DISCUSSION PAPER SERIES

DP12965

THE TERM STRUCTURE OF REDENOMINATION RISK

Christian Bayer, Chi Kim and Alexander Kriwoluzky

INTERNATIONAL MACROECONOMICS AND FINANCE and MONETARY ECONOMICS AND FLUCTUATIONS

CE PR

THE TERM STRUCTURE OF REDENOMINATION RISK

Christian Bayer, Chi Kim and Alexander Kriwoluzky

This Discussion Paper is issued under the auspices of the Centre's research programme in **INTERNATIONAL MACROECONOMICS AND FINANCE and MONETARY ECONOMICS AND FLUCTUATIONS**. Any opinions expressed here are those of the author(s) and not those of the Centre for Economic Policy Research. Research disseminated by CEPR may include views on policy, but the Centre itself takes no institutional policy positions.

  The Centre for Economic Policy Research was established in 1983 as an educational charity, to promote independent analysis and public discussion of open economies and the relations among them. It is pluralist and non-partisan, bringing economic research to bear on the analysis of medium- and long-run policy questions.

  These Discussion Papers often represent preliminary or incomplete work, circulated to encourage discussion and comment. Citation and use of such a paper should take account of its provisional character.

THE TERM STRUCTURE OF REDENOMINATION RISK

Abstract

This paper assesses redenomination risk in the euro area. We first estimate daily default-risk-free yield curves for French, German, and Italian bonds that can be redenominated and for bonds that cannot. Then, we extract the compensation for redenomination risk from the yield spreads between these two types of bonds. Redenomination risk primarily shows up at the short end of yield curves. At the height of the euro crisis, spreads between first-year yields were close to 7% for Italy and up to -2% for Germany. The ECB's interventions designed to reduce breakup risk successfully did so for Italy, but increased it for France and Germany.

Christian Bayer - christian.bayer@uni-bonn.de
Universität Bonn and CEPR

Chi Kim - chi.kim@wiwi.uni-halle.de
University of Halle

Alexander Kriwoluzky - alexander.kriwoluzky@wiwi.uni-halle.de
DIW Berlin, University of Halle

The term structure of redenomination risk[*]

Christian Bayer[†] Chi Hyun Kim[‡] Alexander Kriwoluzky [§]

May 30, 2018

Abstract

This paper assesses redenomination risk in the euro area. We first estimate daily default-risk-free yield curves for French, German, and Italian bonds that can be redenominated and for bonds that cannot. Then, we extract the compensation for redenomination risk from the yield spreads between these two types of bonds. Redenomination risk primarily shows up at the short end of yield curves. At the height of the euro crisis, spreads between first-year yields were close to 7% for Italy and up to -2% for Germany. The ECB's interventions designed to reduce breakup risk successfully did so for Italy, but increased it for France and Germany.

JEL classification: E44, F31, F33, F45, G12, G14
Keywords: Euro Crisis, Redenomination Risk, Yield Curve, ECB Interventions

1 Introduction

Since the euro crisis, a potential breakup of the euro area has been an ongoing concern that might become again very pressing with the latest political developments in Italy. In particular between 2010-2013, there were serious expectations that some countries might leave the monetary union with positive probability. Since such expectations can become self-fulfilling when they drive up sovereign yields (c.f. Obstfeld, 1986; Corsetti and Dedola, 2013; Coeuré, 2013; De Grauwe and Ji, 2013), these breakup expectations were one of the key motivations for the European Central Bank's (ECB's) interventions during the crisis.[1] Yet, even in hindsight, it is difficult to assess how likely the scenario was of a euro area breakup and how successful the ECB was in fighting breakup expectations. Our paper uses daily financial market data to estimate market expectations of a euro area breakup from differences in yield curves of securities, which are differentially affected by a country leaving the euro area.

A country (or a group of countries) breaking away from the euro area would introduce a new currency upon the event. This will be followed by a redenomination of contracts, likely including debt contracts, because the legal tender changes. However, the country is able to do so only for (debt) contracts that fall under that country's own jurisdiction. Investors will take this risk of a redenomination of their contracts into account. In particular, they will consider that a newly introduced currency might depreciate (or appreciate) vis-à-vis the euro. This introduces a spread between otherwise identical securities that differ only in jurisdiction.[2] Importantly, this spread will have a term structure that reflects how the likelihood of a country's exit from the euro area changes over various horizons.

Therefore, we identify redenomination risk by comparing entire yield curves for default-risk-free returns on bonds issued under domestic and foreign jurisdiction instead of bond yields for a given time to maturity. The yield curves are estimated using a non-parametric approach following McCulloch (1971, 1975). The advantage of this approach is its flexibility and hence its potential to pick up redenomination risk at any time horizon. In order to apply the non-parametric approach, we have to collect an extensive data set of bond prices and coupon payments from Bloomberg and Datastream. We use sovereign bonds as bonds of domestic jurisdiction, i.e., as bonds that we expect

---

[1]See, e.g., the statement by the ECB's president, Mario Draghi, on July 26, 2012, in a speech at an investment bankers' conference

[2]Choi et al. (2011), Clare and Schmidlin (2014), Corradin and Rodriguez-Moreno (2014), and Schumacher et al. (2015) show that there are indeed systematic return differences in sovereign bonds issued under domestic and foreign law, in line with our hypothesis.

to be redenominated. As bonds that are always expected to be repaid in euro, we use corporate bonds, denominated in euro, emitted by an issuer in one country under another countrys jurisdiction. To obtain riskless yield curves for these two group of bonds, we control for default risk and subtract credit default swap (CDS) premia from all bond returns.[3] By doing so, on the one hand, we are able to obtain yield curves of default-risk free domestic-law government bonds that only represent the riskless interest rate and redenomination risk. On the other hand, we obtain yield curves of default-free foreign-law corporate bonds that only contain the riskless interest rate (without redenomination risk, from now on referred as "safe international corporate €-bonds"). Comparing these two yield curves will give us our redenomination risk measure.

We have three main findings: First, for the period of the European debt crisis, 2010-2014, we find that default-risk-free Italian sovereign bonds show substantially higher yields compared to safe international corporate €-bonds. Interestingly, the opposite holds true for France and Germany, where the spread is negative. Second, these spreads show up mostly at the short end of the yield curve (mostly up to one year). Third, the spreads move systematically after ECB policy interventions. After the ECB's second Securities Market Programme, the Longer-Term Refinancing Operations, and the announcement of the Outright Monetary Transactions program, default-risk-free sovereign short-term yields fell in *all three* countries relative to the yield on safe international corporate €-bonds.

Interpreting the spread along the lines of an uncovered interest rate parity as a compensation for expected changes in the exchange rate, financial markets were expecting Italy to potentially leave the euro area and depreciate its new currency. In particular, these expected changes in the exchange rate had substantial effects on the short end of the yield curve. They peak around the time of the collapse of the Berlusconi government at the end of 2011: the spread on one-year yields was roughly 7% in Italy. Even for France and Germany, the spreads are non-negligible with a *negative* one-year yield difference of, on average, around 0.75% and over 2% at peak. In other words, financial markets were considering the possibility that these countries might also leave the euro area, introducing a new currency that then appreciates. Using this interpretation, the ECB's policy interventions have reduced redenomination risk in Italy, but they have increased it for France and Germany.

To demonstrate that our interpretation of the yield spread as redenomination risk is

---

[3]Hull et al. (2004), Blanco et al. (2005), Ang and Longstaff (2013), Aizenman et al. (2013), and Arce et al. (2013) use credit default swaps as a direct measure of the price of default risk of debt issuers in the asset markets as well.

valid, we use an episode that we can expect has no other impact on financial markets than through breakup expectations: the time when the German constitutional court examined the potential *ultra-vires* character of the ECB's Outright Monetary Transactions program. The court hearings took place between April 2013 and February 2014. At the start of the hearing, the court was surprisingly open to the complainants' case against the ECB's policy. At the same time, the one-year yield on German default-risk-free sovereign bonds falls substantially relative to safe international corporate €-bonds. Consequently, the spread quickly went to -1.5% and then slowly returned to zero when the constitutional court transferred the case to the European Court of Justice, which finally denied the *ultra-vires* character of the Outright Monetary Transactions program. We view this episode as evidence that the spreads we construct measure redenomination risk indeed.

With these results, our paper contributes to a recent literature on the effect of ECB interventions on euro area financial markets. De Pooter et al. (2012), Eser and Schwaab (2013), Falagiarda and Reitz (2015), Fratzscher and Rieth (2015), and Zettelmeyer and Trebesch (2018) show that ECB interventions are successful in decreasing the sovereign spreads of euro area crisis countries. Redenomination risk is a particularly important part of these spreads, because it necessarily affects all domestic interest rates in a country. In turn, this means that redenomination risk limits the ECB's capacity to fully affect the relevant short-term interest rates through its conventional monetary policy.

This is why a series of recent studies has focused on the prevailing breakup risk in the euro area. Some of this literature uses exclusively sovereign bonds and derivatives on them. Di Cesare et al. (2012) compare the sovereign yield spreads of euro area countries with their model-based values. Inter alia, they observe a strong divergence between these two measures during a time when the breakup of the euro area is frequently mentioned by market participants. In line with our results, they find evidence that market participants may have expected an appreciation of the new German currency and a depreciation of the currencies of non-core countries. De Santis (2015) constructs an empirical measure of redenomination risk for France, Italy, and Spain. Different from our approach, which disentangles between short-run and long-run redenomination risk, he examines redenomination risk at the five year horizon. He uses five-year quanto government bond CDS of France, Italy, and Spain in relation to the quanto CDS of German government bonds as a benchmark, whereas we assume that German bonds under domestic law are also exposed to redenomination risk. Among others, his analysis shows that redenomination risk has a significant impact on the sovereign yield spreads of the three countries. Krishnamurthy et al. (2018) assess the different channels of

4

euro area sovereign bond yields. As in their paper, we use return differences between bonds traded under domestic and foreign law to estimate redenomination risk. They construct a rolling sample of bonds with three to five years to maturity and document the average return difference (after CDS premia) between the two types of bonds. We, in contrast, consider a wider range of bonds, using yield curve estimation to make the bond yields comparable. What is more, the yield curve estimates allow us to analyze the term structure of redenomination risk. Our findings suggest that it is important to look at short-term yields because redenomination risk is concentrated there. On a more theoretical level, our paper relates to Kriwoluzky et al. (2015). They set up a small open economy model in which a country is a member of a currency union at first, but where the possibility of an exit emerges and is reflected in return differences on sovereign bonds.

The remainder of the paper is organized as follows: Section 2 develops the empirical model we use to measure redenomination risk. Section 3 describes the data set we use. Section 4 presents the findings. Section 5 concludes. An appendix follows that describes the estimation method in detail and provides extensive robustness checks.

2 Identifying redenomination risk

Our measure of redenomination risk relies on estimates of yield curves for two sets of bonds: bonds issued under *domestic* and under *foreign* jurisdiction. For both types of bonds, we estimate default-risk-free yield curves out of bond prices, coupon payments, and credit default swap (CDS) premia. To illustrate our identification of redenomination risk, we start with the pricing of a risky bond by a risk-neutral investor.

2.1 Pricing a bond

A bond i is described by its promised coupon (and principal) payments $CF_i(\tau)$ at any payment date τ. We work in discrete time. The bond is subject to two fundamental risks: first, the issuer might default on the promised payments CF_i, or, second, the exchange rate $e(\tau)$ of the currency in which the bond payments are denominated might change vis-à-vis the euro.

