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

Jiri Woschitz
BI Norwegian Business School

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Kjell G. Nyborg
University of Zurich,
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Nyborg (corresponding author): Department of Banking and Finance, University of Zurich, Plattenstrasse 14, CH-8032 Zurich, Switzerland. email: kjell.nyborg@bf.uzh.ch. Woschitz: Department of Finance, BI Norwegian Business School, B4y, NO-0442 Oslo, Norway. email: jiri.woschitz@bi.no.

Abstract

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

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.

JEL classification: G12, E43, E58

Keywords: central bank, reserves, convertibility premium, liquidity premium, term structure, yield curve, collateral policy, haircut

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, 2023). Our focus is on the ultimate medium of exchange in modern monetary systems, namely, central bank reserves. Exploiting the institutional structure of current monetary architecture, we find evidence that is broadly consistent with, but also expands on, the Hicksian view that the utility of money shows up in asset prices. The asset class we study are government bonds. To deal with potential term effects, we develop a novel difference-in-differences approach in curves.

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). 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). In this paper, we shift gears by focusing on reserves and convertibility into this form of money. Specifically, we make use of the monetary policy implementation framework in the euro area to precisely measure a security's "moneyness" 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 are important because they are the ultimate medium of exchange in modern two-tier monetary systems; 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 a loaf of bread 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 spillover effects to equity markets and Li and Li (2023) 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

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

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. The ECB publishes a daily list with eligible securities and their haircuts on its webpage. In this repo-based framework, the rate of convertibility of a security into new reserves straight from the central bank is defined by its 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.

We test for potential term effects for two reasons. First, statistics of treatment effects on bond yields can be biased or mismeasured if term effects are present but not controlled for (Nyborg and Woschitz, 2024). Second, there is good reason to expect there to be term effects in the convertibility premium: the counterparties in Eurosystem repos are banks, and banks hold a preponderance of relatively short duration paper (Koijen, Koulischer, Nguyen, and Yogo, 2021). Fecht, Nyborg, Rocholl, and Woschitz (2016) report that the average duration of collateral held by German banks for use in Eurosystem repos is between two and three years. Since banks can only alleviate monetary constraints with eligible assets that they hold, we might, therefore, expect to see a convertibility premium predominantly at shorter maturities. An alternative hypothesis is that there should be no term effect since banks could, in principle, also buy longer-dated bonds or because marginal banks hold securities across the maturity spectrum. We will let the data speak for itself on this issue.

We first develop novel and clean identification of variation in haircuts in Eurosystem repos. This exploits differential treatment of same-country government bonds by the Eurosystem with respect to haircuts and specific events where this changed. We estimate delta curves, that is, differences in single-country spot curves between treated and control bonds, around the events and use a difference-in-differences (DiD) approach to measure the haircut effect along the maturity spectrum. As far as we know, we are the first to employ flexible yield curve modeling in a DiD setting. The identification strategy, the data, and the methodology allow us to study haircut effects over the term structure for two different countries, Spain and Italy, around four events for each country. We find a positive overall haircut effect on spot rates in all eight country-event combinations. In short, a higher rate of convertibility into reserves increases market value. In terms of magnitudes, a one percentage point haircut reduction decreases the one-year Italian spot rate, for example, by approximately two basis points. This may sound small, but represents ten basis points for an observed five percentage point haircut change.

We also find that the haircut effect tapers off and becomes insignificant at longer maturities, around five years in the case of Italy. Thus, there is a habitat dimension to the convertibility premium (Culbertson, 1957; Modigliani and Sutch, 1966 and 1967; Vayanos and Vila, 2021). This is consistent with the fact that the entities (banks) that can convert assets into reserves hold relatively short term paper. The existence of a term effect supports the view that the impact of a central bank's collateral policy depends on the assets held by the players that can access the central bank's operations (Nyborg and Strebulaev, 2001).

The large yield spreads of Italian and Spanish government bonds over German ones since the financial crisis mean that we are not finding reserves convertibility premia in riskfree assets, but in risky ones. This is consistent, for example, with a home bias in banks' government bond holdings and, at least some, Italian and Spanish banks having poor interbank-market access over the sample period. A general point suggested by our findings is that reserves convertibility premia depend on which banks face constraints and what assets these banks hold.

Our final result is 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.

These findings show that there is 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), concerns regarding bank runs or crises (Bagehot, 1873; Diamond and Dybvig, 1983; Allen, Carletti, Gale, 2014; Chen, Goldstein, Huang, Vashishtha, 2022; Lengwiler and Orphanides, 2023), and payment-flow volatility (Li and Li, 2023). 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.

Our paper relates to several strands of the literature. Longstaff (2004), Krishnamurthy and Vissing-Jorgensen (2012), Greenwood, Hanson, and Stein (2015), and Nagel (2016), among others, study liquidity premia in Treasury securities, defined as spreads relative to yields of other safe instruments. Treasuries typically have low yields relative to other assets, but Treasuries can also trade at discounts to estimates of their intrinsic fair values (Fleckenstein and Longstaff, 2021). 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 (2023) 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, as a first, 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.

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. With the two-tier monetary system in mind, it should be clear that central bank provisioning of reserves to banks is not the same thing as extending leverage to relatively risk tolerant investors. Furthermore, banks do not lend reserves to nonbanks; they lend deposits, which they issue themselves through the act of lending (as in Figure 1, Example b). In the euro area, there is a delay of about two months before increased lending hits reserve requirements (Fecht, Nyborg, Rocholl, 2011), which are 1% of short-term liabilities. Yet, we find an immediate price reaction to changes in haircuts in Eurosystem repos. As touched on above, a contributing factor to this finding could be that a bank may want a reserves cushion when lending because the borrower can use the deposits received in transactions that involve other banks, which would draw off reserves from the original lender. This is a monetary logic, however. New reserves from the central bank can be valuable to a bank if its reserves are being drained, while constraints in the interbank market are making it difficult or costly to replace them. The existence of a reserves convertibility premium is not dependent on specific uses, but on reserves directly from the central bank having positive marginal utility to a bank.

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 excellent overviews). The prices of Treasury securities are known to be affected by conventional monetary policy[2]

[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).

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, 2023). With respect to collateral frameworks, Nyborg (2016), Van Bekkum, Gabarro, and Irani (2018), Cassola and Koulischer (2019), and Lentner (2021) 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) conclude 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 and, methodologically, by combining DiD with curve fitting to estimate treatment effects over the maturity spectrum (Nelson and Siegel, 1987; Diebold and Li, 2006).

Remaining structure: Section 2 provides an overview of the identification strategy, based on "haircut inconsistencies." Section 3 discusses the institutional framework, the data, and the incidence of haircut inconsistencies. Section 4 describes the DiD events. Section 5 provides preliminary analysis of yields and spot curves. Sections 6 and 7 contain the main analysis. Section 8 concludes.

2. 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

[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).

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, which is why we focus on these two countries.

Nyborg (2016) provides examples with couplets of same-country zero-coupon bonds that mature on the same day, yet are in different rating categories. The bond with the lower haircut always has the lower yield. Because such perfectly matched couplets are relatively rare, however, our approach involves fitting yield curves. 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 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 4.

The first event date (one for each country) corrects the mistake. On June 3 and August 9, 2013, several Spanish, respectively Italian, government bonds had their haircuts increased, reflecting their individual bond ratings and in compliance with the official collateral framework

[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.

[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.

rules at the time. In our terminology, the bonds were moved from rating category 1 to 2. Defining bonds that were moved as treated, we would expect to see the post-event yield curve of treated bonds shift up relative to that of non-treated control bonds. This is also what we find, with a term effect that vanishes at longer maturities.

Subsequent event dates are the same for both countries. The second event is a haircut update on October 1, 2013.[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 a divergence in the yield curves of these two classes of 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 Spanish and 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, for each country, we find that the overall effect of harmonization is a convergence of the spot curves of the two classes of bonds. There are both announcement *and* implementation effects, but the latter dominates.

3. 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 Spain and Italy.

[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.

3.1 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.

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]

[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."

[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.

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. Below, we provide statistics on the incidence of haircut inconsistencies for both the full and filtered samples of securities.

3.2 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, being in Liquidity Category I, have the lowest haircuts, ceteris paribus. For fixed- and zero-coupon bonds, there are six residual maturity buckets, namely, 0–1, 1–3, 3–5, 5–7, 7–10, 10+ years.[12] Haircuts are increasing in maturity, ceteris paribus, but constant within each bucket and with a markup for zeros. Since October 2008, the ECB has 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.[13] Panel A contains the ordinary haircut rules for euro-denominated assets in Liquidity Category 1. Panel B provides extraordinary haircuts applied to Greek and Cypriot sovereign paper. As the financial crisis evolved and ratings dipped, Portugal, Ireland, Greece, and Cyprus received temporary exemptions from Eurosystem minimum rating requirements (at least the equivalent of BBB− on the S&P scale). While Portuguese and Irish government bonds continued to receive ordinary haircuts during these exemption periods, the ECB set extraordinary haircuts for Greece and Cyprus.[14] Panel C shows additional haircuts to assets denominated in foreign currency.

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

[12] Securities with floating, and until January 3, 2013, inverse floating coupons (ECB, 2012) can also be eligible.

[13] 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.

[14] Rating rules exemptions were temporarily suspended at various points in time for Greece and Cyprus (for details see Nyborg, 2016, Subsections 5.4 and 6.2, and the references therein).

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.

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

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. 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.

[15] 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.

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

3.3 Examples

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

Insert Table 3 here.

In Example 1, both securities mature on January 31, 2015. The first bond is in rating category 1 and receives a haircut of 0.5%, whereas the second bond is in rating category 2 and has a haircut of 6.0%. This haircut inconsistency results from the bonds' individual ratings. The first security has a highest rating of AL by DBRS (equivalent to A− on the S&P scale) and, therefore, receives a low haircut. In contrast, the highest (and only) issue rating for the second security is BBB+ from Fitch, which earns it a higher haircut. Finally, the yield on the security with the higher haircut is 0.284% as compared with 0.205% for the other, a difference of approximately eight basis points. This translates into an increase in yield of 1.4 bps per percentage point increase in haircut.

In Example 2, the securities mature on January 31, 2018 and have Eurosystem haircuts of 2.5% and 10.0%, respectively. The first security has no individual issue rating and, therefore, receives a collateral framework rating based on the highest country rating for Spain. This is AL by DBRS, which places the security in rating category 1. The second bond, however, is rated BBB+ by Fitch. Since it has no other rating, it is assigned to rating category 2. Again, the security with the higher haircut has the higher yield, 1.283% versus 1.108%. This translates into an increase in yield of 2.3 bps per percentage point increase in haircut.

3.4 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 distribution of bonds across rating categories as well as on the incidence of haircut inconsistencies. The daily distributions of rating categories are plotted over time in Figure 2a for the full dataset of 5,704 government bonds and in Figure 2b

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

for the subset of 2,454 bonds with market prices. As seen, the vast majority of paper is in rating category 1. For example, in the full dataset, 90.57% of the security-day observations are in rating category 1, 6.90% are in rating category 2, and 2.45% represent exempt Greek and Cypriot securities.

Insert Figure 2 and Table 4 here.

Table 4, 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. Out of twenty-nine countries, there are nine with inconsistencies. These are Italy, Spain, Slovenia, Ireland, Hungary, Latvia, Portugal, Greece, and Cyprus. Panel A (B) shows that there are a total of 1,621 (1,142) country-days and 1,142 (593) securities involved. In either panel, the majority of securities are from Italy and Spain. These two countries are especially dominant in the subset of securities with market prices, combining for 68.8% of country-days with haircut inconsistencies and 79.3% of all securities. They are also the countries with the best coverage of haircut inconsistencies across the maturity spectrum over time (see Table A.1 in the Internet Appendix). In the remainder of the paper, therefore, we focus on Italy and Spain.

4. 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 Sections 6 and 7 and specify the sets of treated and control bonds.

