January 7, 2015, inclusive, for the full sample (including securities without market 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 (details are in Table 1, Panel B, and references there).



Rating category 1 Rating category 2

Figure A.2. Final sample: Residual maturity by rating category over time.
This figure plots residual maturities by rating category in the final sample of Italian zero-coupon bonds with market prices for the sample period July 19, 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 same dates as described in Figure 3 in the paper.