The price, $p_{i,t}$ (in €), which a risk-neutral investor is willing to pay for this bond at time t, is given by:

$$p_{i,t} = \sum_{\tau > t}^{\infty} \frac{[1 - \pi_{i,t}(\tau)]\, e_t^{-1}(\tau)}{1 + r_t(\tau)} CF_i(\tau), \tag{1}$$

where $\pi_{i,t}(\tau)$ is the probability the investor assigns at time t to the bond issuer's default-ing on $CF_i(\tau)$, $e_t(\tau)$ is the exchange rate (in quantity quotation) the investor expects at trading-time t to hold at payment time τ to convert $CF_i(\tau)$ into €, and $r_t(\tau)$ is the time value of money used to discount the future cash flows of the bond at payment date τ to their value at time t.

While expectations about the exchange rate and the time value of money should be the same across all bonds (of the same currency and under the same jurisdiction), expectations of default are bond specific. Therefore, we need to control for them to homogenize various bonds. In order to do this, we use CDS to directly identify the cost of the probability of default.[4]

A risk-neutral investor will be willing to buy a CDS if the premia to be paid on the swap, $CDS_{i,t}(\tau)$, equal the expected losses under default. Hence, the price of the bond with default risk should be equal to the price of a default-risk-free bond,

$$p_{i,t} = \sum_{\tau > t}^{\infty} \frac{e_t^{-1}(\tau)}{1 + r_t(\tau)} cf_{i,t}(\tau),$$ (2)

whose cash flows $cf_{i,t}(\tau) \equiv CF_i(\tau) - CDS_{i,t}(\tau)$ are certain.

2.2 The term structure of expected exchange rate changes

In this paper, we consider only bonds that promise payments in €. Therefore, as long as the country of the bond issuer remains in the euro area, the exchange rate $e(\tau)$ is unity. Yet, a country leaving the euro area can redenominate contracts that are issued under domestic law, in particular its sovereign bonds, into the new currency it introduces. Therefore, when the investor assigns a positive probability that the country of the issuer will leave the euro area, exchange rate expectations can deviate from unity $e_t(\tau) \neq 1$. Consequently, in the case of a country leaving the euro area, $e_t(\tau) < 1$ implies an expected appreciation and $e_t(\tau) > 1$ an expected depreciation of its new currency vis-à-vis the euro. We group bonds by country of origin c issued under domestic law and estimate a discount rate for default-risk-free cash flows, $R_{t,c}^{dom}(\tau) = \frac{e_{t,c}^{-1}(\tau)}{1+r_t(\tau)}$, from:

$$p_{i,t} = \sum_{\tau > t}^{\infty} R_{t,c}^{dom}(\tau) cf_{i,t}(\tau) + \varepsilon_{i,t}.$$ (3)

Equation (3) implies that we can back out the exchange rate expectations by di-

---

[4]Blanco et al. (2005) show that CDS prices have a valid relation to the theoretical default price of a bond and provide an upper bound of the price of credit risk.

viding the discount rate on domestic bonds $R_{t,c}^{dom}$ by a discount rate for bonds free of redenomination risk. To this end, we use bonds issued by a corporation in one euro area country under the jurisdiction of another country. Again, we control for default risk by using CDS premia and estimate the default-risk-free discount rate $R_t^{int}(\tau) = \frac{1}{1+r_t(\tau)}$ as:

$$p_{i,t} = \sum_{\tau > t}^{\infty} R_t^{int}(\tau) cf_{i,t}(\tau) + \varepsilon_{i,t}. \tag{4}$$

Thus, the exchange rate of country c expected at time t in place at a future time τ is

$$e_{t,c}(\tau) = R_t^{int}(\tau)/R_{t,c}^{dom}(\tau)$$

Using these measures of expected exchange rates, we estimate the growth rate of the expected exchange rate between time τ_1 and τ_2 (expected at time t) as:

$$\Delta e_{t,c}(\tau_2, \tau_1) \equiv \frac{e_{t,c}(\tau_2)}{e_{t,c}(\tau_1)} - 1 = \frac{R_t^{int}(\tau_2)}{R_{t,c}^{dom}(\tau_2)} \frac{R_{t,c}^{dom}(\tau_1)}{R_t^{int}(\tau_1)} - 1. \tag{5}$$

One advantage of looking at these expected growth rate measures is that they correct for any fixed differences in domestic law and foreign law bonds that lead to proportionally higher discount factors for one type of bond or the other.

3 Data

We collect an extensive data set from Bloomberg and Datastream. The data set contains data on bond prices, their coupon payments, and prices for CDS written on these bonds. Importantly, the CDS we use do not insure redenomination risk. The data cover French, German, and Italian bonds. All bonds of our sample have a fixed-coupon and are euro-denominated, non-callable, and non-guaranteed. The sample runs from January 1, 2010 to September 21, 2014. The end-date of the sample is given by the introduction of new CDS that insure redenomination risk as well as those we cannot separate from other CDS given our data.

We consider sovereign bonds issued under domestic law as bonds that exhibit redenomination risk. We expect these bonds to be definitely redenominated into the new currency in the case of an exit from the monetary union because of their importance for the banking sector. Some of our bonds exhibit the Collective Action Clause (CAC), which allows for a supermajority of creditors to enforce the restructuring terms on minority holdout creditors. All euro area sovereign bonds that are issued after January 1,

2013 include these CACs. Nevertheless, this clause will not be able to avoid the redenomination of sovereign debt under domestic law according to *lex monetae* (see Moore and Wigglesworth, 2017; Codogno and Galli, 2017). For each country, we are able to obtain a sufficient amount of sovereign bonds to estimate their yield curves (see Table 1). On average we have 25 (France) to 34 (Italy) bonds per country and per day available for the yield curve estimation. The minimum amount of bonds available for the estimation of the yield curve on a single day is 12 (Germany).

Collecting data to estimate the daily yield curve for bonds that do not contain redenomination risk is challenging. We address this challenge in the following ways. First, we consider bonds issued by a domestic issuer that are subject to foreign law. Bonds falling under this category are bonds issued by large French and Italian corporations. Among these corporations are Carrefour, Thales, Enel, and Fiat. All foreign-law French corporate bonds are under English law, while the issuer is either from France or a subsidiary of the French parent company in the Netherlands. All Italian bonds are under English law and the issuer is either from Italy or a subsidiary of the Italian parent company in Luxembourg and Belgium. We do not find German corporations that issue bonds under non-German law. However, many of the large German corporations issue their bonds through a subsidiary outside Germany (under German law). We include these bonds in our sample as well. Examples are bonds from Volkswagen International Finance BV with limited liability in the Netherlands emitted under German law. Further German corporations that we include, among others, are Deutsche Telekom and Siemens, and they all issue bonds through similar vehicles. Their bonds do not contain redenomination risk for the following reason. On the one hand, they will not be redenominated in the case Germany exits the monetary union because they are issued by a foreign subsidiary of Volkswagen. On the other hand, they will not be redenominated in the case of a Dutch exit from the monetary union, because they are issued under (from a Dutch point of view) foreign, namely, German, law. Even if both countries exit, the issued bonds would still be bonds of a foreign issuer from a German point of view and therefore unlikely to be redenominated. Even if we only consider bonds issued under English law, none of our results change; see the appendix. For a complete overview of the corporations, see Table 2. In order to estimate the yield curve as precisely as possible, we pool all bonds issued under foreign jurisdiction. On average we observe 186 bonds each day. The minimum amount of bonds available on a single day is 80.

Table 1: Bond data availability per day

Bond type	# bonds in total	Average	Min.	Max.
Domestic law sovereign bonds				
France	39	25	13	39
Germany	43	27	12	43
Italy	64	34	14	64
International law corporate bonds	353	186	80	228

Sources: Bloomberg and Datastream

Table 2: The issuer of the corporate bonds

Corporation	Headquarters	Issuer country	Jurisdiction	# Bonds
Airbus Group	France	Netherlands	English law	7
Carrefour S.A.	France	France	English law	18
Saint Gobain S.A.	France	France	English law	23
Électricité de France	France	France	English law	15
Lafarge S.A.	France	France	English law	9
Thales S.A.	France	France	English law	5
Total S.A.	France	France	English law	19
Veolia Environnement S.A.	France	France	English law	16
Wendel	France	France	English law	1
BASF SE	Germany	Netherlands	German law	4
BMW Group	Germany	Netherlands	German law	17
Deutsche Telekom AG	Germany	Netherlands	German law	36
EnBW AG	Germany	Netherlands	German law	9
E.ON SE	Germany	Netherlands	German law	20
Lanxess AG	Germany	Netherlands	German law	2
Metro Group	Germany	Netherlands	German law	5
Innogy SE	Germany	Netherlands	German law	11
Siemens AG	Germany	Netherlands	German law	10
Suedzucker AG	Germany	Netherlands	German law	3
Volkswagen Group	Germany	Netherlands	German law	18
Atlantia S.p.A	Italy	Italy/Luxembourg	English law	9
Edison S.p.A	Italy	Italy	English law	3
Enel	Italy	Italy/Netherlands	English law	26
Eni S.p.A.	Italy	Italy/Belgium	English law	20
Telecom Italia S.p.A.	Italy	Italy/Luxembourg	English law	24
Leonardo S.p.A.	Italy	Italy/Luxembourg	English law	6
Fiat S.p.A.	Italy	Luxembourg	English law	17

Sources: Bloomberg, Datastream, and Base Prospectus of the issued corporate debt.

We control for default risk by subtracting CDS premia from the coupon payments. All CDS premia we use are contracted as a fraction of the face value of the bond and therefore have to be paid in the same currency as the bond. Consequently, we can only include bonds in our analysis for which we are able to obtain CDS prices. The CDS data set covers daily data on CDS prices of ten different maturities (six months, 1-5, 7, 10, 20, and 30 years). Since the bonds have different maturity dates, we construct a precise CDS price measure for different maturity dates by interpolating between the CDS prices with ten different maturities. Almost all our CDS include the modified-modified restructuring (MM) clause, which is the standard convention for European corporate contracts.[5]

4 Results

Using this data set, we estimate a yield curve for default-risk-free corporate bonds that are emitted by an issuer in one country under the law of another country and for default-risk-free sovereign bonds issued by France, Germany and Italy. In this section, we first present our estimates of the term structure of redenomination risk. Afterwards, we provide evidence on the relationship between our measure of redenomination risk and the ECB's unconventional monetary policy interventions. Finally, we demonstrate that we indeed successfully measure redenomination risk. To this end, we make use of the German constitutional court hearing regarding OMT and of the co-movement of Google search intensities, which reflect public concern regarding the euro crisis and redenomination risk around ECB interventions.

### 4.1 The term structure of redenomination risk

We identify the redenomination risk or, to be precise, the expected *change* in the exchange rate, from the yield differences between default-risk-free sovereign bonds and the default-risk-free corporate €-bond yield. We estimate the yield on both types of bonds and calculate the expected change in the exchange rate that the spread implies according to equation (5) over the first, second, and third year for each trading day. Figure 1 shows the result of this exercise; Figure 2 shows the same estimates but after applying a one-sided moving average filter to reduce the noise in the estimated time series. The columns show the three countries, the rows the different horizons. For the interpretation, it is important to recall that the rows display spreads in the yields over

---

[5]For some corporations, we were not able to obtain CDS with an MM clause. For these cases, we use CDS with the CR clause (CR=Full Restructuring). This is the case for one French and two Italian corporations.

the first, second, and third year from the trading day and not spreads of one-, two-, and three-year yields. Therefore, the first row reflects the expected exchange rate movement up until the end of the first year after the trading day, while the second row refers to the expected exchange rate movement between the end of the first and the end of the second year after the trading day. Analogously, the third row refers to expectations regarding the third year after the trading day. This means that one obtains, for example, the cumulated expected exchange rate movements over the first three years from the trading day, i.e. the spread in the three-year yields, by summing over all three rows.