4.1 Event dates

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

Two features are immediately obvious from the figure. First, for each country, there is an initial date when a large mass of bonds are moved into rating category 2. This represents mass corrections of the collateral framework implementation errors discussed above. Second, haircut inconsistencies disappear again on December 15, 2014, when the ECB implemented a rule change designed for that exact purpose (Nyborg, 2016, Table 6.1). Vertical bars in Figures 2c and 2d represent these and other key event dates that affect haircuts differentially across bonds.[18] In chronological order, these are:

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

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

  - There was a second, smaller mass correction of collateral framework implementation errors on April 1, 2014 (blue longdash-dotted line in Figures 2c and 2d). This involved sixteen Italian and ten Spanish short-dated (less than one year to maturity) bonds. 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)

[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.

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 Figures 2c and 2d, respectively, Italian and Spanish government securities in rating category 2 shift back to category 1 on this date (ECB, 2014a). This upgrade occurs because both Italy and Spain had a country rating of AL from DBRS.

4.2 Treated and control bonds

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

In the Italian sample, 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.

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

Finally, we exclude security-day observations with less than ten calendar days to maturity. For Italy (Spain), we are left with 177 (72) zero-coupon bonds for a total of 45,690 (16,558) security-day observations on 422 sample days. The total number of bonds that at some point in time are in rating category 2 are 96 (25) for Italy (Spain), comprising 23,554 (4,905) security-day observations. Figures 2e and 2f provide the number of bonds in each rating category over time in these final samples for Italy and Spain. For both countries, there are bonds in each category every day from the first divergence date until haircut harmonization.

5. Preliminary analysis: High versus low haircut bonds

This section takes a preliminary look at yield differentials between same-country bonds in different rating categories, i.e., high- and low-haircut bonds. We use the final sample with daily observations on 177 Italian and 72 Spanish zero-coupon bonds described in Section 4.2. All surviving 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. Security-day observations with stale prices are dropped.[20] These are defined as cases where the bid, ask, and mid-prices are unchanged from the previous day. All securities are euro-denominated. For each country, we initially report on unconditional differences in yields between the two groups. We then introduce a simple 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 averages of these over time.[21]

5.1 Overview and summary statistics

For each country, Figure 3 provides time-series plots of average residual maturities and average yields from the first divergence date (August 9, 2013 in Italy and June 3, 2013 in Spain) to the last business day before haircut harmonization (December 12, 2014). Table 5 provides summary statistics across sample days, including on yield spreads between rating categories. Because Figure 3 shows that average residual maturities and relative yields in the four coun-

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

[21] Nguyen (2020) looks at the relation between yields and Eurosystem haircuts by running Fama-MacBeth regressions with government bond yields relative to Germany on the left-hand-side and haircuts and controls on the right-hand-side, pooling together different countries, maturities, coupons, and rating categories, and finds a positive correlation between yields relative to those of German government bonds and haircuts. 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).

try and rating-category subpopulations change after the second divergence date, summary statistics are provided separately for the periods before and after this date (April 1, 2014).

Insert Figure 3 and Table 5 here.

Figure 3a shows the average spot rate within each rating category over time for each country. High-haircut bonds have higher yields. For Italy, 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). For Spain, the difference is 0.521 pps and -0.136 pps in the first and second subperiods, respectively (both statistically significant at the 1% level). 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 3b and Table 5. For example, for Italy, as an average across days, rating category 2 bonds have a residual maturity that is around seven years longer than category 1 bonds in the first subperiod, dropping to 1.82 years thereafter.

Figure 3c presents a simple term-structure correction using the six Eurosystem maturity buckets, namely, 0-1, 1-3, 3-5, 5-7, 7-10, and 10+ years (Table 1). For each country and rating-category combination, we first average yields across all bonds in the same maturity bucket and then across buckets (six for Italy, three for Spain). This gives us two time series with simple maturity-controlled average yields on a daily basis for each country. Figure 3c and the corresponding statistics in Table 5 show that this simple term-structure correction has significant impact on the measured difference in yields between bonds in rating categories 1 and 2. For Italy, the average differences across days are now 8.4 bps and 2.8 bps in the first and second subperiods, respectively; for Spain, the corresponding numbers are 18.6 bps and 5.5 bps, respectively (all significant at the 1% level).

Table 5 also includes information on the ranges of residual maturities across days in the Italian and Spanish samples. For Italy, these maturity ranges never fall below 23.00 and 24.00 years for rating category 1 and 2 bonds, respectively. For Spain, residual maturities are shorter in the second half of the sample period, with average ranges of 3.34 and 3.36 years for rating categories 1 and 2, respectively. Time series plots of residual maturities are in Figure A.1 in the Internet Appendix.

5.2 Average daily spot and delta curves

To control more precisely for term-structure effects, in this subsection, we estimate daily spot and delta curves using cubic specifications. In the DiD analysis below, we also estimate Italian yield curves using the Diebold and Li (2006) factorization of the Nelson and Siegel (1987) curve. This does not work well for Spain because, over the relatively short maturity range in the Spanish sample, the yield curve is upward sloping and convex on many days (so that convergence is not achieved). We, therefore, start with the more versatile cubic specification. As emphasized by Nelson and Siegel (1987), cubics have the same number of parameters as their own curve, but often provide better fits. One of their main motivations for developing their exponential decay model is that cubics (and other polynomials) are not well suited to extrapolation beyond the sample range of maturities, since they blow up at long maturities. In this paper, however, extrapolation is not an issue. Cubic curves can be fitted with ease because our samples of Italian and Spanish bonds consist entirely of zero coupon bonds.

Estimation is carried out separately for Italy and Spain on a daily basis, and we report the averages of these daily runs. Specifically, we employ the Fama-MacBeth procedure with the following specification over the same periods for Italy and Spain as in Figure 3:

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

where $yield_{it}$ is the yield-to-maturity of bond i on day t; $\mathbf{Mat}_{it}$ 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 $\gamma_{k,j}$, $k = 0, \ldots, 3$; and $\mathbb{1}_{RC2,it}$ is an indicator variable that is one if bond i is in rating category 2 on day t and zero otherwise.

The Fama-MacBeth procedure runs Specification (1) for each sample day and, in a second step, calculates the averages of each of the eight coefficients across the individual sample day regressions. Thus, the estimated average spot curve for rating category 1 is

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

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

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

where $\{\widehat{\gamma}_{k,2}\}_{k=0}^{3}$ are the estimated regression coefficients. This is the main object of interest.

Table 6 reports the results, with t-statistics based on Newey-West standard errors with five lags.[22] The letters a, b, and c denote statistical significance (two-sided) at the 1%, 5%, and 10% levels, respectively. The average adjusted R^2 of the individual cross-sectional regressions (in step 1 of the Fama-MacBeth procedure) is 99.59% for Italy and 97.27% for Spain, showing that the cubic specification fits the data exceptionally well.

Insert Table 6 here.

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

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

6. Main analysis: Difference-in-differences regressions

The finding above that government bonds with relatively high haircuts have higher yields controls for residual maturity and country. However, it is possible that same-country government bonds in different rating categories also differ in other, unknown respects. Our main analysis, therefore, uses a DiD approach with identification coming from the exogenous haircut shocks to some bonds in the events detailed in Section 4. Recall that, for each event, a bond is classified as treated if it is in rating category 2 before or after the event date. The remaining bonds, those that are in rating category 1 both before and after the event date, are controls.

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

By using four events for each country, we set the bar high.

In the DiD regressions in this section, we continue to use a cubic spot curve specification (because of Spain). In Section 7, we complement this with estimation using the Diebold and Li (2006) factorization of the Nelson and Siegel (1987) curve for Italy. Results are qualitatively the same and quantitatively very similar. Inference is based on standard errors clustered at the individual bond level.

As discussed in Section 4, 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 and Spanish bonds. We have not found press releases or news reports that speak to this. However, if yields are affected by the implementation of haircut harmonization, which was fully anticipated, then yields should also react to the mass-correction and haircut update events if reserves are tight.

6.1 Bond data for the event studies

We run DiD regressions over event windows of ten and twenty business days for each of the four events.[23] The underlying data is the cleaned sample of zero-coupon bonds discussed in

[23] For the second event (haircut update), we form windows after excluding the announcement date (September 27, 2013) and the single business day between the announcement and implementation (September 30,

Section 4.2 and used in Section 5. From this, for each event, we filter out bonds that move across ECB maturity buckets (see Table 1) or experience rating changes by one of the four official rating agencies within the twenty-day window. In addition, for each event window, we filter out bonds that do not have fresh (non-stale) market prices every day within the window. This ensures equal consideration of sample bonds with respect to the estimation of yield curves and treatment effects.[24]

Insert Table 7 here.

For each event window and country, Table 7 reports on the number and percentage of treated and control bonds by ECB maturity bucket. In the case of Italy (Panel A), for the first event, thirty-nine control and sixty-one treated bonds pass the filters for the ten-day event window. Two of the controls are filtered out for the twenty-day window. For the first two events, control bonds are concentrated toward the short end of the maturity spectrum, whereas treated bonds are concentrated toward the long end. Italian control and treated bonds are more evenly distributed for the last two events. For Spain (Panel B, Table 7), there are bonds in only the first three ECB maturity buckets (up to five years). The first two events see relatively many treated bonds in the 1-3 year bucket. For the last two events, treated bonds shift toward the 0-1 year bucket.

6.2 Alternative DiD specifications

We consider two DiD specifications. The first is

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

where $\mathbb{1}_{Treated,i}$ ($\mathbb{1}_{Post,t}$) is an indicator variable that is one for treated bonds (the event and post-event dates) and zero otherwise. α and δ are the corresponding coefficients. β_{DiD} is the DiD estimator. The rest of the notation is as in Subsection 5.2 so that $\mathbf{\Gamma}'\mathbf{Mat}_{it}$ represents a polynomial of degree three.

Equation (4) is a standard DiD specification from the literature, transferred to a yield-curve setting. Through $\mathbf{\Gamma}'\mathbf{Mat}_{it}$, the specification explicitly controls for the term structure of

2013). So, for this event, we estimate a combined announcement and implementation effect.

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

interest rates. However, it does so while imposing a parallel-shift restriction. In particular, Specification (4) imposes a level treatment effect over the term structure so that estimation of it essentially generates an average treatment effect across the treated bonds in the sample.[25]

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

Controlling and testing for differential effects across the maturity spectrum is of interest by and of itself. For example, with respect to central bank collateral policy, it is important to know how different segments of the yield curve react to haircut changes. Furthermore, failing to control for differential treatment effects can bias the results. For instance, if long-dated bonds are not much impacted by haircut changes and long-dated bonds are over-represented in the treated sample, a specification that estimates an average effect will tend to push the DiD estimator toward zero. The converse would be the case if short-dated bonds were over-represented among the treated bonds. Failing to control for term effects could also lead to spurious results if some sections of the term structure experience drifts over the event window that are unrelated to treatment. These issues are germane given our data because treated bonds are not uniformly distributed across maturities (Table 7). For example, for Italy, treated bonds are skewed toward longer maturities, especially in the first two events.

We allow for heterogeneous treatment effects by fitting a fully flexible model, where no

[25] A related DiD specification that is common in the literature is:

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

where the α_i's and δ_t's are individual unit and time fixed effects, respectively, and y_{it} is the outcome variable. This is often adopted in fixed-income settings, with y_{it} as the yield (sometimes a yield spread) on bond i at time t (e.g., Todorov, 2020). The results on β_{DiD} using (4′) are qualitatively identical and quantitatively extremely close to those using (4), although the fit is much worse because (4′) does not capture the relation between yield and time to maturity (see Table A.2 in the Internet Appendix). Like (4), Specification (4′) essentially estimates the average effect across treated sample bonds. A simple way to try to deal with heterogeneous treatment effects over the maturity spectrum would be to run (4′) on selected maturity buckets. However, besides the theoretical issue as to how those maturity buckets should be formed, implementing this approach can be problematic because of a paucity of bonds that constrains how fine the maturity-bucket grid can be.

particular relation is imposed between pre- and post-event spot curves for treated and control bonds. In particular, for each event, our second, and main, specification is

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

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

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

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

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

where $\{\widehat{\gamma}_{k,j}\}_{k=0}^{3}$ are the estimated regression coefficients, $j = 2, \ldots, 4$. The DiD estimator is given by the vector $\widehat{\boldsymbol{\Gamma}}_4$, and the delta curve of interest is $\Delta_4(x)$. In this setup, the estimated treatment effect depends on, and controls for, maturity in a fully flexible way. The DiD delta curve captures the treatment effect at each maturity rather than as an average across sample bonds. The basic method can be implemented with alternative spot curve specifications, which we discuss further in Section 7.