We find that redenomination risk influences the short end of the yield curve rather than the long end. For the first year and the second year after the trading date, the spread between the two yields is typically positive for Italy. At peak, which is around the collapse of the Berlusconi government at the end of 2011, the yield spread for Italy is around 7% for one-year yields and around 3% for the second-year yield. For France and Germany, we observe negative spreads at least for the first year. The negative yield differences for France and Germany are also sizeable and around -0.75% on average, with peaks close to -2% for one-year yields. Fluctuations and the differences from zero become smaller for horizons further away from the trading day. Within the third year from the trading day, the implied expected exchange rate movements for all three countries no longer differ systematically from zero. This result suggests that the breakup expectations of market participants function as "expectation shocks" and have a significant influence on the sovereign bond yields of France, Germany, and Italy in the short-run. This was exactly the concern of the ECB: the influence of such expectation shocks coming from breakup expectations, which can start a self-fulfilling spiral of redenomination risk and, thus, lead to an eventual real exit of the countries (European Central Bank, 2014). What is more, since redenomination risk affects mostly the short end of the yield curve, it affects exactly that end which convetional monetary policy uses as its instrument.

12

Figure 1: Expected exchange rate movements
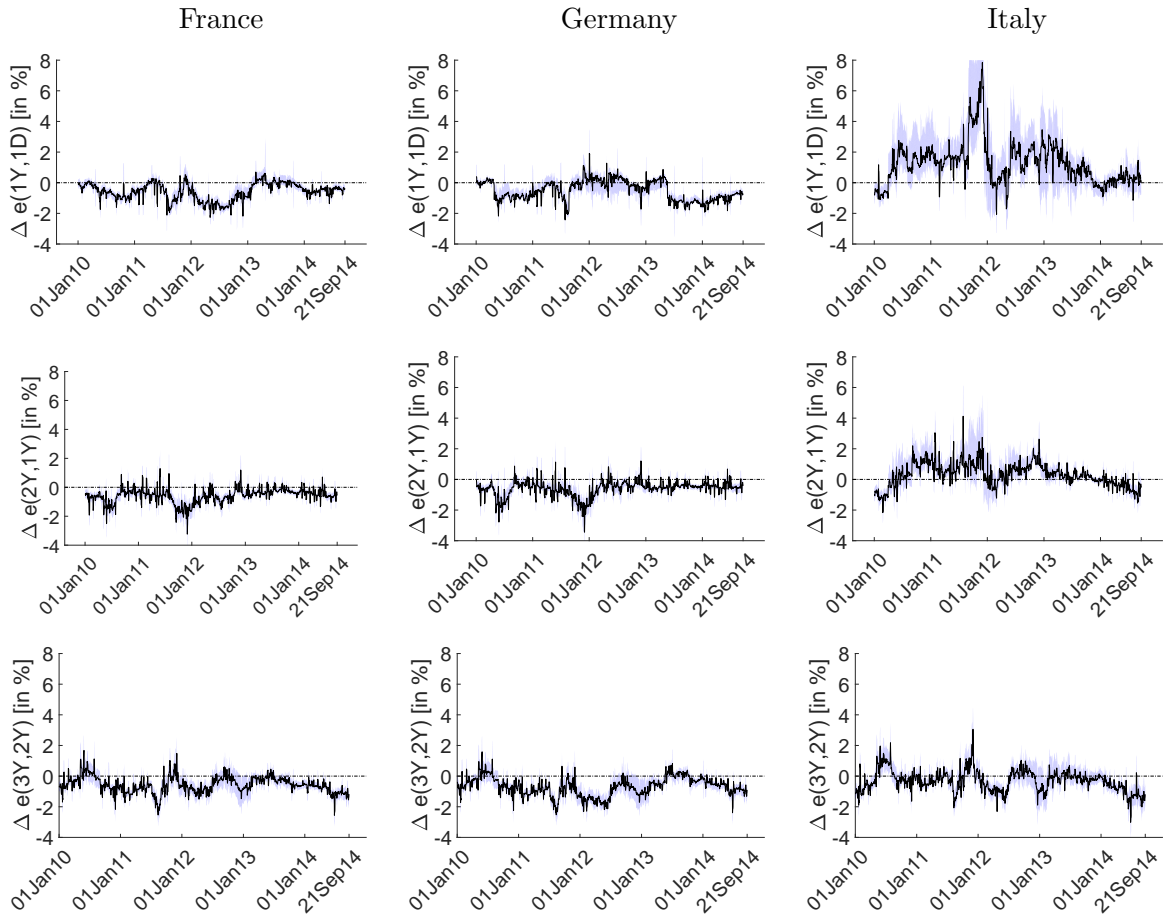
France   Germany   Italy

Notes: Expected changes in the exchange rate as implied by (5) for the estimated yield curves for CDS-insured sovereign bonds and CDS-insured international corporate €-bonds. The first row gives the expected exchange rate movements between the day after the trading day and the 365th day after. The second and third rows display the expected exchange rate movement between the 366th and the 730th day and between the 731st and the 1095th day after the trading day, respectively. In short, the rows display the expected exchange rate movement for the first, second and third year after the trading day. Bootstrapped 68-percent confidence bands as shaded area.

Figure 2: Expected exchange rate movements (smoothed)
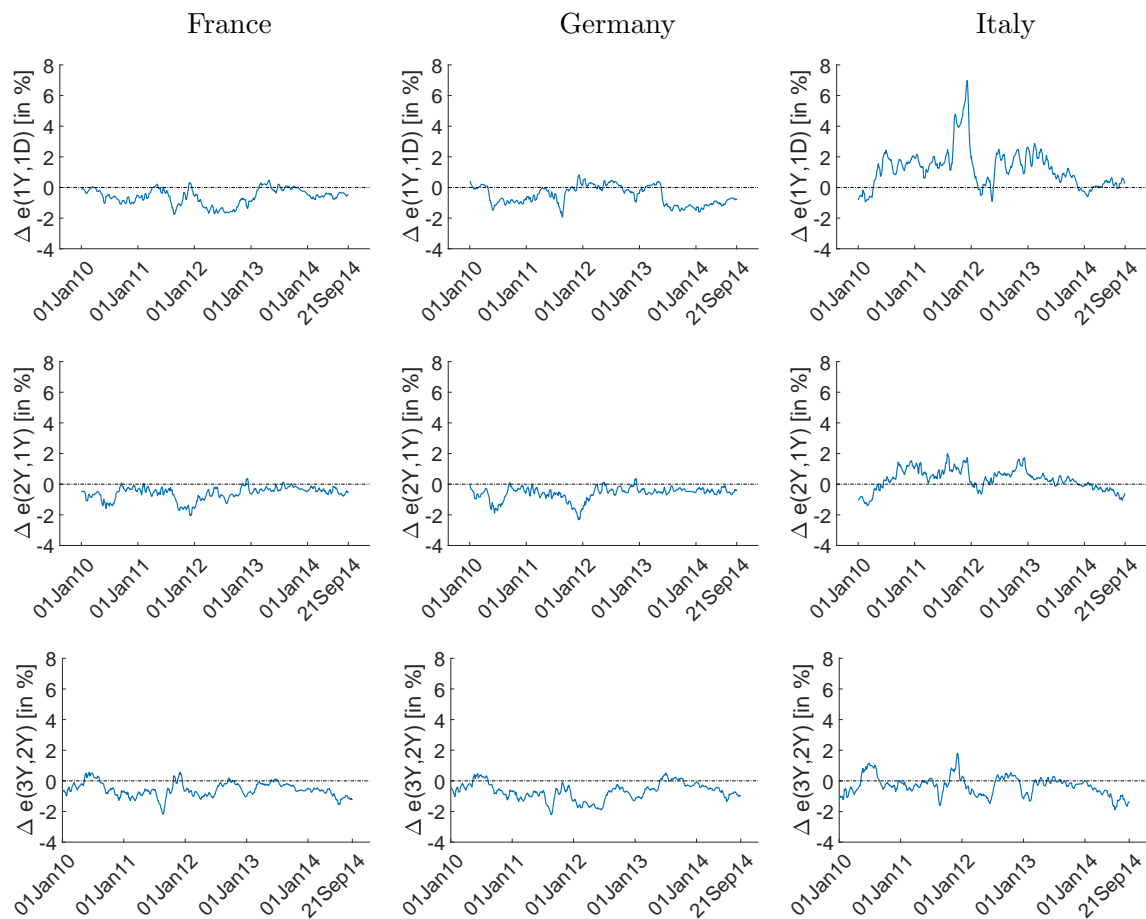
Notes: See Figure 1. The data have been smoothed using a one-sided moving average filter that goes back 13 days.

4.2 Policy interventions

The ECB intervened in the bond market by establishing four programs that aimed – among other things – to reduce breakup expectations as part of its unconventional monetary policy during the European sovereign crisis. On May 10, 2010 the ECB announced its first Securities Market Program (SMP-1), and the program was renewed (SMP-2) on August 8, 2011. On December 1, 2011 the ECB announced that it would engage in Longer-Term Refinancing Operations (LTRO) to stabilize the banking sector in the euro area. Finally, on July 26, 2012, the ECB president, Mario Draghi, held his famous "whatever-it-takes" speech, which was followed by the ECB's official announcement of its Outright Monetary Transactions (OMT) program on August 2, 2012. The eventual modalities were made public on September 6, 2012.

Figure 3 displays the first- and second-year yield spreads from Figure 1, again interpreted as expected exchange rate movements, with the dates of the ECB's interventions displayed in the graph. We focus on the expected exchange rate movements in the first and second years after the respective transaction dates because we have seen that there is little yield spread for years farther in the future and no systematic or large movements in these spreads.

A first visual inspection suggests that all of the ECB's programs have brought down the spread between default-risk-free sovereign and default-risk-free international corporate €-bonds for Italy. Yet, they also seem to have decreased the yield of default-risk-free sovereign bonds relative to default-risk-free international corporate €-bonds in France and Germany. Given that the yield spread is typically negative for these countries before the ECB intervention, the spread increases in absolute value after the intervention. Interpreting the spread again as expectations about a change in the exchange rate vis-à-vis the euro, this suggests that after the ECB interventions, expectations regarding a French and/or German exit from the euro area increased, where such an exit would be followed by an *appreciation* of the newly introduced currency.

Figure 4 shows how the spreads for the first- and second-year yields move around an ECB intervention. We calculate the average yield spread 20 trading days before and after an announcement/implementation of an ECB program. We find that the spread *declines* after each program for all countries. The effect of the LTRO and the OMT is by far the largest for Italy (-3% and -1.5%, respectively), while the SMP programs mostly move down the spread for France and Germany. Results are significant as Table 3 in Appendix C shows and robust to alternative specifications, see Appendix B.

In summary, our estimates provide evidence for the existence of redenomination risk

15

Figure 3: ECB interventions and expected exchange rate movement. The first column shows the expected change in the exchange rate in the first year from trading date, the second column shows the change in the second year from the first year
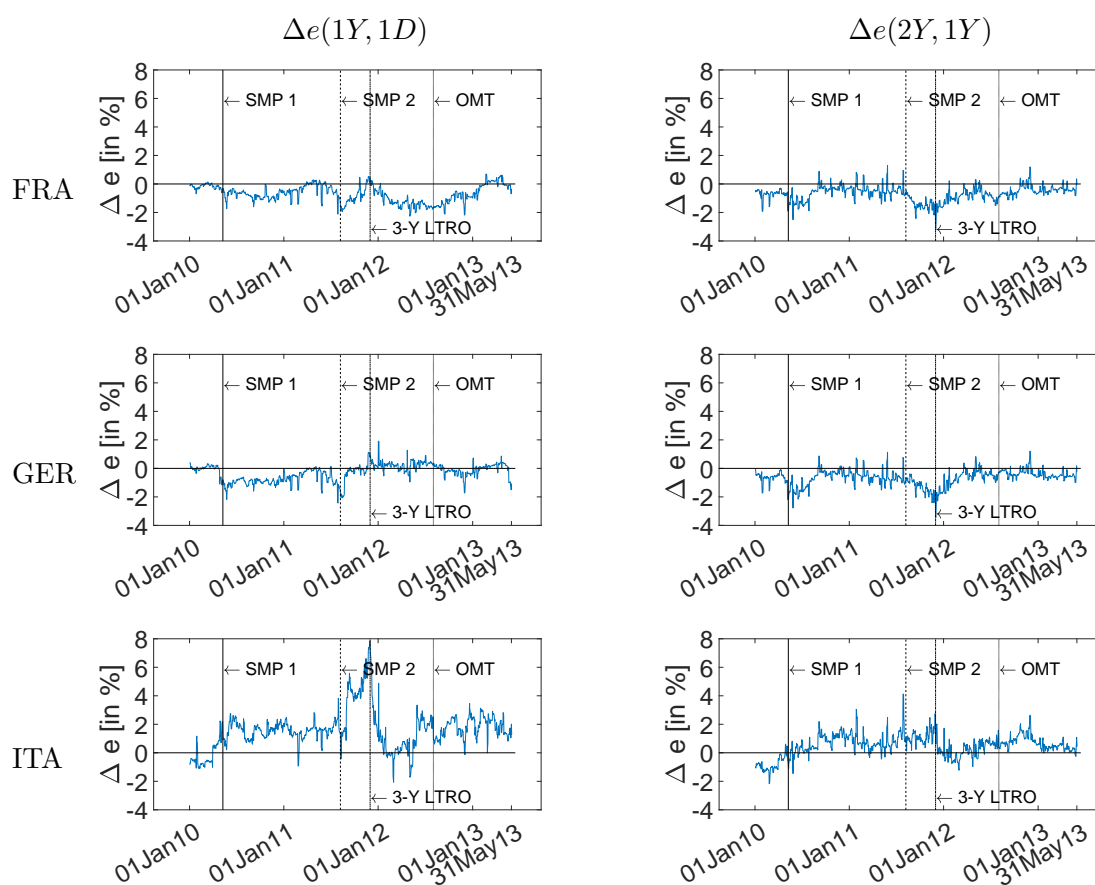
Notes: See Figure 1. The vertical dotted lines represent the days of ECB policy interventions. For the OMT program, we display both the date of the "whatever-it-takes" speech and the date when the details of the program are announced.

Figure 4: Expected changes in exchange rate around intervention dates
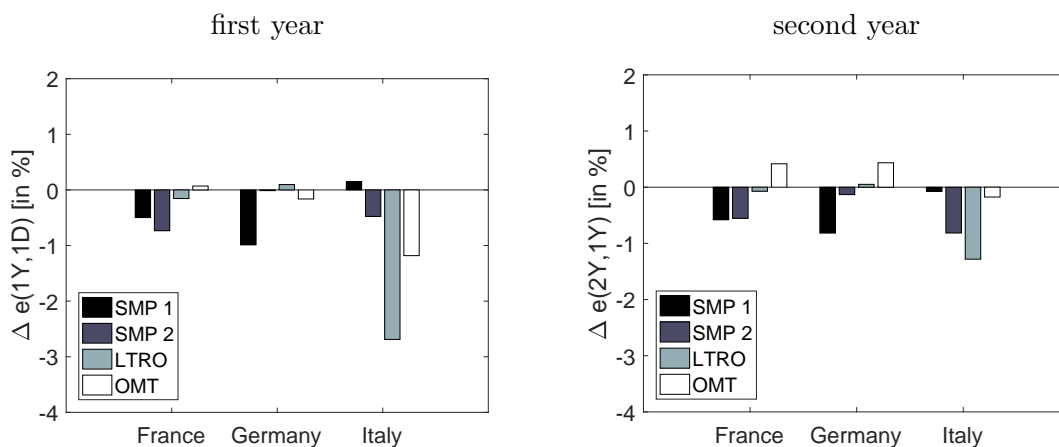
Notes: The figure displays the average yield spreads between default-risk-free sovereign and safe international corporate €-bonds over the 20 days before and the 20 days after the ECB intervention. See Figure 1 for further information on the series of redenomination risk. The left panel refers to the yield spread over the first year, and the right panel refers to the spread in the second year yield. A negative number indicates a decline in the yield spread. For OMT we use August 2, 2012, the day of the official ECB announcement. For bootstrapped confidence bounds and significance, see Table 3 in Appendix C.

and for the ECB's policy being effective at reducing it in Italy but at the cost of increasing it in the non-crisis countries.

4.3 Do we really identify redenomination risk?

In this section, we test the credibility of our redenomination risk measures. As a first step, we address the potential risk factors, which may distort our measures of redenomination risk. Specifically, we consider the existence of CDS counterparty risk, liquidity risk, and legal risk of securities. As a next step, we conduct a case study on an event that should have influenced exclusively the market expectations about Germany leaving the euro area: the German Federal Constitutional Court's decision regarding the legality of the Outright Monetary Transactions program. If our method correctly estimates redenomination risk, only our German redenomination risk measure should be influenced by this event. Finally, we also examine the relationship between Google search trend on the term "euro crisis" and our redenomination risk measures.

4.3.1 Counterparty, liquidity, and legal risk: why the term-structure of redenomination risk is important

Our measure of redenomination risk is a spread between a default-risk-free sovereign bonds and default-risk-free international corporate €-bonds. Yet, this spread could potentially pick up additional factors other than redenomination risk. Liquidity risk, counterparty risk regarding the CDS, and legal risk are three potential culprits here.

Let us first address the counterparty risk of CDS. A CDS buyer is exposed to counterparty risk if the CDS does not fully insure against the risk of a default because the insurer itself might (partly) default. The basic principle of counterparty risk is very similar to the default risk of debt issuers: at each trading date t, the CDS buyer assigns a probability to the CDS seller's default on the payments and thus is willing to pay a lower CDS premia than without this risk.[6] This probability affects all CDS sold by the CDS seller similarly. More precisely, it affects even those with different maturities, because if the CDS seller is expected to default, then she should default on all payments, irrelevant of its maturity. Therefore, counterparty risk should be correlated across different time horizons, just as we observe this in annual CDS premia (see e.g. De Santis, 2015). If our redenomination risk measure is exposed to this counterparty risk, we should observe this correlation across different maturities. However, this is not the cas as we do not observe these characteristics in our redenomination risk measure. They are very different over the three periods from the trading date.

Similarly, our spread measure might pick up differences in liquidity between sovereign bonds and the corporate bonds in our sample. In particular, one would expect that the premium for liquidity risk is strongest for bonds far away from maturity, not for bonds close to maturity (c.f. Longstaff et al., 2005; Covitz and Downing, 2007; Schwarz, 2017). However, the redenomination risk (movements) are strongest for the spread between the short ends of the yield curve and not for the additional yields at the longer end of the curve.

Finally, we also take into consideration the fact that the bonds in our sample are governed by different legal rules. If some markets are "riskier" than the others, our spreads might pick up these differences. In order to address this problem, we compare the first-year and second-year yields of corporate bonds issued by Dutch subsidiaries of German firms and bonds issued by French firms under English law. The differences are plotted in Figure 5. This analysis gives an idea of which order of magnitude legal risk should have in our redenomination risk measure. Most of the time, the differences

---

[6]See equation 1 for the details how we define default risk in our bond pricing model.

Figure 5: Difference between German and French international corporate bonds
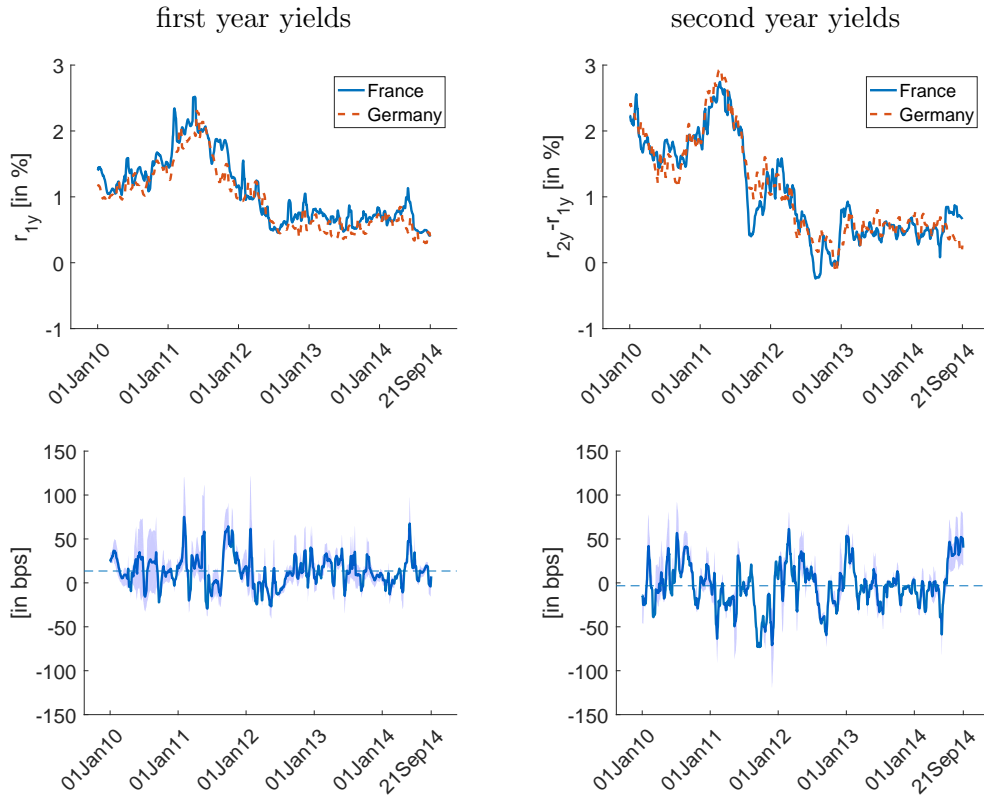
Notes: The first column displays our estimates of first-year yields (one-year yields minus one-day yields) of bonds issued by French corporations under English law and of Dutch subsidiaries of German corporations under German law (upper panel) and the difference thereof (lower panel). The second column displays the same for second-year yields (two-year yields minus one-year yields). We display the moving-average smoothed differences for better readability and a reduction of estimation uncertainty.

are small and substantially below the estimated redenomination risks. In addition, the second-year yield spread is more volatile than the first-year yield, while this is the opposite for our redenomination risk measure. All this speaks against the hypothesis that our redenomination risk measures reflect primarily time variations in the premia for legal risk.

4.3.2   The German constitutional court case regarding OMT

The evidence notwithstanding, we cannot entirely exclude the possibility that our measure, the yield curve spread, picks up something else than redenomination risk. Therefore, we conduct a case study on an event that should have exclusively influenced the

19

market expectations about a country leaving the euro area. Examining the movements in our redenomination risk measure during this event will further support the credibility of our approach.