6.3 Exclusion restriction

With respect to the exclusion restriction, we are not aware of reasons as to why the DiD delta curves should change systematically around our events except as a result of the haircut changes we have described. First, we are not aware of other, contemporaneous events that could affect bond yields. 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, our empirical design fully controls for individual country effects. Unconditionally, spot rates of same-country government bonds in different rating categories have a very high degree of comovement. In Figure 3c, the correlations between the two rating category series are 99.72%

for Italy and 98.75% for Spain.

Insert Figure 4 here.

As a diagnostic to assess the plausibility of the exclusion restriction, we check the parallel-trends condition for all eight country-events, using the treated- and control-bond samples described in Table 7 for the twenty-day estimation window. For each country-event, Figure 4 plots the yields of treated and control bonds (red crosses and blue circles, respectively) as averages in five-day increments from fifteen business days before the event date to ten days after. For each day, we first average yields within Eurosystem maturity buckets and then across these maturity-bucket averages. These daily averages are then averaged within each five-day interval. There is no visible difference in the pre-event trends of the treated and control bonds in any of the eight subplots of Figure 4. This supports that the exclusion restriction is satisfied for all eight events. Note, however, that even if there are treatment-unrelated shifts in the curves of treated and control bonds over the event dates, the fully flexible specification controls for this (Nyborg and Woschitz, 2024).

6.4 Results

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

Insert Tables 8 and 9 here.

Before discussing the main results, we comment briefly on goodness of fit. For Italy, this is extremely good for both specifications, with the fully flexible model in Table 9 having a slight edge. Across the two specifications and all events and windows, the lowest adjusted R^2 is 99.18%.[26] So the cubic specification provides a consistently excellent fit for Italy. For Spain, the fit is also good, but not as consistent. Across the two specifications, adjusted R^2 does not drop below 98.00% over the first two events, but goes as low as 86.08% over the last

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

two events.[27] Again, the fully flexible model, Equation (5), fits better.

6.4.1 Parallel-shifts specification: Average treatment effects

The results on the treatment effect in the parallel-shifts model are in Table 8. We start in reverse chronological order by first discussing events 3 and 4, which concern the announcement and implementation of haircut harmonization, respectively. This allows us to comment immediately on announcement versus implementation effects, which may also be relevant with respect to the first events to the extent they were anticipated by market participants. As discussed above, if *current* access to central bank money is priced, we should see an implementation effect even if haircut changes are fully anticipated.

The results for haircut harmonization implementation show a statistically significant (1% level) treatment effect on the yields of treated Italian bonds of −2.7 bps and −3.3 bps over the ten- and twenty-day event windows, respectively. This is approximately 50% of the 6.0 bps average difference between the spot curves of Italian rating category 2 and 1 bonds estimated in Section 5.2. For Spain, the corresponding numbers are −1.4 bps and −2.0 bps, both significant at the 5% level. This shows that, on average over the maturity spectrum, an increase in their convertibility into reserves causes government bond prices to rise. It is noteworthy that we find this *even though this event was fully anticipated*.

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

Given our finding that yield differentials shrink when haircuts are harmonized, we would expect to see the opposite when haircuts diverge, as they do on the first two event dates. This is also what we find. In the case of the first divergence date, Table 8 shows a statistically significant treatment effect of 3.7 bps (5% level) over the ten-day window for Spanish government bonds. In the case of the haircut update event, the treatment effect is statistically significantly positive at least at the 5% level for both the ten- and twenty-day windows for Italy. Thus, overall, the conclusion from Table 8 is that government bond yields are decreasing in their degree of convertibility into reserves.

[27] Model (4) (parallel shifts), harmonization implementation (event 4), twenty-day window.

The results are weaker, however, for the first two events. For instance, for the first divergence date, we do not find a significant treatment effect for Italian bonds. Because the DiD estimator in Specification (4) essentially captures the average treatment effect across treated bonds, this weaker result could simply reflect that treated-bond maturities in the first two events are skewed toward the long end of the term structure (Table 7). As discussed in the Introduction, the haircut effect might be smaller at longer durations, since banks hold predominantly short-duration bonds. Thus, we now turn to our main specification, Equation (5), which allows measurement of heterogeneous treatment effects over the term structure.

6.4.2 Fully flexible specification: Heterogeneous treatment effects

The results on the specification with fully flexible yield curves, Equation (5), are in Table 9 and in Figures 5 (Italy) and 6 (Spain). The table shows treatment effects at different maturities for both the ten- and twenty-day estimation windows, with z-statistics in parentheses. Standard errors are calculated by the delta method and clustered at the individual bond level. The figures plot the treatment delta curves, $\Delta_4(x)$, for each country-event under ten-day event windows and with 10% confidence bands.

Insert Figures 5 and 6 here.

There are two key takeaways from the table and the two figures. First, overall, government bond yields are increasing in their convertibility into reserves. Second, the effect is heterogeneous over the term structure. For both countries and across all four events, the effect is relatively strong at shorter maturities, becoming insignificant at the longer end. This is consistent with banks being the only counterparties in Eurosystem repos and the fact that banks hold predominantly short-term paper. That the convertibility premium tapers off at longer maturities also helps explain the relatively weak results under the parallel-shifts specification for the first two events, which have an overweight of long-dated bonds.

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

For the second event (haircut update), the figures report statistically significant positive treatments effects out to a maturity of 3.53 years for Italy and after 1.74 years for Spain (where the longest bond has a maturity of around four years). In terms of magnitudes, the point estimate of the DiD effect for the one-year Italian yield is 6.2 bps and 2.8 bps for the ten- and twenty-day estimation windows, respectively, dropping to 4.1 bps and 2.5 bps, respectively, at two years.[28] The corresponding numbers for Spain at a maturity of two years are 1.4 bps and 2.1 bps.

The two haircut harmonization events exhibit the same overall pattern, with significant treatment effects at relatively shorter maturities. For Italy, there is a statistically significant negative treatment effect up to 4.74 years at the announcement of haircut harmonization. At implementation, significance extends up to 5.72 years. There is also a significant negative treatment effect at the announcement for Spain at short maturities and beyond 1.76 years at implementation.

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

To estimate the full impact of harmonization, we also need to take into account the interim period, between announcement and implementation. Doing this, the full harmonization treatment effect on one year spot rates is estimated as -10.1 bps, or -1.8 bps per percentage point reduction in haircut.[29] The estimated harmonization treatment effects in Spain are smaller, but move in the same direction as for Italy.

In summary, the eight event studies – four for each country – tell a consistent story. Government bond yields are increasing in haircuts in central bank repos for reserves in the short-to-mid range of the term structure. For the first two events, where haircuts of treated bonds increase relative to controls, the estimated treatment effect on the yields of treated bonds is positive. For the last two events, where haircuts of treated bonds decrease relative to controls, the treatment effect is negative. The results for Italy show that the effect is significant up to around five years of residual maturity. Insignificance at the long end is consistent with eligible counterparties in Eurosystem repos (banks) typically holding shorter duration bonds.

[28] The small, but statistically significant positive treatment effect in the Italian sample for maturities larger than 17.16 years (Figure 5) is not robust to the Diebold and Li (2006) yield-curve specification (Section 7).

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

Our findings show that economically significant effects can be achieved with sufficiently large changes in haircuts. However, policy is likely to have the most significant impact in habitats where players with access to central bank repos are active.

7. Yield curve specifications with exponential decay

In this section, we repeat the analysis in Section 6 with differential treatment effects using the Nelson and Siegel (1987) yield-curve specification. This model and its extensions, e.g., Svensson (1994), are characterized by exponential decay of the impact of slope and curvature factors. Thus, these models do not "blow up" at very long maturities, as cubics do. Models with exponential decay are, therefore, better suited to extrapolation beyond the range of maturities observed in the data (Nelson and Siegel, 1987). However, in this paper, our main concern lies with fit within the sample range of maturities, where cubics fit the data extremely well. Still, employing the Nelson-Siegel/Diebold-Li (NSDL) model offers a solid robustness check to our results in Section 6.[30]

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

7.1 Specification

We employ the Diebold and Li (2006) factorization of the Nelson and Siegel (1987) model, which is designed to mitigate multicollinearity. The 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

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

[30] The Nelson and Siegel (1987) model is widely used in the literature as well as by central banks 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).

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

The four parameters in Equation (8) can be estimated with nonlinear least squares (NLS). Alternatively, as emphasized by Diebold and Li (2006), if λ_t is given, the three remaining parameters can be estimated by OLS. Fixing the decay parameter at a time-invariant value, λ, is common in practice. The decay parameter determines the point where the loading on the curvature factor, $\beta_{2,t}$, obtains its maximum (Diebold and Li, 2006). Based on practice, Diebold and Li pick this to be at a maturity of 30 months. The "Diebold-Li lambda" is then $\lambda = 0.0609$, which translates into 0.7308 when the unit for residual maturity is years (as in our case). 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.3, Panel A in the Internet Appendix).

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

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

where $\mathbf{L}_{it}$ 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 $\beta_{k,j}$, $k = 0, \ldots, 2$. The rest of the notation is as before. Estimation is over ten- and twenty-day event windows using NLS.

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

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

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

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

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

7.2 Results

We use the same data as in Section 6. For each event and time-window combination, we run Equation (10) using NLS, estimating λ and the other parameters jointly. Table 10 provides estimated treatment effects on treated bonds at selected maturities. z-statistics (in parentheses) use standard errors calculated by the delta method and are clustered at the individual bond level. In addition, for each event, the treatment delta curve, $\Delta_4^{dl}(x)$, is plotted in Figure 7 with 10% confidence bands. The figures are based on ten-day event windows.[31]

Insert Table 10 and Figure 7 here.

We start with the results for haircut harmonization (events 3 and 4). For conciseness, we focus on the ten-day window. Figure 7 shows a statistically significant negative harmonization announcement effect out to 10.03 years. This is longer than under the cubic specification (4.74 years). Point estimates are also slightly larger in absolute value under the NSDL yield curve specification. For example, for a time-to-maturity of one year, the treatment effect is -1.8 bps, versus -1.5 bps under the cubic specification.

For harmonization implementation, Figure 7 shows that the "significance boundary" is at 5.47 years. This is similar to under the cubic specification (5.72 years). Treatment effect point estimates are also similar. For a residual maturity of one year, it is -4.0 bps under the NSDL yield curve specification versus -4.3 bps under the cubic specification.

As discussed above, to capture the full harmonization effect, we also need to consider potential changes in spot rates over the interim period between announcement and implementation. We would expect to see a time-value effect over this period if implementation leads to an increase in monetary convenience yield. At a maturity of one year, the difference between the two curves shrinks by 3.6 bps. Taking this into account, the total treatment effect of haircut harmonization under the NSDL specification can be approximated as -9.4 bps, or -1.7 bps per pp reduction in haircut. Again, this is almost the same as under the cubic specification (-1.8 bps).

The haircut-harmonization findings can be summarized as follows: Goodness of fit and estimated treatment effects are similar under the NSDL and cubic yield-curve specifications. Quantitatively, both models offer superb fit and show consistently significant treatment effects

[31] We have also estimated Equation (10) 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 combination. The results, which are in the Internet Appendix (Table A.3, Panel B), are practically indistinguishable from those in Table 10.

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.

As regards the first two events, Figure 7 shows a statistically significant treatment effect out to 2.76 years and 1.90 years for the first and second events, respectively. These significance boundaries are smaller than under the cubic specification, but the R^2's are also lower. At a maturity of one year, the point estimates of the treatment effects are 1.2 bps and 4.3 bps for the first divergence date and the haircut update, respectively.