One such key event is the German Federal Constitutional Court's (*Bundesverfassungsgericht,* BVerfG) decision regarding the legality of the Outright Monetary Transactions (OMT) program. Several individual members of the German parliament across all political parties had filed a complaint against the participation of any German government agency in both the European Stability Mechanism and the ECB's OMT program in 2012. The target of the complaint was the German federal government in general and the Bundesbank in particular. The BVerfG separated the two cases in 2012 and decided against the urgency of the complaint in the same year. In general, this was perceived as taking a pro-euro(pean) stance.

The court announced on April 19, 2013 that it would hold a two-day hearing on June 11/12, 2013, in order to prepare its final decision (press release No. 29/2013) on the OMT case. The hearing's agenda and the juridical topics to be discussed suggested that the court might now be leaning toward a critical view of the OMT. The court announced that it would discuss not only the potential *ultra-vires* character of the OMT but also whether the program would touch the identity of the German constitution. Had the court ruled in favor of the former, the Bundesbank would have been obliged to stop any action that would directly or indirectly support the OMT program. Had the court ruled in favor of the latter, Germany would have needed to replace its existing constitution with a new one in order to remain in the euro area, which would have required a referendum. In both cases, a German exit from the EU would have been the likely inevitable consequence.

The court also decided to have economic experts testify during the hearing to assess the validity of the ECB's claim of an impediment to the monetary transmission channel (through the existence of redenomination risk). Importantly, the BVerfG's list of experts included some economists who had publicly announced their skepticism regarding the ECB's policy. Potentially the politically most important of those experts was the Bundesbank itself. On April 26, the bank's written statement to the court (from December 21, 2012) was leaked to the press. This statement was expected to be the basis of the Bundesbank president's upcoming testimony in court and it contained, among others, a number of passages that were skeptical about sovereign spreads reflecting non-fundamental redenomination risk, the existence of which was a key argument for the ECB's program. Instead, the Bundesbank argued that redenomination risk was, if anything, an issue that reflected fundamental political uncertainty and as such is something

Figure 6: Expected exchange rate movements around the German federal constitutional court hearings
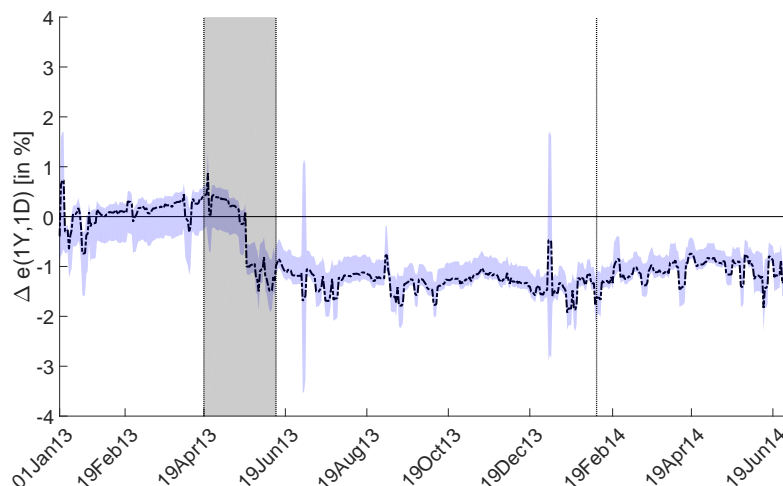
Notes: See Figure 1. The shaded area covers the time period between the announcement of the hearing on April 19, 2013 and the BVerfG hearing on June 12, 2013. The case was widely debated during this period. One particular event is the publication of the Di Fabio (2013) paper at the end of May. The second vertical line is the day at which the BVerfG hand the case over to the CJEU.

that is and should remain outside the realm of monetary policy. Finally, in May 2013 a German think-tank produced a legal analysis by a former justice at the constitutional court (Di Fabio, 2013) that explicitly discussed a German exit from the EU as a potentially necessary consequence of the ECB's actions and the BVerfG's decision. The analysis was covered in the largest quality German newspaper, the Frankfurter Allgemeine Zeitung, on June 02 under the headline "Former constitutional court justice Di Fabio 'In a pinch, Germany is obliged to leave the Euro'" ("Ehemaliger Bundesverfassungsrichter Di Fabio: 'Notfalls ist Deutschland zum Euro-Austritt verpflichtet'").

In sum, between the announcement of the hearing and the hearing itself, a number of pieces of information led the conclusion that the court might come to a ruling that viewed the ECB program as being in conflict with the German constitution or the Treaty on the Functioning of the European Union. In fact, on February 7, 2014, the court ruled that the program, from the court's interpretation of the treaty, was indeed probably an *ultra-vires* act. Yet, the court did not reach a final conclusion, which would have forced Germany to exit the EU, but instead decided that it would ask the European Court of Justice (CJEU) for its judgment and interpretation of the treaty.

In his final statement on January 14, 2015, the advocate general of the CJEU sug-

gested that the CJEU view the OMT program as being in line with the EU treaty, a line the CJEU followed in its decision on June 16, 2015. The BVerfG's final decision on the case was published on June 21, 2016. It follows the CJEU's ruling but qualifies it in setting limits on what the OMT program would need to look like in practice for German agencies to be allowed to participate.

In line with our interpretation of the estimated spreads as redenomination risk, the estimated spreads for Germany pick up this episode. Between the announcement of the hearing and the hearing itself, the spread between German default-risk-free sovereign bonds and safe international corporate €-bonds becomes more negative and declines sharply to almost -1.5%, where it stays until the BVerfG decides to have the case judged by the CJEU. From that point, the spread slowly disappears; see Figure 6. Remarkably, the persistent drop shows up only in the German spreads but not in the French or Italian spreads.[7] This speaks for our interpretation of the spread as indeed reflecting redenomination risk.

4.3.3 Search interest for the euro crisis

A final piece of evidence comes from Google search trends.[8] We look at the search intensity for the term "euro crisis" in local language (*crise euro, Eurokrise, crisi euro*) for France, Germany, and Italy and calculate how much the search intensity is affected by the ECB's intervention.[9] If the search intensity goes up, we view this as evidence that the public in the respective country is more concerned with the currency; if the search intensity goes down, public concern about the currency likely becomes less intense. Since Google trends data come in the form of an index $s_t \in [0, 100]$, we calculate the rate of change as $\Delta s_t := 2\frac{s_t - s_{t-1}}{s_t + s_{t-1}}$.
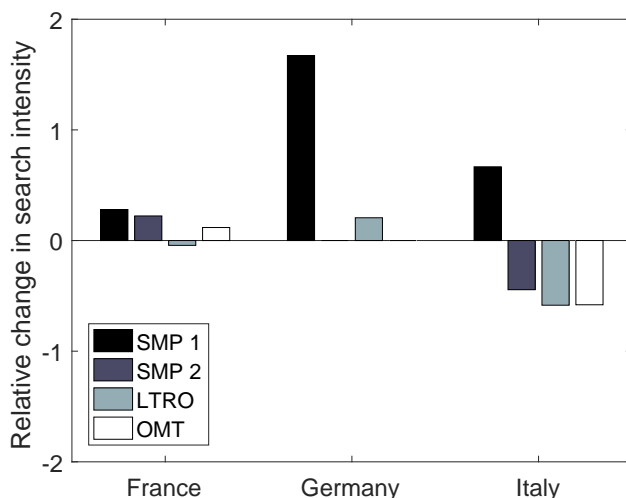
Figure 7 presents the results. In all three countries, search intensities go up after SMP-1, which is in line with our results for redenomination risk, where the absolute spread increases in all three countries, too. The effect of SMP-1 on German search intensities stands out, as did its impact on redenomination risk for Germany. For SMP-

---

[7]Importantly, there is no change in the composition of the German sovereign bonds in our sample such that the strong and persistent decline in the one-year yield does not reflect unobserved heterogeneity in the bonds.

[8]An issue here is, of course, that the language is not spoken just in the respective country. In addition, the term *crise euro* also means euro crisis in Portuguese. However, given the size of the countries relative to other European countries that use the same language or term, we can still attribute most of the change in search to the respective country.

[9]If the intervention takes place before Wednesday, we compare the search intensity of the week before the intervention with the intervention week. If it takes place on Wednesday or later, we compare the week after the intervention with the week of the intervention.

Figure 7: Change in the search intensity for "eurocrisis"

2, LTRO, and OMT, we find again patterns that are in line with redenomination risk movements: search intensity mildly goes up in France and Germany but it goes down in Italy. In other words, the ECB's policy interventions seem to have calmed the perception of the euro crisis in Italy as an interesting and urgent topic, but if anything, they have increased the perception of the euro being in crisis in the non-crisis countries.

5 Conclusion

In this paper we document the term structure of redenomination risk. The term structure enables us to show how breakup expectations have an influence on the short-run dynamics of sovereign bond yields. We identify redenomination risk by comparing yields of bonds that differ in jurisdiction. First, we estimate daily yield curves for default-risk-free sovereign bonds issued by France, Germany, and Italy under their respective domestic jurisdictions. These bonds will be redenominated in the case of an exit of the respective country from the euro area into the new currency the country issues. Second, we estimate daily yield curves for safe international corporate €-bonds issued by corporations in these countries under a foreign jurisdiction. This legal setting prohibits the

redenomination of the bond into a newly issued currency.

Our results confirm that the ECBs fear of (self-fulfilling) expectations of a breakup disrupting its control over the short-end of the yield curve and potentially leading to a real exit of the countries was a justified concern. At the peak of the crisis, breakup expectations of market participants had a considerable impact on the sovereign bond yields in the short end of the yield curve. Furthermore, we are able to show that the ECB was indeed able to reduce the implied redenomination risk for Italy, which was one of the crisis-hit countries. Nevertheless, there was a downside to this: the exit expectations of France and Germany rather increased. This is hardly surprising in light of the fact that France and Germany as the two largest euro-area and non-crisis countries bear the fiscal risks of the ECB's unconventional policies.

References

Aizenman, J., Hutchison, M., and Jinjarak, Y. (2013). What is the risk of european sovereign debt defaults? fiscal space, cds spreads and market pricing of risk. *Journal of International Money and Finance*, 34:37–59.

Ang, A. and Longstaff, F. A. (2013). Systemic sovereign credit risk: Lessons from the US and Europe. *Journal of Monetary Economics*, 60(5):493–510.

Arce, O., Mayordomo, S., and Peña, J. I. (2013). Credit-risk valuation in the sovereign cds and bonds markets: Evidence from the euro area crisis. *Journal of International Money and Finance*, 35:124–145.

Blanco, R., Brennan, S., and Marsh, I. W. (2005). An empirical analysis of the dynamic relation between investment-grade bonds and credit default swaps. *The journal of Finance*, 60(5):2255–2281.

Choi, S. J., Gulati, M., and Posner, E. A. (2011). Pricing terms in sovereign debt contracts: a greek case study with implications for the european crisis resolution mechanism. *Capital Markets Law Journal*, 6(2):163–187.

Clare, A. and Schmidlin, N. (2014). The impact of foreign governing law on european government bond yields.

Codogno, L. and Galli, G. (2017). "italexit is not a solution for italy's problems". *LSE EUROPP*.

Coeuré, B. (2013). Outright monetary transactions, one year on. *American Economic Review*, 76(1):72–81.

Corradin, S. and Rodriguez-Moreno, M. (2014). Limits to arbitrage: Empirical evidence from euro area sovereign bond markets.

Corsetti, G. and Dedola, L. (2013). The mystery of the printing press: Self-fulfilling debt crises and monetary sovereignty. *Mimeo Oxford University.*

Covitz, D. and Downing, C. (2007). Liquidity or credit risk? the determinants of very short-term corporate yield spreads. *The Journal of Finance*, 62(5):2303–2328.