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

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 novel DiD specification that takes account of term effects in a fully flexible way, we capture a pure reserves convertibility effect over the maturity spectrum. Our findings show that reserves are 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 and Spanish 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 reflect safety, since the convertibility premium is essentially a form of liquidity premium. 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. Unfortunately, our identification approach does not generate a sufficient number of events to examine this. 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)						Residual maturity (years)					
		0-1	1-3	3-5	5-7	7-10	>10	0-1	1-3	3-5	5-7	7-10	>10
Panel A: Regular haircuts													
Rating		**Apr. 8, 2010 – Sep. 30, 2013**						**Oct. 1, 2013 – May 25, 2017**					
AAA to A−	Fixed	0.5	1.5	2.5	3.0	4.0	5.5	0.5	1.0	1.5	2.0	3.0	5.0
(Category 1)	Zero	0.5	1.5	3.0	3.5	4.5	8.5	0.5	2.0	2.5	3.0	4.0	7.0
BBB+ to BBB−	Fixed	5.5	6.5	7.5	8.0	9.0	10.5	6.0	7.0	9.0	10.0	11.5	13.0
(Category 2)	Zero	5.5	6.5	8.0	8.5	9.5	13.5	6.0	8.0	10.0	11.5	13.0	16.0
Panel B: Extraordinary haircuts applied to securities exempt from minimum rating rule requirements													
Exempted country		**Dec. 21, 2012 – Dec. 14, 2014(1)** **Jun. 29, 2016 – May 25, 2017(1)**						**Dec. 15, 2014 – Feb. 10, 2015(1)**					
Greece	Fixed	15.0	33.0	45.0	54.0	56.0	57.0	6.5	11.0	16.5	23.0	34.0	40.0
	Zero	15.0	35.5	48.5	58.5	62.0	71.0	6.5	12.0	18.0	26.0	39.5	52.5
		May 9, 2013 – Mar. 31, 2016(1)											
Cyprus	Fixed	14.5	27.5	37.5	41.0	47.5	57.0						
	Zero	14.5	29.5	40.0	45.0	52.5	71.0						
Panel C: Additional haircuts applied to assets denominated in foreign currency													
		Apr. 8, 2010 – Dec. 31, 2010(2)						**Nov. 9, 2012 – May 25, 2017**					
Currency		Add additional haircut to regular (or extraordinary) haircut						Apply additional haircut as valuation markdown before regular (or extra-ordinary) haircut					
GBP and USD		8.0						16.0					
JPY		8.0						26.0					

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

Table 3. Haircut inconsistencies and yield differentials: Two examples.
This table shows two pairs of eligible Spanish zero-coupon government bonds that mature on the same date, but have different haircuts, as seen in the public list of eligible collateral for June 16, 2014. The table also provides the following information valid on this date (from Bloomberg): (1) the ratings from all four official rating agencies for all four securities (issue ratings) as well as for Spain (country rating), and (2) the securities' end-of-day yields. In Example 1, both securities mature on January 31, 2015, and in Example 2 they mature on January 31, 2018. The ratings rule in place on June 16, 2014 for government bonds is as follows: Each security is assigned a "collateral framework rating" (for the purpose of determining the haircut) equal to the highest issue rating, alternatively, if there is no issue rating, the highest country rating is chosen. For each security, the resulting rating is indicated in boldface. The rating categories in Column 4 are given in terms of the S&P scale. Data sources: Bond maturities and haircuts are from the public list of eligible collateral published on Friday, June 13, 2014, applying on Monday, June 16, 2014. Rating and yield data is from Bloomberg.

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

Table 4. Haircut inconsistencies across countries.

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

Country	Days	Securities	Distribution of securites over haircut-inconsistency days								
			Rating categories 1 and 2			Rating category 1			Rating category 2		
			Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Panel A: Full Sample											
Cyprus	40	55	54.5	54	55	9.9	1	52	44.6	2	54
Greece	46	77	70.5	67	74	67.2	4	72	3.3	2	63
Hungary	97	13	12.3	12	13	1.0	1	1	11.3	11	12
Ireland	198	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: Sub-sample with market prices											
Cyprus	33	5	4.1	3	5	1.5	1	4	2.6	1	4
Greece	1	13	13.0	13	13	1.0	1	1	12.0	12	12
Hungary	97	13	12.0	9	13	1.0	1	1	11.0	8	12
Ireland	194	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									

Table 5. Summary statistics.

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

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

Table 6. Average delta curve coefficients over time.

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

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

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

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

		First divergence			Haircut update			Harmonization announcement			Harmonization implementation		
		Italy: August 9, 2013											
	Maturity buckets (in years)	Spain: June 3, 2013			October 1, 2013			September 1, 2014			December 15, 2014		
		Window (business days)			Window (business days)			Window (business days)			Window (business days)		
		10 days	in %	Δ 20 days	10 days	in %	Δ 20 days	10 days	in %	Δ 20 days	10 days	in %	Δ 20 days
Panel A: Italy													
Treated bonds	0-1	3	4.9		3	4.8	-1	11	16.4	-2	14	20.3	-5
	1-3	4	6.6		4	6.5		3	4.5		3	4.3	-1
	3-5	2	3.3		2	3.2		4	6.0		5	7.2	-1
	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	-2
	10-15	16	26.2		16	25.8		18	26.9		16	23.2	-2
	15-20	13	21.3		13	21.0		10	14.9		10	14.5	
	>20	9	14.8		9	14.5	-1	8	11.9		8	11.6	-1
Total treated		61	100.0	0	62	100.0	-2	67	100.0	-2	69	100.0	-12
Control bonds	0-1	15	38.5	-2	15	36.6	-2	5	17.2	-1	4	14.3	-1
	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	-2	41	100.0	-2	29	100.0	-1	28	100.0	-1
Panel B: Spain													
Treated bonds	0-1	2	25.0		2	22.2		9	69.2		11	73.3	-1
	1-3	5	62.5		5	55.6		3	23.1		3	20.0	
	3-5	1	12.5		2	22.2		1	7.7		1	6.7	
Total treated		8	100.0	0	9	100.0	0	13	100.0	0	15	100.0	-1
Control bonds	0-1	17	50.0	-4	11	39.3	-1	5	27.8		7	33.3	
	1-3	11	32.4		10	35.7		11	61.1		13	61.9	-1
	3-5	6	17.6	-1	7	25.0		2	11.1		1	4.8	
Total controls		34	100.0	-5	28	100.0	-1	18	100.0	0	21	100.0	-1

Table 8. DiD estimator under the cubic, parallel shifts specification.

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

	Haircut differential widens				**Haircut differential shrinks**			
	First divergence				Harmonization		Harmonization	
	Italy: August 9, 2013		Haircut update		announcement		implementation	
	Spain: June 3, 2013		October 1, 2013		September 1, 2014		December 15, 2014	
	Window (business days)		Window (business days)		Window (business days)		Window (business days)	
	10 days	20 days	10 days	20 days	10 days	20 days	10 days	20 days
Panel A: Italy								
DiD	-0.003	-0.006	$\mathbf{0.023}^{a}$	$\mathbf{0.019}^{b}$	$\mathbf{-0.011}^{b}$	$\mathbf{-0.024}^{b}$	$\mathbf{-0.027}^{a}$	$\mathbf{-0.033}^{a}$
	(-0.54)	(-0.85)	(3.36)	(2.35)	(-2.01)	(-2.39)	(-2.95)	(-2.83)
Adj. R-squared	0.9955	0.9945	0.9957	0.9940	0.9932	0.9918	0.9955	0.9947
No. bonds (T/C)	61/39	61/37	62/41	60/39	67/29	65/28	69/28	57/27
Panel B: Spain								
DiD	$\mathbf{0.037}^{b}$	0.044	0.021	0.013	-0.003	-0.007	$\mathbf{-0.014}^{b}$	$\mathbf{-0.020}^{b}$
	(2.45)	(1.54)	(1.06)	(0.61)	(-0.69)	(-1.30)	(-2.11)	(-2.58)
Adj. R-squared	0.9894	0.9800	0.9835	0.9791	0.9188	0.9297	0.8993	0.8608
No. bonds (T/C)	8/34	8/29	9/28	9/27	13/18	13/18	15/21	14/20

Table 9. Treatment effects at selected maturities under the cubic, fully flexible specification.

This table provides estimated treatment effects (in pps) of treated bonds at selected maturities for each event and country using the fully flexible DiD specification $yield_{it} = \mathbf{\Gamma}_1' \ \mathbf{Mat}_{it} + \mathbf{\Gamma}_2' \ \mathbf{Mat}_{it} \ \mathbb{1}_{Treated,i} + \mathbf{\Gamma}_3' \ \mathbf{Mat}_{it} \ \mathbb{1}_{Post,t} + \mathbf{\Gamma}_4' \ \mathbf{Mat}_{it} \ \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} \ + \ \varepsilon_{it}$ with notation as in Table 8. The DiD estimator is given by the vector $\mathbf{\Gamma}_4$. The specification is run with OLS individually for Italy (Panel A) and Spain (Panel B) over the ten- and twenty-day event windows for each event date as indicated in the table using the samples of zero-coupon bonds with non-stale market prices each day in the respective windows discussed in Table 7. For the "haircut update" event, we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013). Each panel provides the estimated treatment effect at selected maturities for each event window, with z-statistics (in parentheses) calculated using the delta method 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 column to the far right 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**					
Residual	First divergence			Haircut update			Harmon. announcement			Harmon. implementation		
maturity	Italy: August 9, 2013			October 1, 2013			September 1, 2014			December 15, 2014		
(in years)	10 days	20 days	DiD hc	10 days	20 days	DiD hc	10 days	20 days	DiD hc	10 days	20 days	DiD hc
Panel A: Italy												
0.5	**0.020**^{b}	**0.031**^{a}	5.0	**0.074**^{a}	**0.029**^{c}	0.5	**-0.016**^{a}	-0.011	0.0	**-0.048**^{a}	**-0.052**^{a}	−5.5
	(2.04)	(3.10)		(4.58)	(1.83)		(-2.80)	(-1.36)		(-2.70)	(-2.77)	
1	**0.019**^{b}	**0.027**^{a}	5.0	**0.062**^{a}	**0.028**^{b}	0.5	**-0.015**^{a}	-0.009	0.0	**-0.043**^{a}	**-0.047**^{a}	−5.5
	(2.34)	(3.31)		(4.49)	(2.09)		(-3.21)	(-1.52)		(-2.94)	(-2.93)	
2	**0.017**^{b}	**0.019**^{a}	5.0	**0.041**^{a}	**0.025**^{b}	1.0	**-0.013**^{a}	-0.007	0.0	**-0.036**^{a}	**-0.037**^{a}	−6.0
	(2.58)	(3.01)		(3.85)	(2.54)		(-3.56)	(-1.64)		(-3.42)	(-3.20)	
3	**0.016**^{b}	**0.013**^{c}	5.0	**0.024**^{b}	**0.023**^{b}	1.0	**-0.012**^{a}	-0.005	0.0	**-0.029**^{a}	**-0.028**^{a}	−6.0
	(2.18)	(1.78)		(2.48)	(2.51)		(-2.85)	(-1.11)		(-3.55)	(-3.16)	
5	0.013	0.002	5.0	-0.001	0.018	2.5	-0.009	-0.003	0.0	**-0.017**^{b}	**-0.016**^{c}	−7.5
	(1.31)	(0.24)		(-0.07)	(1.64)		(-1.55)	(-0.39)		(-2.16)	(-1.89)	
8	0.007	-0.006	5.0	-0.016	0.012	4.0	-0.006	-0.002	0.0	-0.006	-0.005	−9.0
	(0.63)	(-0.50)		(-1.30)	(0.88)		(-0.87)	(-0.18)		(-0.64)	(-0.54)	
12	-0.000	-0.010	5.0	-0.009	0.004	4.0	-0.004	-0.003	0.0	0.003	0.000	−9.0
	(-0.04)	(-0.58)		(-0.73)	(0.40)		(-0.56)	(-0.27)		(0.35)	(0.04)	
16	-0.008	-0.008	5.0	0.013	0.001	4.0	-0.003	-0.005	0.0	0.006	0.002	−9.0
	(-0.56)	(-0.39)		(1.11)	(0.18)		(-0.40)	(-0.46)		(0.61)	(0.16)	
20	-0.016	-0.007	5.0	**0.029**^{b}	0.005	4.0	-0.002	-0.006	0.0	0.008	0.008	−9.0
	(-1.19)	(-0.35)		(2.57)	(0.70)		(-0.28)	(-0.59)		(0.79)	(0.62)	
Adj. R-squared	0.9962	0.9953	–	0.9962	0.9948	–	0.9933	0.9921	–	0.9960	0.9953	–
No. bonds (T/C)	61/39	61/37	–	62/41	60/39	–	67/29	65/28	–	69/28	57/27	–

Table 9 – *continued*

Residual maturity (in years)	Haircut differential widens						Haircut differential shrinks					
	First divergence			Haircut update			Harmon. announcement			Harmon. implementation		
	Spain: June 3, 2013			October 1, 2013			September 1, 2014			December 15, 2014		
	10 days	20 days	DiD hc	10 days	20 days	DiD hc	10 days	20 days	DiD hc	10 days	20 days	DiD hc
Panel B: Spain												
0.5	**0.025**[a]	**0.036**[a]	5.0	-0.005	0.000	0.5	**-0.013**[b]	**-0.019**[b]	0.0	0.002	-0.004	−5.5
	(3.36)	(3.75)		(-0.39)	(0.00)		(-2.23)	(-2.14)		(0.27)	(-0.49)	
1	**0.039**[a]	**0.034**[a]	5.0	0.007	0.018	0.5	-0.002	-0.006	0.0	0.010	0.008	−5.5
	(4.82)	(4.66)		(0.64)	(1.11)		(-0.31)	(-0.68)		(1.19)	(0.77)	
2	**0.026**[a]	**0.028**[b]	5.0	**0.014**[b]	**0.021**[b]	1.0	-0.004	-0.003	0.0	**-0.020**[b]	**-0.028**[b]	−6.0
	(2.76)	(2.36)		(2.16)	(2.16)		(-0.59)	(-0.50)		(-2.68)	(-2.09)	
3	0.010	-0.003	5.0	0.009	0.005	1.0	-0.008	-0.004	0.0	**-0.010**[c]	-0.010	−6.0
	(1.26)	(-0.28)		(1.68)	(0.62)		(-0.92)	(-0.66)		(-2.02)	(-1.60)	
Adj. R-squared	0.9897	0.9816	–	0.9844	0.9801	–	0.9257	0.9388	–	0.9146	0.8774	–
No. bonds (T/C)	8/34	8/29	–	9/28	9/27	–	13/18	13/18	–	15/21	14/20	–

Table 10. Treatment effects at selected maturities under the Diebold-Li (2006) fully flexible specification.

This table provides estimated treatment effects (in pps) of treated bonds at selected maturities for each event, as indicated in the table, 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 three dimensional vector of regressors with elements 1, $l_1(x_{it};\lambda) = \left(1 - e^{-\lambda x_{it}}\right)/(\lambda x_{it})$, 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, and λ is the decay parameter. $\mathbf{B}_j$, $j = 1, \ldots 4$, are the corresponding three-dimensional vectors of coefficients and $\mathbf{B}_4$ is the DiD estimator. The rest of the notation is as in Table 8. The underlying data are the ten- and twenty-day event-windows on the Italian sample of zero-coupon bonds with non-stale market prices each day over the respective windows discussed in Table 7. For each event and window, the model is estimated with NLS with a seed value for lambda of $\lambda = 1$. The resulting lambda estimates are shown at the bottom of the table. For the "haircut update" event, we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013). For each event and window, the table provides the estimated treatment effects at selected maturities with z-statistics (in parentheses) underneath which are 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. Statistically significant coefficients (at 10%-level or better) are marked in bold. For each event, the third 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**					
Residual	First divergence			Haircut update			Harmon. announcement			Harmon. implementation		
maturity	August 9, 2013			October 1, 2013			September 1, 2014			December 15, 2014		
(in years)	10 days	20 days	DiD hc	10 days	20 days	DiD hc	10 days	20 days	DiD hc	10 days	20 days	DiD hc
0.5	0.008	**0.022**^{a}	5.0	**0.067**^{a}	0.032	0.5	**-0.016**^{b}	-0.012	0.0	**-0.044**^{a}	**-0.045**^{a}	−5.5
	(1.02)	(2.62)		(4.14)	(1.23)		(-2.27)	(-0.98)		(-2.62)	(-2.70)	
1	**0.012**^{b}	**0.013**^{b}	5.0	**0.043**^{a}	0.024	0.5	**-0.018**^{a}	**-0.016**^{c}	0.0	**-0.040**^{a}	**-0.040**^{a}	−5.5
	(2.11)	(2.33)		(3.56)	(1.41)		(-3.39)	(-1.89)		(-3.02)	(-3.04)	
2	**0.014**^{c}	0.002	5.0	0.014	0.014	1.0	**-0.021**^{a}	**-0.020**^{b}	0.0	**-0.032**^{a}	**-0.032**^{a}	−6.0
	(1.95)	(0.30)		(1.46)	(1.25)		(-3.02)	(-2.17)		(-3.70)	(-3.51)	
3	0.013	-0.004	5.0	0.002	0.009	1.0	**-0.021**^{a}	**-0.022**^{c}	0.0	**-0.025**^{a}	**-0.025**^{a}	−6.0
	(1.56)	(-0.46)		(0.18)	(0.76)		(-2.58)	(-1.90)		(-3.42)	(-3.18)	
5	0.007	-0.009	5.0	-0.004	0.004	2.5	**-0.020**^{b}	**-0.022**^{c}	0.0	**-0.016**^{c}	**-0.015**^{c}	−7.5
	(0.85)	(-1.08)		(-0.46)	(0.40)		(-2.43)	(-1.83)		(-1.89)	(-1.85)	
8	-0.002	-0.010	5.0	0.001	0.003	4.0	**-0.016**^{b}	**-0.019**^{c}	0.0	-0.007	-0.006	−9.0
	(-0.18)	(-0.97)		(0.14)	(0.34)		(-2.21)	(-1.75)		(-0.82)	(-0.82)	
12	-0.008	-0.010	5.0	0.007	0.003	4.0	-0.011	-0.014	0.0	0.000	0.000	−9.0
	(-0.76)	(-0.71)		(0.97)	(0.33)		(-1.15)	(-1.02)		(0.03)	(0.01)	
16	-0.012	-0.010	5.0	0.011	0.004	4.0	-0.008	-0.011	0.0	0.004	0.003	−9.0
	(-0.96)	(-0.60)		(1.31)	(0.31)		(-0.62)	(-0.61)		(0.64)	(0.46)	
20	-0.015	-0.010	5.0	0.014	0.004	4.0	-0.006	-0.009	0.0	0.006	0.005	−9.0
	(-1.04)	(-0.54)		(1.45)	(0.30)		(-0.38)	(-0.42)		(0.79)	(0.59)	
Adj. R-squared	0.9941	0.9929	–	0.9940	0.9925	–	0.9964	0.9955	–	0.9962	0.9960	–
No. bonds (T/C)	61/39	61/37	–	62/41	60/39	–	67/29	65/28	–	69/28	57/27	–
$\widehat{\lambda}$	0.5836	0.6076	–	0.5979	0.5916	–	0.3948	0.4069	–	0.2633	0.2842	–

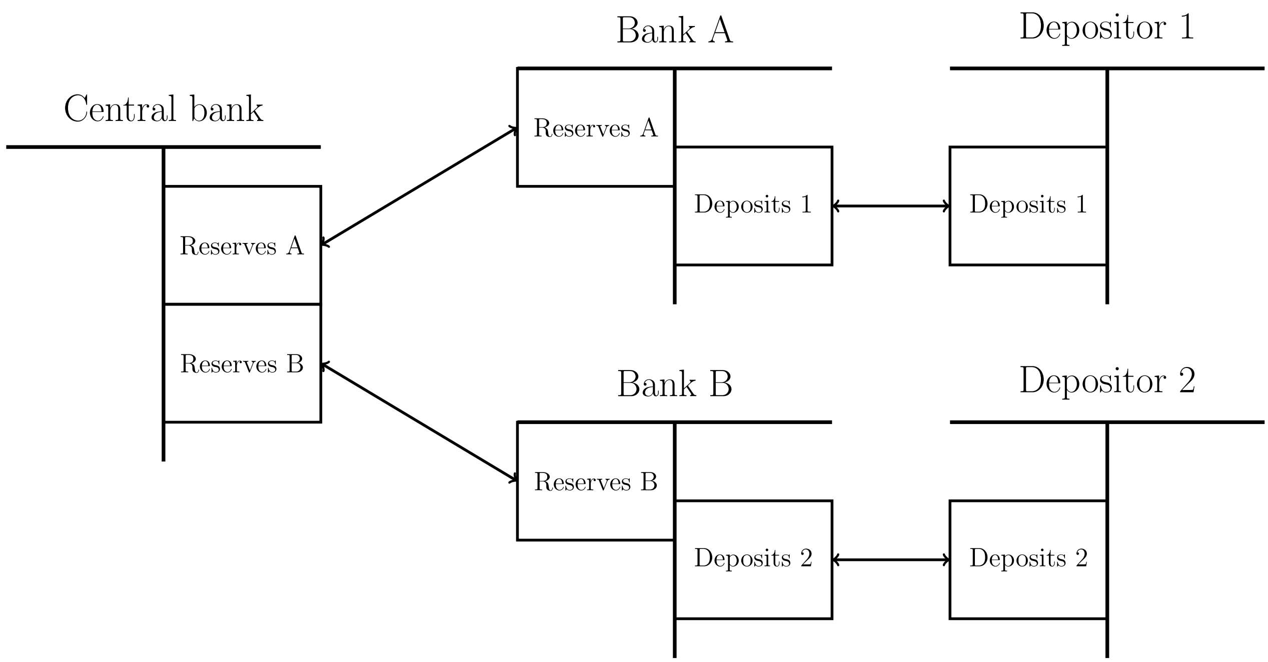


Figure 1. The modern two-tier monetary system.

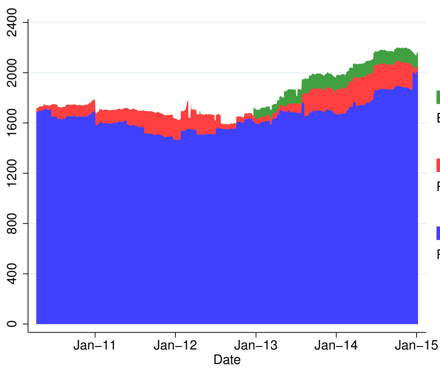
In the modern two-tier monetary system, transactions ultimately settle in central-bank money (reserves or banknotes). This figure focuses on reserves. In the two-tier system, depositors hold deposits with banks, who, in turn, hold deposits (reserves) with the central bank. Payments between depositors 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.

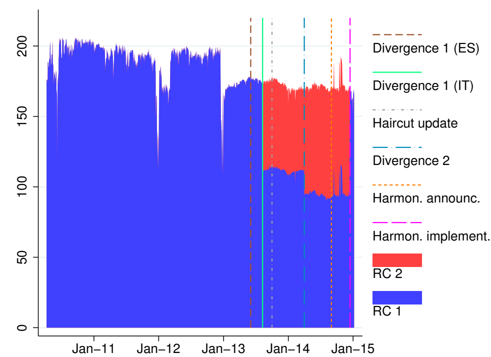
b. Financial assets and leverage. Depositor 1 borrows from Bank A to buy risky assets. The borrowed funds appear as the deposit shown in the figure. Depositor 1 has a corresponding liability toward Bank A (not shown), which is an asset for Bank A (not shown). When Depositor 1 buys the risky securities 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.

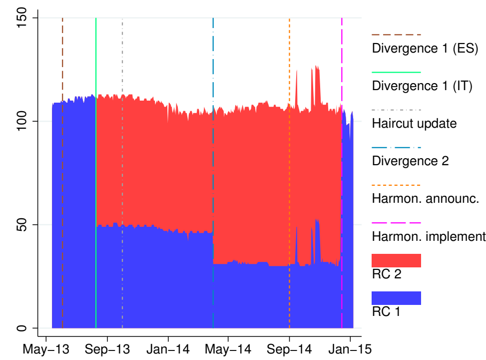
d. Banknote withdrawal. Depositor 1 withdraws banknotes from her account with Bank A. To get the banknotes, Bank A exchanges reserves for banknotes with the central bank or Bank B.