De Grauwe, P. and Ji, Y. (2013). Self-fulfilling crises in the eurozone: An empirical test. *Journal of International Money and Finance*, 34:15–36.

De Pooter, M., Martin, R., and Pruitt, S. (2012). The effects of official bond market intervention in europe. *Federal Reserve Board of Governors mimeo.*

De Santis, R. (2015). A measure of redenomination risk. *ECB Working Paper*, April(1785):1–46.

Di Cesare, A., Grande, G., Manna, M., and Taboga, M. (2012). Recent estimates of sovereign risk premia for euro-area countries.

Di Fabio, U. (2013). Die Zukunft einer stabilen Wirtschafts-und Währungsunion: Verfassungs- sowie europarechtliche Grenzen und Möglichkeiten, München. Technical report, Stiftung Familienunternehmen.

Eser, F. and Schwaab, B. (2013). Assessing asset purchases within the ecbs securities markets programme.

European Central Bank (2014). The determinants of euro area sovereign bond yield spreads during the crisis. *Monthly Bulletin, May.*

Falagiarda, M. and Reitz, S. (2015). Announcements of ecb unconventional programs: Implications for the sovereign spreads of stressed euro area countries. *Journal of International Money and Finance*, 53:276–295.

Fratzscher, M. and Rieth, M. (2015). Monetary Policy, Bank Bailouts and the Sovereign-Bank Risk Nexus in the Euro Area. Technical report.

Hull, J., Predescu, M., and White, A. (2004). The relationship between credit default swap spreads, bond yields, and credit rating announcements. *Journal of Banking & Finance*, 28(11):2789–2811.

Krishnamurthy, A., Nagel, S., and Vissing-Jorgensen, A. (2018). ECB policies involving government bond purchases: Impact and channels. *Review of Finance*, 22(1):1–44.

Kriwoluzky, A., Müller, G., and Wolf, M. (2015). Exit expectations and debt crises in currency unions. CEPR Discussion Papers 10817.

Longstaff, F. A., Mithal, S., and Neis, E. (2005). Corporate yield spreads: Default risk or liquidity? new evidence from the credit default swap market. *The Journal of Finance*, 60(5):2213–2253.

McCulloch, J. H. (1971). Measuring the term structure of interest rates. *The Journal of Business*, 44(1):19–31.

McCulloch, J. H. (1975). The tax-adjusted yield curve. *The Journal of Finance*, 30(3):811–830.

Moore, E. and Wigglesworth, R. (2017). "euro redenomination risk edges on to investor's radar". *FT.com*.

Obstfeld, M. (1986). Rational and self-fulfilling balance-of-payments crises. *American Economic Review*, 76(1):72–81.

Schumacher, J., Chamon, M., and Trebesch, C. (2015). Foreign Law Bonds: Can They Reduce Sovereign Borrowing Costs? Annual Conference 2015 (Münster): Economic Development - Theory and Policy 113199, Verein für Socialpolitik / German Economic Association.

Schwarz, K. (2017). Mind the gap: Disentangling credit and liquidity in risk spreads.

Zettelmeyer, J. and Trebesch, C. (2018). ECB Interventions in Distressed Sovereign Debt Markets: The Case of Greek Bonds. Working Paper Series WP18-1, Peterson Institute for International Economics.

A   Estimation method

We apply the cubic spline method of McCulloch (1971, 1975) to estimate the default-risk-free discount rates $R_{t,c}^{dom}(\tau)$ and $R_t^{int}(\tau)$. Compared to the parametric alternatives, which specify a single functional form of the forward rates over the entire maturity domain, this approach models the instantaneous forward rate curve with piecewise cubic polynomials joined at predetermined knot points. This enables high flexibility of the estimation method, which is useful for our purpose because our goal is not to obtain a smooth representation of the yield curve, but to rather obtain an accurate measure of the riskless interest rate *and* the cost of redenomination risk in the prices of the euro-denominated bonds.

The following notation will be used. Let $p_{i,t}$, $i = 1, \ldots, K$ denote the observed dirty prices of K bonds at time t from which the term structure is to be inferred. Bond i has fixed payments, $c_i(\tau_j)$, where τ_j, $j = 1, \ldots, m_i$ are the coupon payment dates of a bond i with maturity m_i. The payment $c_i(\tau_j)$ consists of coupon and repayment of principal at maturity net of CDS premia. According to the bond pricing formula, the dirty price of a bond i is the discounted future cash flows of the bond until maturity:

$$p_{i,t} = \sum_{j=1}^{m_i} c_i(\tau_j) d_t(\tau_j). \tag{6}$$

where $d_t(\tau_j)$ is the discount factor of maturity τ_j and is identical for all bonds but can change over trading days t.

We estimate the unknown discount curve, $d(t_j)$ with a piecewise cubic spline model:

$$d_t(\tau_j, \beta) = 1 + \sum_{l=1}^{L} \beta_t^l g^l(\tau_j).$$

Here $g^l(t_j), l = 1, \cdots, L$, defines a set of piecewise cubic basis functions, which satisfy $g^l(0) = 0$. For $l < L$, the basis functions are defined as

$$g^l(\tau_j) = \begin{cases} 0 & \tau_j < q_{l-1}, \\ \frac{(\tau_j - q_{l-1})^3}{6(q_l - q_{l-1})} & q_{l-1} \le m_{ij} < q_l, \\ \frac{(q_l - q_{l-1})^2}{6} + \frac{(q_l - q_{l-1}(\tau_j - q_l))}{2} + \frac{(\tau_j - q_l)^2}{2} - \frac{(\tau_j - q_l)^3}{6(q_{l+1} - q_l)} & q_l \le \tau_j < q_{l+1}, \\ (q_{l+1} - q_{l-1}) \left[\frac{2q_{l+1} - q_l - q_{l-1}}{6} + \frac{\tau_j - q_{l+1}}{2} \right] & q_{l+1} \le \tau_j. \end{cases}$$

These functions are twice-differentiable at each knot point to ensure a smooth and

continuous curve around the points. For $l = 1$ we set $q_{l-1} = q_l = 0$ and for $l = L$, the basis function is given by $g^l(\tau_j) = \tau_j$.

The cubic-splines-based term structure estimation divides the term structure into segments with knot points. We use an L-parameter spline with $L-1$ knot points q_l. For $1 < l < L - 1$ the knot points are defined as

$$q_l = \tau_h + \theta(\tau_{h+1} - \tau_h), \tag{7}$$

with $h = \frac{(l-1)K}{L-2}$ and $\theta = \frac{(l-1)K}{L-2} - h$. The first knot point is $q_l = 0$ and the last knot corresponds to the longest maturity of the bond in the sample. The number of basis functions n are set to the nearest square root of the number of observed bonds N. Cubic polynomial functions are then used to fit the term structure over these segments.

We can rewrite equation (6) in a vector notation

$$\mathbf{p}_t = \iota'_m \left(\mathbf{C} \cdot \mathbf{D}_t \right) + \epsilon_t, \tag{8}$$

where ι_m is an $m \times 1$ vector of ones, and $\cdot$ represents a element-wise multiplication of the matrices $\mathbf{C}$ and $\mathbf{D}_t$. m is the longest maturity of the sample. $\mathbf{C}$ is an $m \times K$ matrix, with $c_i(\tau_j)$ in cell i, j. Note that if bond i has no payment on date τ_j, $c_i(\tau_j) = 0$. The dirty prices of the K bonds are listed in the $1 \times K$ vector $\mathbf{p}$. The discount factor matrix, also n $m \times K$ matrix, is the weighted sum of the $l = 1, \ldots, L$ basis functions

$$\mathbf{D}_t = \iota_m \iota'_K + \beta_t^1 \mathbf{G}^1 + \cdots + \beta_t^L \mathbf{G}^L. \tag{9}$$

If we combine and rearrange equations (8) and (9), we obtain the following equation:

$$\underbrace{\mathbf{p}_t - \iota' \mathbf{C}}_{z_t} = \underbrace{\beta_t^1 \iota' \mathbf{C} \cdot \mathbf{G}^1 + \cdots + \beta_t^L \iota' \mathbf{C} \cdot \mathbf{G}^L}_{\beta_t X_t} + \epsilon_t$$
$$\mathbf{z}_t = \beta_t \mathbf{X}_t + \epsilon_t \tag{10}$$

We estimate the unknown parameter vector β_t with ordinary least squares (OLS) for each individual trading day separately.

B Robustness and further results

## B.1 Yield curve estimation with weighted least squares

Our baseline model estimates the yield curve by ordinary least squares and thus puts equal weight on all bonds in the sample. However, the issued volume differs across bonds, in some cases by a substantial amount. Since it could be that prices fluctuate more for low volume bonds, OLS might not be efficient. As a proxy for bonds with a lower issued volume having potentially larger error terms, we run a robustness check where we weight bonds by the square root of their issued volume applying a weighted least squares (WLS) estimator. The results do not differ much from our baseline treatment; see Figures 8 and 9.

Figure 8: Expected exchange rate movement, first, second and third year from trading date, WLS
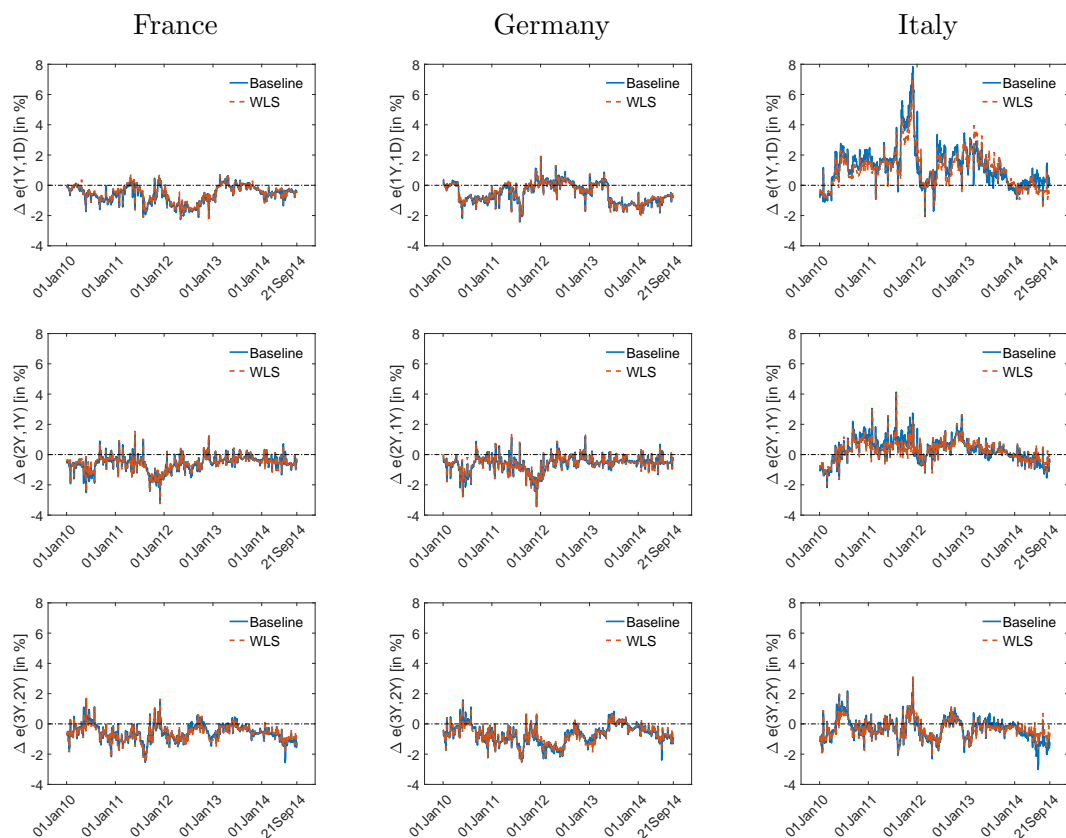
Notes: See Figure 10 for baseline. WLS refers to yield curve estimates where bonds are weighted by the square root of their nominal volume.