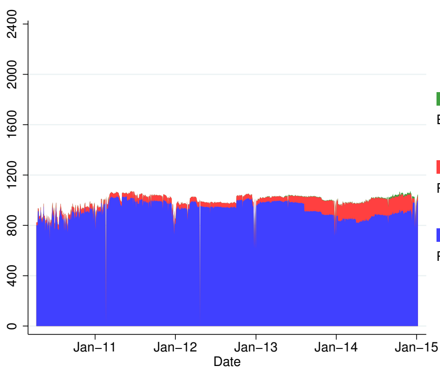
(a) Full sample.



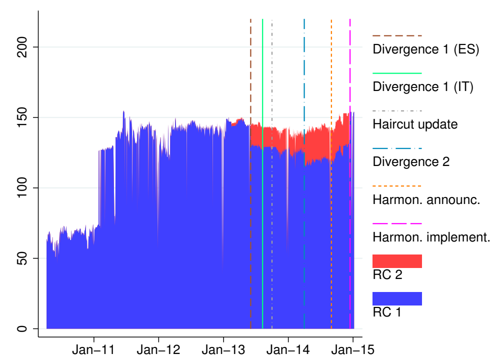
(c) Italian bonds with market prices.



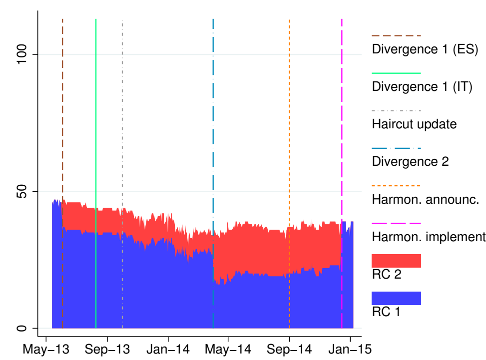
(e) Italian zero-coupon bonds with market prices.



(b) Bonds with market prices.

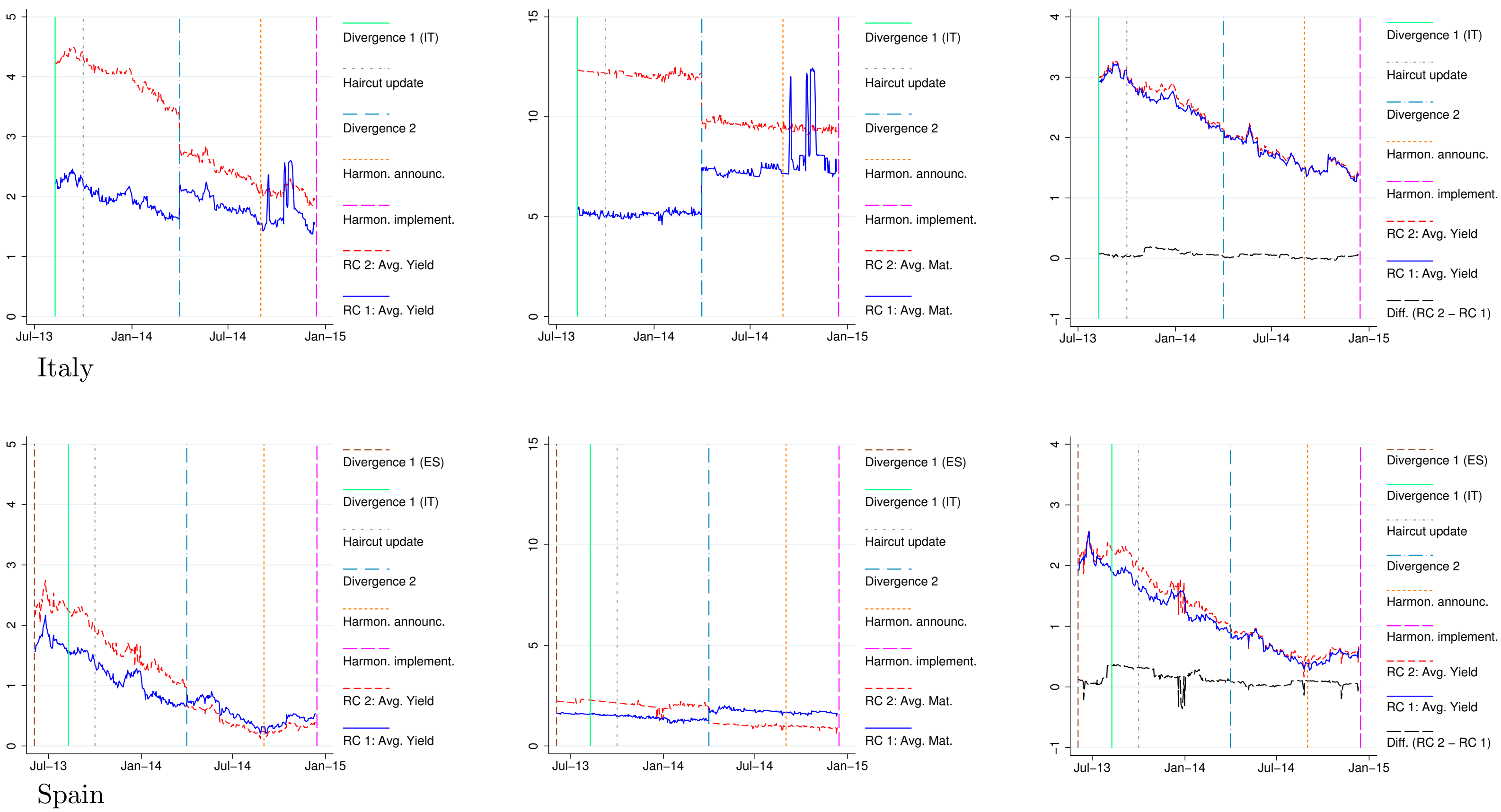


(d) Spanish bonds with market prices.



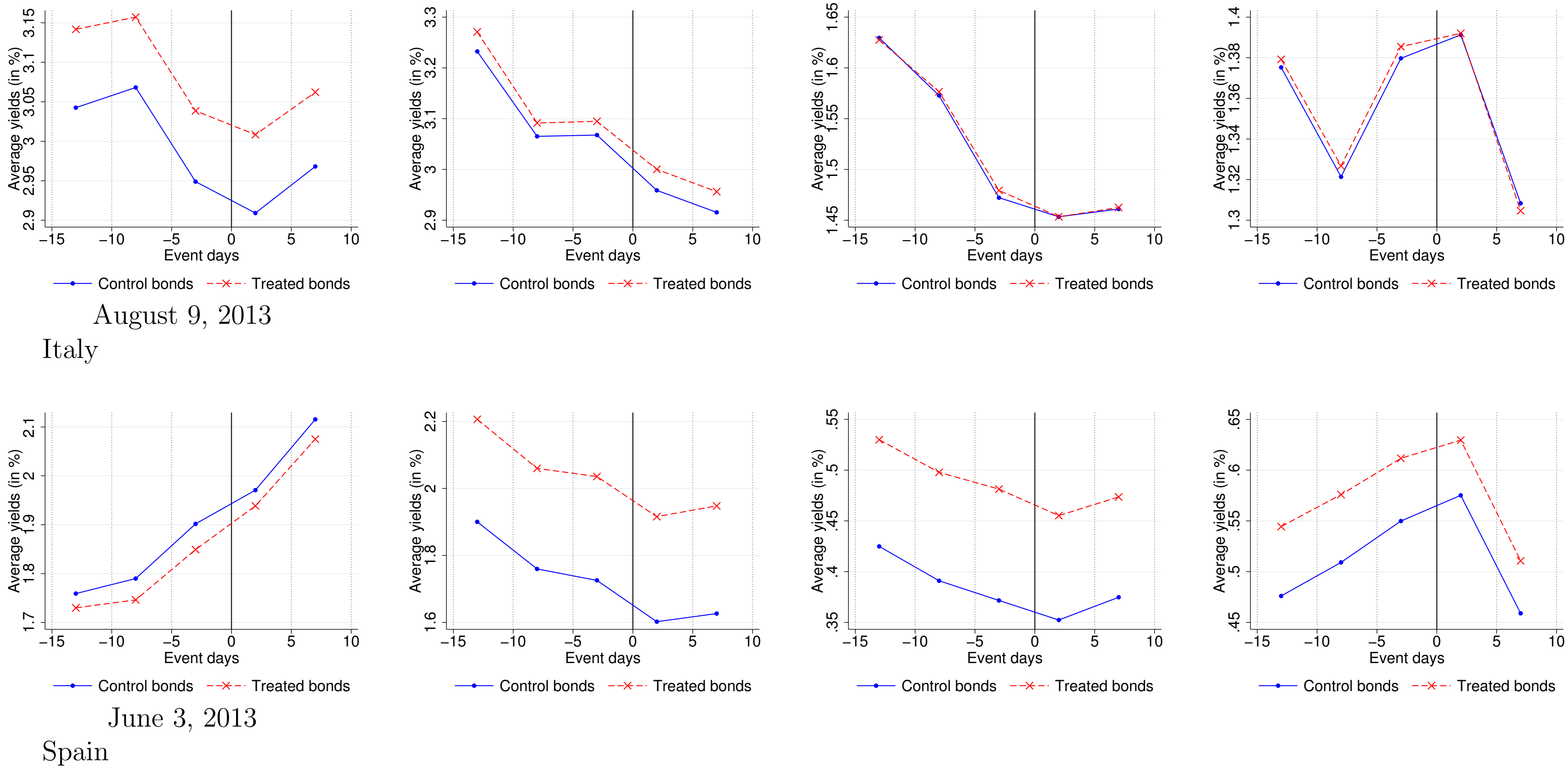
(f) Spanish zero-coupon bonds with market prices.

Figure 2. Daily distributions of central-government bonds by rating category.
This figure shows the number of fixed- and zero-coupon government bonds by rating category over time. Subplot (a) shows the full sample from April 9, 2010 to January 7, 2015, inclusive, Subplot (b) the subset with market prices, and Subplots (c) and (d) the subsets with market prices individually for Italy and Spain, respectively, for the same sample period. Subplots (e) and (f) provide, respectively, the final samples of Italian and Spanish zero-coupon bonds with market prices over the period May 13, 2013 to January 7, 2015, inclusive. "RC" stands for rating category. Rating category 1 (2) refers to securities with a rating in the AAA to A− (BBB+ to BBB−) range (on the S&P scale). "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 (brown) dashed line marks the first divergence date in Spain on June 3, 2013, the (mint-green) solid line the first divergence date in Italy on August 9, 2013, the (grey) dash-dotted line the ECB's haircut update on October 1, 2013, the (blue) longdash-dotted line the second divergence date on April 1, 2014, the (orange) shortdashed line the rating and haircut harmonization announcement on September 1, 2014, and the (magenta-colored) longdashed line the implementation of harmonization on December 15, 2014.



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

Figure 3. Italy and Spain: Comparison of bonds across rating categories over time.
This figure provides time-series plots of average yield and average residual maturity from the first divergence dates (August 9, 2013 in Italy and June 3, 2013 in Spain) to the last business day before haircut harmonization (December 12, 2014) based on the final samples of Italian and Spanish zero-coupon central-government bonds (bond-dates with stale prices are excluded). Plots in the first (second) row are for Italy (Spain). Subplots (a) and (b) provide daily averages of yields and residual maturity, respectively, across bonds in each rating category. Subplots (c) show average yields calculated as follows: On each day, for each country, and each rating category, take yield average within the ECB's maturity buckets, then take average across these maturity-bucket means. "RC" stands for rating category. In each subplot the blue, solid (red, dashed) line represents bonds in rating category 1 (2) representing securities with a rating in the AAA to A− (BBB+ to BBB−) range on the S&P scale. Subplots (c) additionally provide 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 2.



(a) First divergence

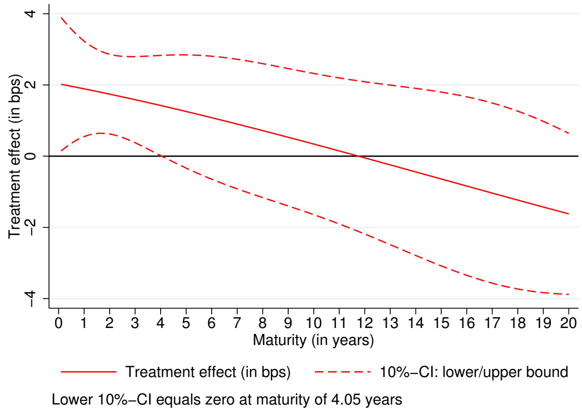
(b) Haircut update
October 1, 2013

(c) Harmon. announcement
September 1, 2014

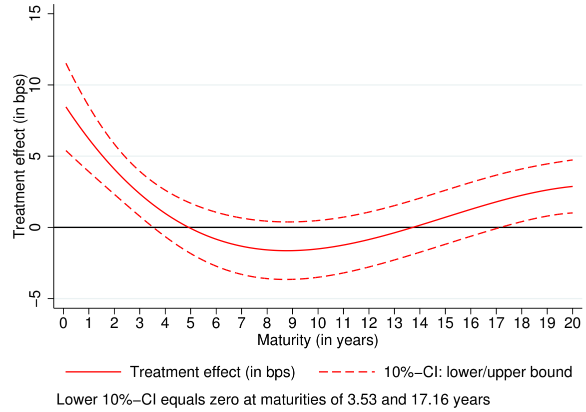
(d) Harmon. implementation
December 15, 2014

Figure 4. Parallel trends for each country-event.

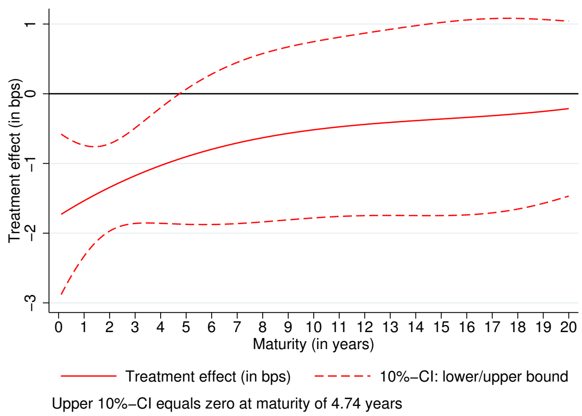
This figure shows average yields separately for treated and control bonds for each country-event using the samples described in Table 7 for the twenty-day window and the preceding five business days for the same bonds. Averages are calculated as in Figure 3c and then across days for five-day subperiods. In each subplot the blue 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). 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).



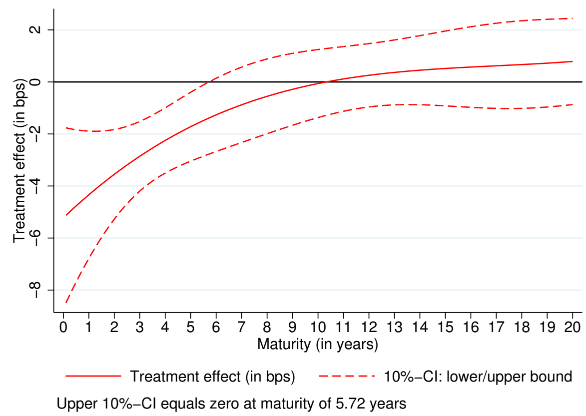
(a) First divergence
August 9, 2013



(b) Haircut update
October 1, 2013

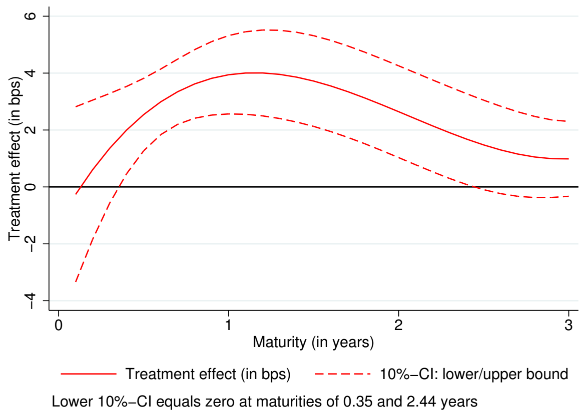


(c) Harmonization announcement
September 1, 2014

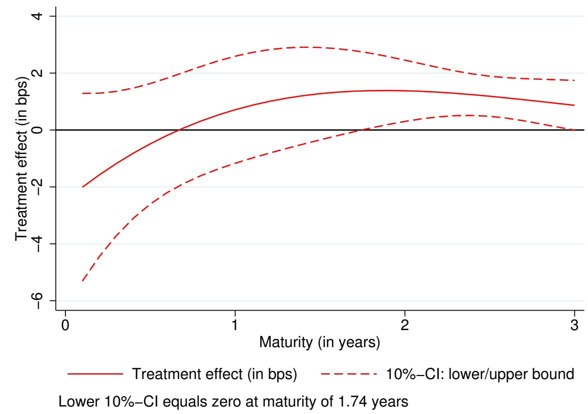


(d) Harmonization implementation
December 15, 2014

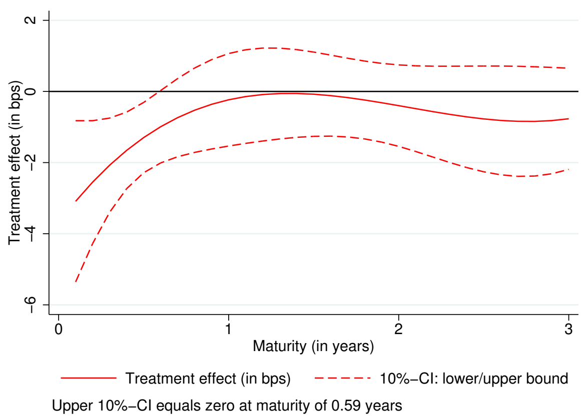
Figure 5. Italy: Change in delta curve for each event (cubic curves).
This figure shows the change in the delta curve under the cubic specification for each of the four events over ten-day windows using the samples of zero-coupon bonds with non-stale market prices for Italy (see Table 7). Estimation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



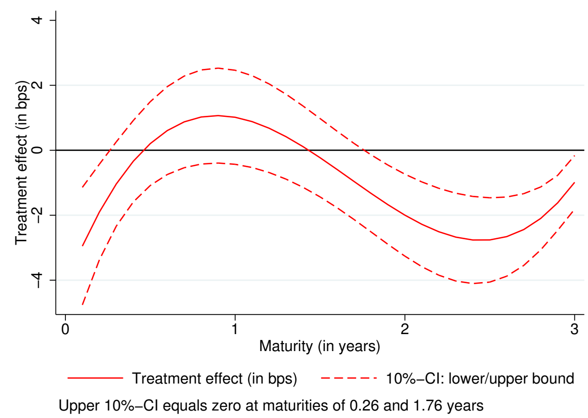
(a) First divergence
June 3, 2013



(b) Haircut update
October 1, 2013

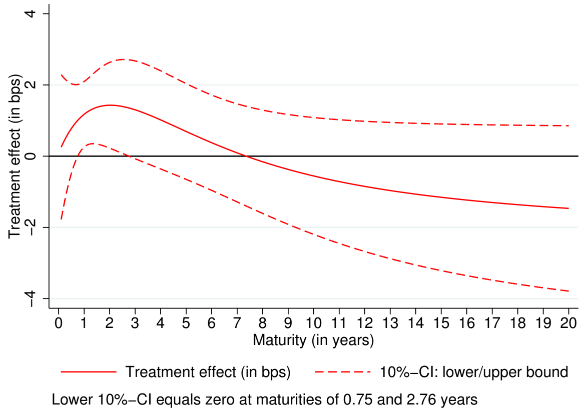


(c) Harmonization announcement
September 1, 2014

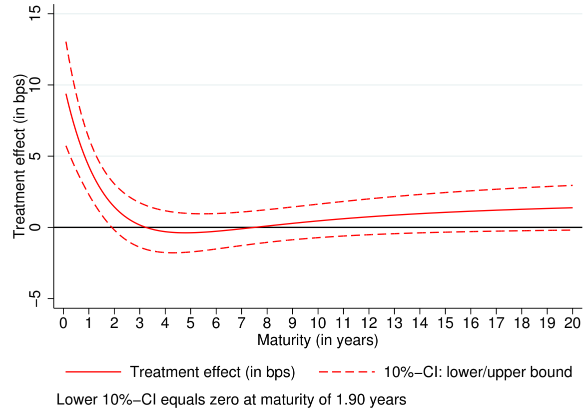


(d) Harmonization implementation
December 15, 2014

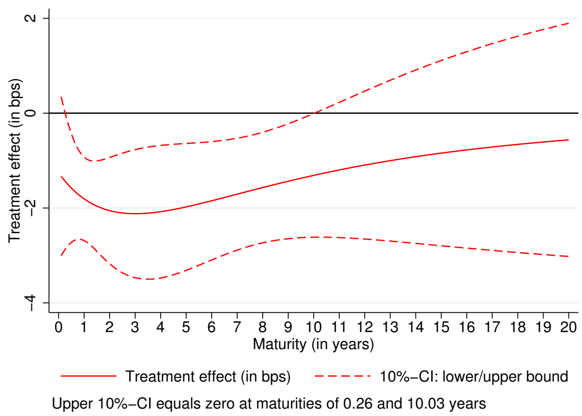
Figure 6. Spain: Change in delta curve for each event (cubic curves).
This figure shows the change in the delta curve under the cubic specification for each of the four events over ten-day windows using the samples of zero-coupon bonds with non-stale market prices for Spain (see Table 7). Estimation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



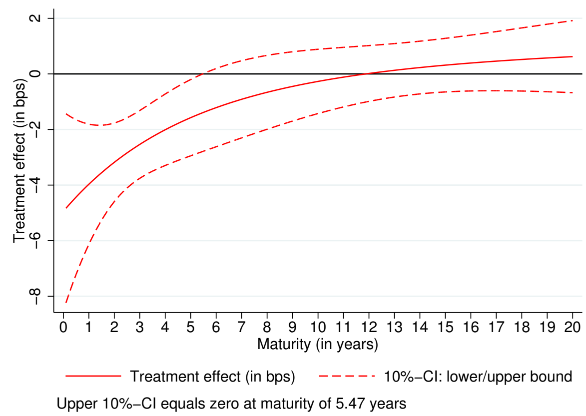
(a) First divergence (Italy)
August 9, 2013



(b) Haircut update
October 1, 2013



(c) Harmonization announcement
September 1, 2014



(d) Harmonization implementation
December 15, 2014

Figure 7. Italy: Change in delta curve for each event (Diebold-Li curves).

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

Internet Appendix

THE PRICE OF MONEY: THE RESERVES CONVERTIBILITY PREMIUM OVER THE TERM STRUCTURE[1]

Kjell G. Nyborg

University of Zurich,
Swiss Finance Institute,
and CEPR

Jiri Woschitz

BI Norwegian Business School

February 2024

[1]Nyborg: Department of Banking and Finance, University of Zurich, Plattenstrasse 14, CH-8032 Zurich, Switzerland. email: kjell.nyborg@bf.uzh.ch.
Woschitz: Department of Finance, BI Norwegian Business School, B4y, NO-0442 Oslo, Norway. email: jiri.woschitz@bi.no.

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 across the maturity spectrum.

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

Panel A: Full Sample

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

Panel B: Sub-sample with market prices

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

Table A.2. DiD estimator under Specification (4′) in Footnote 25.

This table provides estimated treatment effects (in pps) of treated bonds for each event and country using the DiD specification in Equation (4′) in the paper, namely $yield_{it} = \alpha_i + \delta_t + \beta_{DiD}\, \mathbb{1}_{Treated,i} \times \mathbb{1}_{Post,t} + \varepsilon_{it}$, where $\mathbb{1}_{Treated,i}$ is an indicator variable that is one for treated bonds and zero otherwise, $\mathbb{1}_{Post,t}$ is an indicator variable that is one for event and post-event dates and zero otherwise, and α_i and δ_t are individual unit- and time-fixed effects, respectively. β_{DiD} is the DiD estimator. The specification is run with OLS individually for Italy (Panel A) and Spain (Panel B) for each event date as indicated in the table using the samples of zero-coupon bonds with non-stale market prices each day in the respective event windows discussed in Table 7 in the paper. For the "haircut update" event, we exclude the announcement date and the single business day between announcement and implementation (September 27 and 30, 2013). t-statistics are shown beneath the coefficients and are based on standard errors 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.