Figure 9: Changes in expected exchange rate changes (20-day window, WLS)
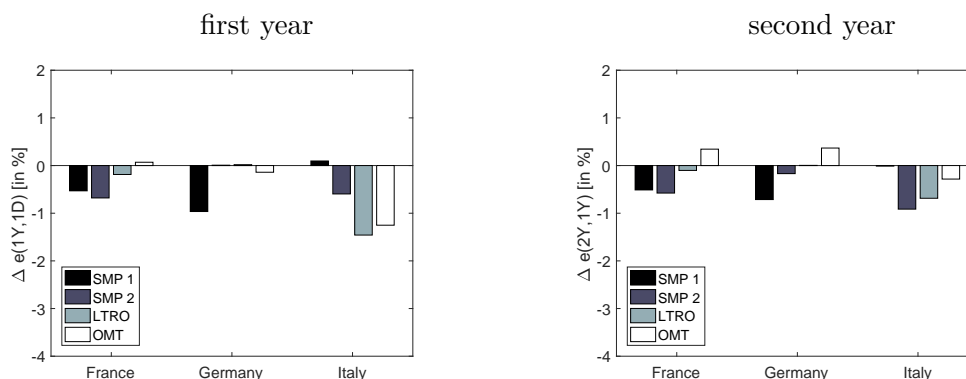
Notes: See Figure 4. The effect is computed from the WLS estimates displayed in Figure 8. For bootstrapped standard errors and significance, see Table 4 in Appendix C.

B.2 The safe international corporate €-bond yield

The assumption that the spread between the yield on the safe international corporate €-bond and the default-risk-free sovereign bond is only redenomination risk is key for our approach. Two potential issues might arise with respect to the safe international corporate €-bond in this respect. First, it might be that markets for Italian, French and German bonds are segmented along the geographical dimension. Second, it might be that the corporate bonds issued under German law still pick up German redenomination risk.

We address the first issue by estimating safe international corporate €-bond yields for French, German, and Italian corporations separately. By contrast, our baseline approach pools all international corporate €-bonds of companies from all three countries. If markets are efficient and not geographically segmented, the separate safe yields should be identical across countries and differences in the estimated yields should only result from estimation uncertainty. Figure 10 represents the country-specific safe corporate €-bond yield estimate of France, Germany, and Italy. French and German bonds show very similar yields over the entire horizon. For Italian safe corporate €-bonds, i.e., after CDS premia, the yields are *lower* than the French and German yields between mid-2010 and mid-2012. This means that we cannot exclude the possibility that markets are regionally separated and that at the height of the Italian crisis some of the decreased demand for Italian sovereign bonds flows into corporate bond demand. However, compared to the default-risk-free sovereign/safe international corporate €-bond spread, the differences between the safe €-bond yield and corporate bonds issued in the three countries are

Figure 10: One-year yield on safe corporate €-bonds by country of issuer
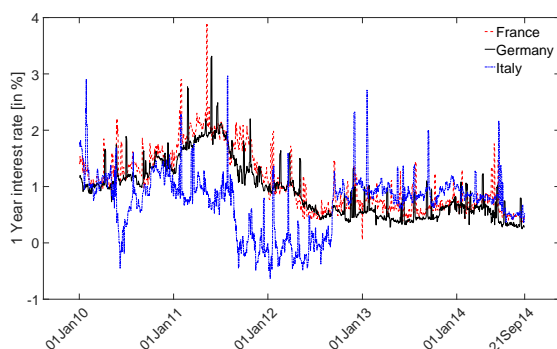
Notes: One-year yield estimates from CDS-insured corporate bonds issued by a corporation in one country under another country's jurisdiction. Bonds are grouped by the country in which the parent company is incorporated if the bond is issued by a subsidiary. All French and Italian bonds are issued under English law, and all German bonds are issued under German law by subsidiaries in the Netherlands.

minor.

For redenomination risk, this means that our baseline estimate for Italy *underestimates* redenomination risk during this period. This means that we infer the same about the effect of ECB interventions whether we use the same yield for corporate bonds in all three countries or the local one; see Figure 11. In general, the estimated time series for redenomination risk hardly changes; see Figure 14. The latter also displays the time series for redenomination risk if we take out all bonds issued under German law from the corporate bond sample. Figure 12 presents the estimated effect of the ECB's interventions on the spread, again using a 20-day window.

Finally, we also show that the choice of the window around the ECB's intervention is not key for our results. We can alternatively use a 5-day window as well and obtain qualitatively the same results; see Figure 13. For completeness, Figure 15 displays all five estimates of the safe international corporate €-bond yield.

Figure 11: Expected changes in exchange rate (20-day window, spread to local safe corporate €-bond yield)

first year

second year
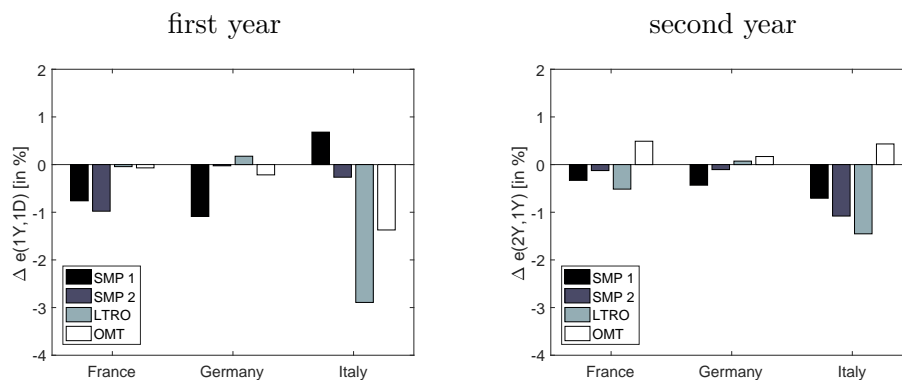
Notes: See Figure 4. Spreads computed using country-specific corporate yields as in Figure 14. For bootstrapped standard errors and significance, see Table 5 in Appendix C.

Figure 12: Expected changes in exchange rate (20-day window, spread to international safe corporate €-bond yield estimated without German-law corporate bonds)

first year

second year
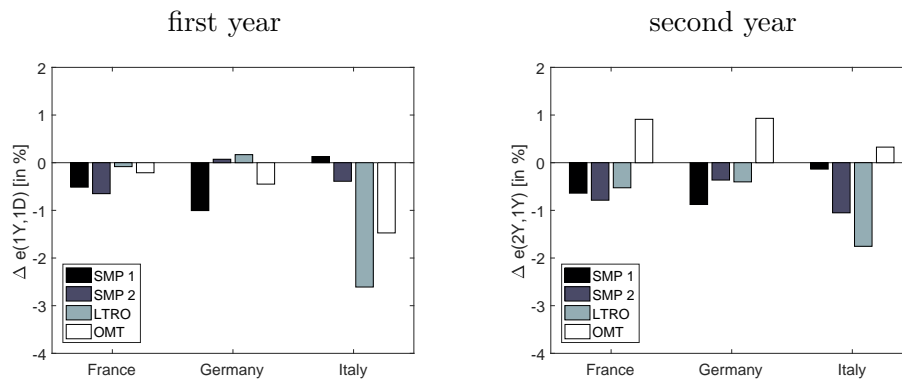
Notes: See Figure 4. The effect is computed from the estimates using corporate yields excluding German-law bonds as displayed in Figure 14. For bootstrapped standard errors and significance, see Table 6 in Appendix C.

Figure 13: Expected change in exchange rate (5-day window)
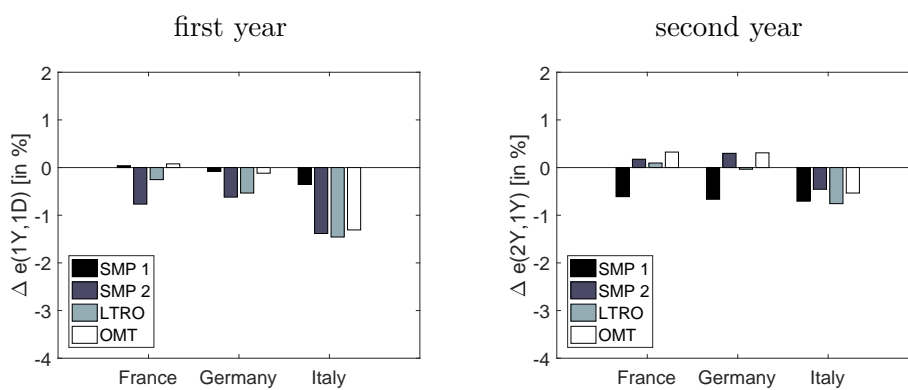
Notes: The graphs display the average change in redenomination risk after an ECB intervention as in Figure 4 but using an average over 5 trading days before and after the intervention. For bootstrapped standard errors and significance, see Table 7 in Appendix C.

Figure 14: Expected exchange rate movement, first, second and third year from trading date, robustness
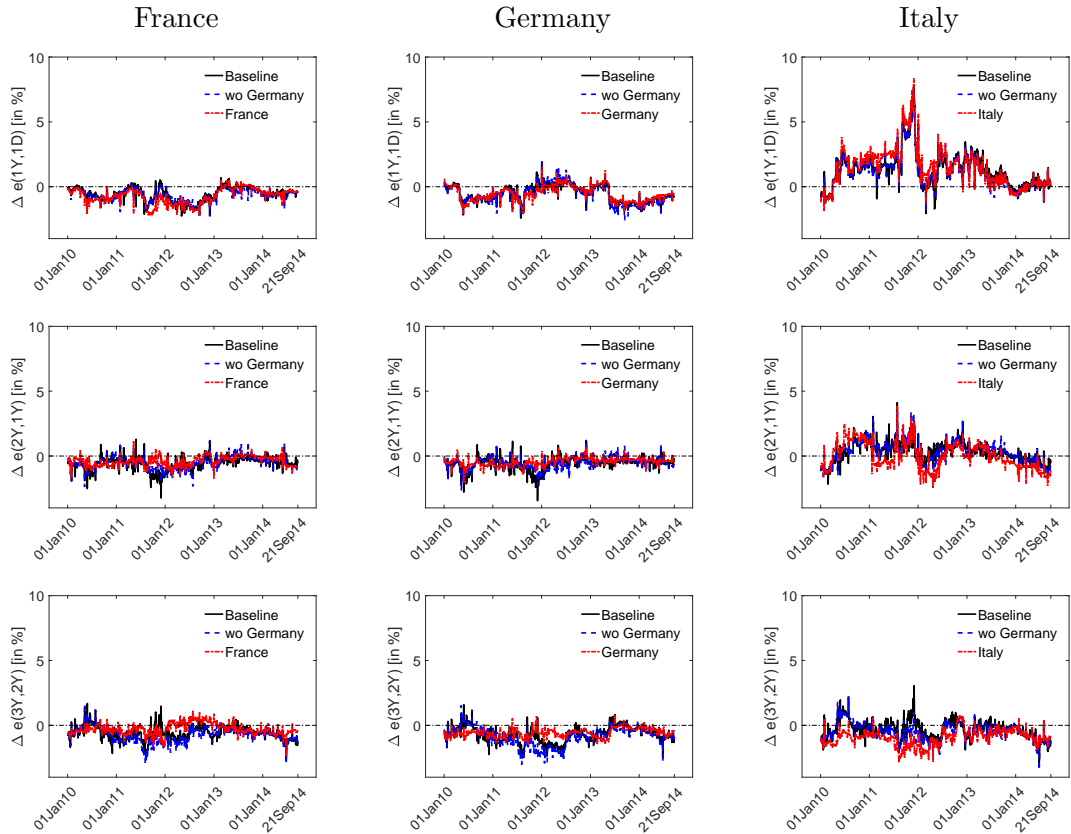
Notes: Expected changes in the exchange rate as implied by (5) for the estimated yield curves for CDS-insured sovereign bonds and CDS-insured international corporate €-bonds. The first row gives the expected exchange rate movements between the day after the trading day and the 365th day after. The second and third rows display the expected exchange rate movement between the 366th and the 730th day and between the 731st and the 1095th day after the trading day, respectively. In short, the rows display the expected exchange rate movement for the first, second and third year after the trading day. The black solid line is our baseline estimates, the blue dashed line rplaces the €-bond yield by an estimate excluding German corporate bonds and the red dotted line uses local corporate €-bonds instead.