	Haircut differential widens				**Haircut differential shrinks**			
	First divergence		Haircut update		Harmonization announcement		Harmonization implementation	
	Italy: August 9, 2013 Spain: June 3, 2013		October 1, 2013		September 1, 2014		December 15, 2014	
	Window (business days)		Window (business days)		Window (business days)		Window (business days)	
	10 days	20 days	10 days	20 days	10 days	20 days	10 days	20 days
Panel A: Italy								
DiD	0.002	0.004	**0.030**^{a}	**0.031**^{a}	**-0.010**^{c}	**-0.023**^{b}	**-0.026**^{a}	**-0.032**^{a}
	(0.31)	(0.51)	(4.13)	(3.37)	(-1.82)	(-2.27)	(-2.97)	(-2.85)
Adj. R-squared	0.4845	0.7288	0.6677	0.8107	0.6221	0.7265	0.7384	0.7348
No. bonds (T/C)	61/39	61/37	62/41	60/39	67/29	65/28	69/28	57/27
Panel B: Spain								
DiD	**0.038**^{b}	0.045	0.023	0.016	-0.002	-0.005	**-0.014**^{b}	**-0.022**^{b}
	(2.28)	(1.41)	(1.08)	(0.69)	(-0.46)	(-0.79)	(-2.17)	(-2.52)
Adj. R-squared	0.6091	0.8262	0.7108	0.8089	0.7945	0.6517	0.5590	0.7773
No. bonds (T/C)	8/34	8/29	9/28	9/27	13/18	13/18	15/21	14/20

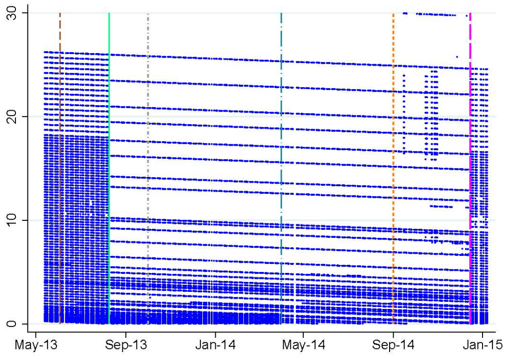
Table A.3. Treatment effects at selected maturities: Alternative estimation of fully flexible Diebold-Li specification.

This table provides estimated treatment effects (in pps) of treated bonds at selected maturities for each event, as indicated in the table, 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 three dimensional vector of regressors with elements 1, $l_1(x_{it}; \lambda) = \left(1 - e^{-\lambda x_{it}}\right) / (\lambda x_{it})$, 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, and λ is the decay parameter. $\mathbf{B}_j$, $j = 1, \ldots 4$, are the corresponding three-dimensional vectors of coefficients and $\mathbf{B}_4$ is the DiD estimator. The rest of the notation is as in Table 8. 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 and window as an average across daily estimates for both rating categories using NLS. 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). For each event and window, the table provides the estimated treatment effects at selected maturities with z-statistics (in parentheses) underneath which are 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. Statistically significant coefficients (at 10%-level or better) are marked in bold. For each event, the third 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			Harmon. announcement			Harmon. implementation		
	August 9, 2013			October 1, 2013			September 1, 2014			December 15, 2014		
	10 days	20 days	DiD hc	10 days	20 days	DiD hc	10 days	20 days	DiD hc	10 days	20 days	DiD hc
Panel A: Estimation using Diebold-Li lambda $\lambda = 0.7308$												
0.5	0.006	**0.018**^{b}	5.0	**0.062**^{a}	0.025	0.5	**-0.021**^{b}	-0.017	0.0	**-0.032**^{a}	-0.023	−5.5
	(0.75)	(2.23)		(3.91)	(0.90)		(-2.50)	(-1.52)		(-4.06)	(-1.64)	
1	**0.011**^{c}	**0.010**^{c}	5.0	**0.039**^{a}	0.018	0.5	**-0.022**^{a}	**-0.020**^{b}	0.0	**-0.018**^{a}	-0.013	−5.5
	(1.77)	(1.71)		(3.33)	(1.08)		(-3.11)	(-2.20)		(-3.22)	(-1.35)	
2	**0.013**^{c}	-0.000	5.0	0.013	0.011	1.0	**-0.022**^{a}	**-0.023**^{b}	0.0	-0.003	-0.002	−6.0
	(1.66)	(-0.01)		(1.31)	(0.98)		(-2.66)	(-1.97)		(-0.54)	(-0.21)	
3	0.011	-0.005	5.0	0.004	0.008	1.0	**-0.020**^{b}	**-0.022**^{b}	0.0	0.003	0.003	−6.0
	(1.37)	(-0.64)		(0.36)	(0.67)		(-2.56)	(-2.00)		(0.46)	(0.40)	
5	0.005	-0.008	5.0	0.001	0.005	2.5	**-0.016**^{b}	**-0.019**^{b}	0.0	0.006	0.005	−7.5
	(0.62)	(-1.11)		(0.08)	(0.49)		(-2.52)	(-2.06)		(1.20)	(0.93)	
8	-0.003	-0.009	5.0	0.004	0.004	4.0	-0.012	-0.015	0.0	0.005	0.004	−9.0
	(-0.32)	(-0.85)		(0.66)	(0.43)		(-1.48)	(-1.21)		(1.41)	(1.08)	
12	-0.008	-0.009	5.0	0.008	0.004	4.0	-0.009	-0.012	0.0	0.004	0.003	−9.0
	(-0.71)	(-0.64)		(1.10)	(0.35)		(-0.84)	(-0.70)		(0.93)	(0.71)	
16	-0.011	-0.009	5.0	0.011	0.004	4.0	-0.008	-0.010	0.0	0.003	0.003	−9.0
	(-0.84)	(-0.56)		(1.23)	(0.30)		(-0.61)	(-0.52)		(0.62)	(0.50)	
20	-0.013	-0.009	5.0	0.012	0.004	4.0	-0.007	-0.009	0.0	0.002	0.002	−9.0
	(-0.90)	(-0.52)		(1.28)	(0.28)		(-0.50)	(-0.44)		(0.46)	(0.40)	
Adj. R-squared	0.9936	0.9926	–	0.9935	0.9920	–	0.9763	0.9769	–	0.9584	0.9631	–
No. bonds (T/C)	61/39	61/37	–	62/41	60/39	–	67/29	65/28	–	69/28	57/27	–
λ	0.7308	0.7308	–	0.7308	0.7308	–	0.7308	0.7308	–	0.7308	0.7308	–

Table A.3 – *continued*

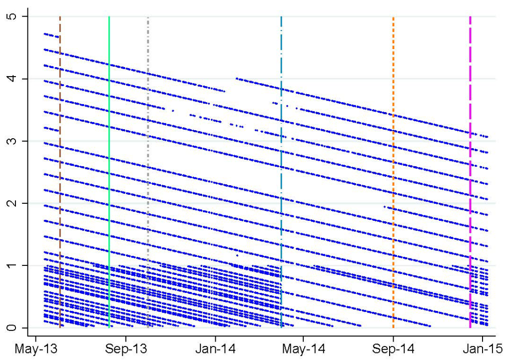
Residual	Haircut differential widens						Haircut differential shrinks					
maturity	First divergence			Haircut update			Harmon. announcement			Harmon. implementation		
(in years)	August 9, 2013			October 1, 2013			September 1, 2014			December 15, 2014		
	10 days	20 days	DiD hc	10 days	20 days	DiD hc	10 days	20 days	DiD hc	10 days	20 days	DiD hc
Panel B: Estimation using event- and window-specific average in-sample lambda												
0.5	0.008	**0.022[a]**	5.0	**0.067[a]**	0.033	0.5	**-0.016[b]**	-0.012	0.0	**-0.044[a]**	**-0.045[a]**	−5.5
	(1.02)	(2.58)		(4.17)	(1.24)		(-2.27)	(-0.99)		(-2.61)	(-2.71)	
1	**0.012[b]**	**0.013[b]**	5.0	**0.043[a]**	0.025	0.5	**-0.018[a]**	**-0.016[c]**	0.0	**-0.040[a]**	**-0.040[a]**	−5.5
	(2.11)	(2.38)		(3.64)	(1.41)		(-3.40)	(-1.93)		(-3.01)	(-3.06)	
2	**0.014[b]**	0.002	5.0	0.014	0.014	1.0	**-0.021[a]**	**-0.020[b]**	0.0	**-0.032[a]**	**-0.032[a]**	−6.0
	(1.96)	(0.32)		(1.51)	(1.33)		(-3.03)	(-2.20)		(-3.68)	(-3.53)	
3	0.013	-0.004	5.0	0.002	0.009	1.0	**-0.021[a]**	**-0.022[c]**	0.0	**-0.025[a]**	**-0.025[a]**	−6.0
	(1.57)	(-0.48)		(0.17)	(0.83)		(-2.59)	(-1.90)		(-3.39)	(-3.18)	
5	0.007	-0.009	5.0	-0.004	0.004	2.5	**-0.020[b]**	**-0.022[c]**	0.0	**-0.016[c]**	**-0.015[c]**	−7.5
	(0.87)	(-1.10)		(-0.47)	(0.42)		(-2.43)	(-1.83)		(-1.88)	(-1.85)	
8	-0.002	-0.010	5.0	0.001	0.003	4.0	**-0.016[b]**	**-0.019[c]**	0.0	-0.007	-0.006	−9.0
	(-0.18)	(-0.97)		(0.12)	(0.34)		(-2.22)	(-1.75)		(-0.82)	(-0.82)	
12	-0.008	-0.010	5.0	0.007	0.003	4.0	-0.011	-0.014	0.0	0.000	0.000	−9.0
	(-0.77)	(-0.71)		(0.97)	(0.33)		(-1.16)	(-1.02)		(0.03)	(0.01)	
16	-0.012	-0.010	5.0	0.011	0.004	4.0	-0.008	-0.011	0.0	0.004	0.003	−9.0
	(-0.96)	(-0.60)		(1.31)	(0.31)		(-0.62)	(-0.61)		(0.64)	(0.46)	
20	-0.015	-0.010	5.0	0.014	0.004	4.0	-0.006	-0.009	0.0	0.006	0.005	−9.0
	(-1.04)	(-0.54)		(1.46)	(0.30)		(-0.38)	(-0.43)		(0.79)	(0.59)	
Adj. R-squared	0.9941	0.9929	–	0.9940	0.9925	–	0.9964	0.9955	–	0.9962	0.9960	–
No. bonds (T/C)	61/39	61/37	–	62/41	60/39	–	67/29	65/28	–	69/28	57/27	–
$\widehat{\lambda}$	0.5804	0.6071	–	0.5932	0.5873	–	0.3929	0.4060	–	0.2655	0.2857	–

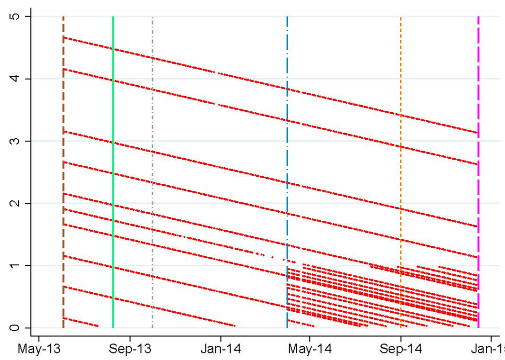


Rating category 1

Rating category 2

(a) Italy





Rating category 1

Rating category 2

(b) Spain

Figure A.1. Final samples: Residual maturity by rating category over time.
This figure plots residual maturities by rating category in the final samples of Italian and Spanish zero-coupon bonds with market prices for the sample period May 13, 2013 to January 7, 2015, inclusive. "RC" stands for rating category. Rating category 1 (2) refers to securities with a rating in the AAA to A− (BBB+ to BBB−) range (on the S&P scale). The vertical lines in each subplot mark the same dates as described in Figure 2 in the paper.

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