Figure 15: The riskless interest rates, five measures

1-Year

2-Year

3-Year
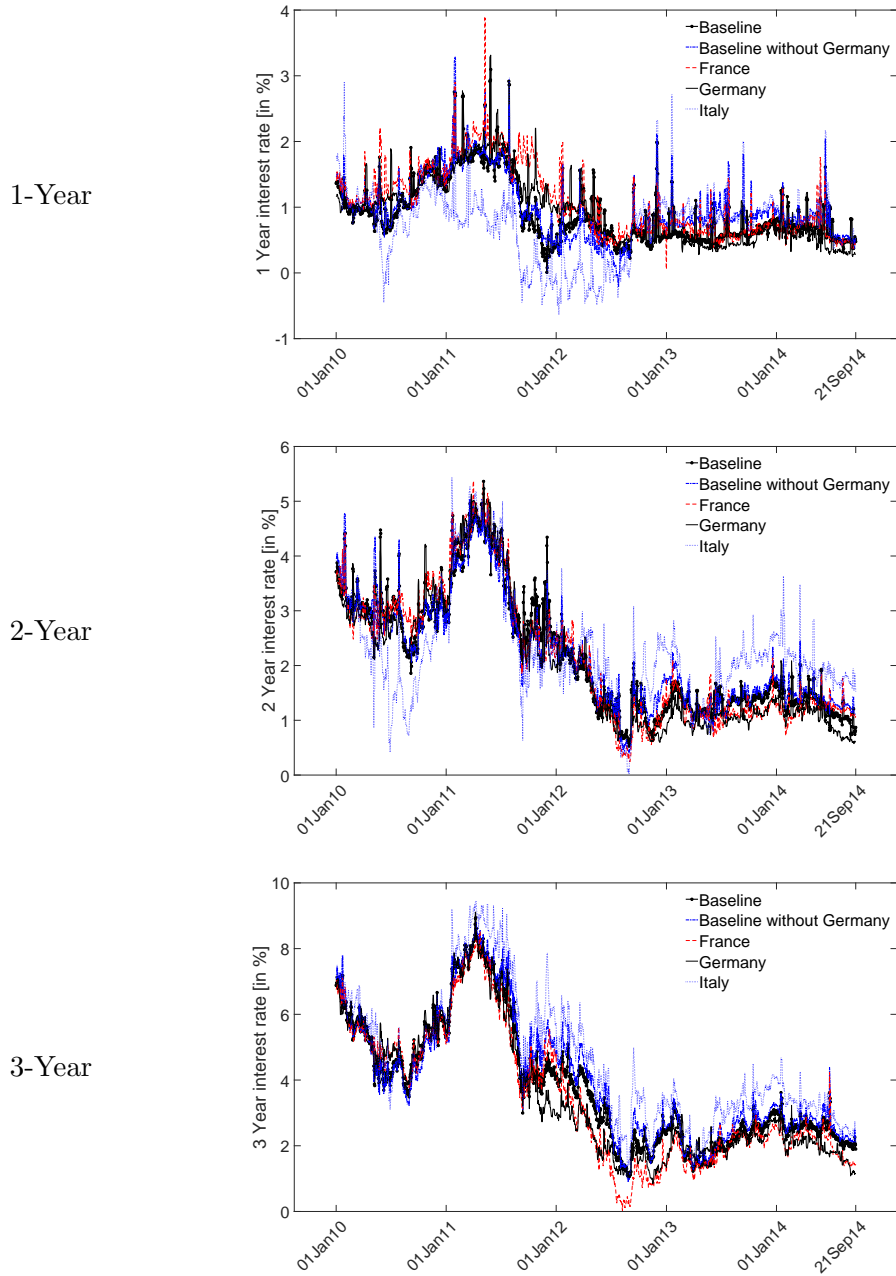
Notes: The figure shows the baseline and four alternative measures of the safe corporate €-bonds rate: Excluding German law bonds, WLS estimate, and the three rates implied by estimating separately by country.

C Significance of policy interventions

Table 3 reports the bootstrapped significance levels of the results displayed in Figure 4. We draw for each day 5000 bootstrap replications from the set of sovereign and corporate bonds (stratified by country) and estimate the corresponding yield curve. On that basis we calculate the average effect of the intervention for each bootstrap replication. Tables 4 to 7 report the bootstrapped standard deviations and significance levels for Figures 9 and 11 to 13.

Table 3: Expected changes in the exchange rate around intervention dates

Event	Country	1st day to 365th day		1st year to 2nd year	
		Estimate	Std. Error	Estimate	Std. Error
SMP-1	France	−0.497***	0.149	−0.580***	0.197
	Germany	−0.989***	0.151	−0.817***	0.192
	Italy	0.147	0.656	−0.076	0.438
SMP-2	France	−0.734***	0.151	−0.554***	0.159
	Germany	−0.013	0.161	−0.131	0.162
	Italy	−0.476	0.822	−0.816	0.519
LTRO	France	−0.155	0.208	−0.071	0.221
	Germany	0.097	0.238	0.051	0.225
	Italy	−2.689***	1.394	−1.281**	0.902
OMT	France	0.070	0.098	0.417***	0.121
	Germany	−0.163	0.192	0.435***	0.131
	Italy	−1.182**	0.635	−0.175	0.297

Note: The table shows the expected changes in exchange rate within a 20-day window around four ECB events. Confidence intervals are calculated with bootstrapping (5000 replications). One asterisk indicates significance at 10% level, two asterisks indicate significance at 5% level, and three asterisks indicate significance at 1% level.

Table 4: Expected changes in the exchange rate around intervention dates (spread estimated with WLS)

Event	Country	1st day to 365th day		1st year to 2nd year	
		Estimate	Std. Error	Estimate	Std. Error
SMP-1	France	−0.530***	0.151	−0.511***	0.197
	Germany	−0.964***	0.151	−0.713***	0.194
	Italy	0.096	0.643	−0.010	0.436
SMP-2	France	−0.679***	0.148	−0.577***	0.164
	Germany	0.008	0.160	−0.169	0.164
	Italy	−0.595	0.809	−0.914	0.505
LTRO	France	−0.187	0.205	−0.102	0.225
	Germany	0.018	0.238	0.004	0.227
	Italy	−1.458***	1.401	−0.686**	0.888
OMT	France	0.070	0.097	0.344***	0.123
	Germany	−0.140	0.195	0.367***	0.132
	Italy	−1.251**	0.640	−0.283	0.303

Note: The table shows the expected changes in exchange rate within a 20-day window around four ECB events. Confidence intervals are calculated with bootstrapping (5000 replications). One asterisk indicates significance at 10% level, two asterisks indicate significance at 5% level, and three asterisks indicate significance at 1% level.

Table 5: Expected changes in the exchange rate around intervention dates (spread to local safe corporate €-bond yield)

		1st day to 365th day		1st year to 2nd year	
Event	Country	Estimate	Std. Error	Estimate	Std. Error
SMP-1	France	−0.760***	0.183	−0.332**	0.175
	Germany	−1.089***	0.145	−0.433***	0.123
	Italy	0.681	0.703	−0.707	0.768
SMP-2	France	−0.978***	0.143	−0.126	0.161
	Germany	−0.026	0.125	−0.105**	0.073
	Italy	−0.265	0.863	−1.080	0.680
LTRO	France	−0.043	0.213	−0.515***	0.244
	Germany	0.176	0.198	0.073	0.130
	Italy	−2.892***	1.468	−1.453**	1.206
OMT	France	−0.069	0.095	0.490***	0.118
	Germany	−0.216	0.181	0.169***	0.082
	Italy	−1.372**	0.664	0.433	0.602

Note: The table shows the expected changes in exchange rate within a 20-day window around four ECB events. Confidence intervals are calculated with bootstrapping (5000 replications). One asterisk indicates significance at 10% level, two asterisks indicate significance at 5% level, and three asterisks indicate significance at 1% level.

Table 6: Expected changes in the exchange rate around intervention dates (spread estimated without German-law corporate bonds)

Event	Country	1st day to 365th day		1st year to 2nd year	
		Estimate	Std. Error	Estimate	Std. Error
SMP-1	France	−0.514***	0.156	−0.639***	0.222
	Germany	−1.005***	0.159	−0.877***	0.219
	Italy	0.130	0.657	−0.135	0.452
SMP-2	France	0.650***	0.172	−0.788***	0.185
	Germany	0.072	0.180	−0.364**	0.188
	Italy	−0.390	0.827	−1.052**	0.528
LTRO	France	−0.082	0.259	−0.526**	0.277
	Germany	0.169	0.285	−0.402	0.279
	Italy	−2.609***	1.407	−1.754***	0.919
OMT	France	−0.211	0.145	0.910***	0.308
	Germany	−0.449**	0.220	0.931***	0.313
	Italy	−1.473***	0.648	0.327	0.413

Note: The table shows the expected changes in exchange rate within a 20-day window around four ECB events. Confidence intervals are calculated with bootstrapping (5000 replications). One asterisk indicates significance at 10% level, two asterisks indicate significance at 5% level, and three asterisks indicate significance at 1% level.

Table 7: Expected changes in the exchange rate around intervention dates (5-day window)

Event	Country	1st day to 365th day		1st year to 2nd year	
		Estimate	Std. Error	Estimate	Std. Error
SMP-1	France	0.040	0.211	−0.610	0.402
	Germany	−0.082	0.345	−0.666	0.424
	Italy	−0.354	1.224	−0.705	0.838
SMP-2	France	−0.767***	0.273	0.175	0.271
	Germany	−0.620**	0.313	0.299	0.280
	Italy	−1.383	1.547	−0.456	0.929
LTRO	France	−0.253	0.414	0.095	0.548
	Germany	−0.534	0.549	−0.035	0.569
	Italy	−1.457	3.038	−0.757	2.131
OMT	France	0.077	0.190	0.325	0.249
	Germany	−0.118	0.382	0.309	0.267
	Italy	−1.308	1.293	−0.534	0.607

Note: The table shows the expected changes in exchange rate within a 20-day window around four ECB events. Confidence intervals are calculated with bootstrapping (5000 replications). One asterisk indicates significance at 10% level, two asterisks indicate significance at 5% level, and three asterisks indicate significance at 1% level.