Euro area sovereign bond risk premia during the Covid-19 pandemic*

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Abstract

We provide a novel framework to decompose euro area sovereign bond yields into five distinct components: *i*) expected future short-term risk-free rates and a term premium, *ii*) a default risk premium, *iii*) redenomination risk premium, *iv*) liquidity risk premium, and *v*) segmentation (convenience) premium. Identification is achieved by considering sovereign bond yields jointly with other rates, including sovereign credit default swap spreads with and without redenomination as a credit event feature. We apply our framework to study the impact of European Central Bank (ECB) monetary policy and European Union (EU) fiscal policy announcements during the Covid-19 pandemic recession. We find that European policy actions mattered, to first order. Both monetary and fiscal policy announcements had a pronounced effect on yields, mostly through default, redenomination, and segmentation (convenience) premia. The ECB's unconventional monetary policy announcements benefited vulnerable countries hard-hit by Covid-19 more than others, owing to unprecedented flexibility in implementing bond purchases. By contrast, EU fiscal policy announcements, and previous ECB unconventional monetary policy announcements, lowered yields more uniformly across countries.

Keywords: Sovereign bond yields, ECB, Kalman filter, event study.

JEL classification: *C22, G11.*

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1 Introduction

The outbreak of the novel Corona virus in the euro area in February 2020 had a pronounced impact on euro area sovereign bond yields. Although the health emergency was common across countries, some were hit earlier and harder by Covid-19 than others, and from different economic and fiscal positions. This asymmetry caused sovereign yields to diverge, creating an obstacle to the even transmission of the European Central Bank (ECB)'s common monetary policy to all parts of the euro area, and to achieving favorable financing conditions for firms, financial institutions, and households (Lane (2020)).[1] In response to the economic fallout of the pandemic, monetary and fiscal policy makers needed to step in to support the economy. Examples of such support include the ECB's Pandemic Emergency Purchase Programme (PEPP), as announced on 18 March 2020, and the European Union (EU)'s recovery package, as initially announced on 23 April 2020. Similar quantitative easing and fiscal support measures have been implemented by central banks and governments in the United States, the United Kingdom, and Japan, among others, each affecting sovereign bond yields (Hartley and Rebucci (2020)).

To assess in detail how sovereign bond yields are impacted by large-scale monetary and fiscal policies, it is of considerable interest to know which bond premia are the most dominant at the time.[2] This paper therefore addresses the following questions: Which underlying risk premia explain the bulk of the observed variation in sovereign yields across euro area countries? Which risk premia explain the observed divergence of sovereign yields at the onset of the Covid-19 pandemic? How successful were monetary and fiscal policy announcements in stabilizing yields? Finally, which channels explain most of the policy announcements' impacts?

As its main contribution, this paper proposes a novel financial framework to decompose euro area sovereign bond yields into five distinct premia: *i*) expected future short-term risk-free rates and a term premium, *ii*) a default risk premium, *iii*) redenomination risk premium, *iv*) liquidity risk premium, and *v*) segmentation premium. This is non-trivial, as these components are unobserved and can be hard to ascertain. To our knowledge, our framework is the first to allow empirical

[1] Eser, Carmona Amaro, Iacobelli, and Rubens (2012) and ECB (2014) document that private borrowing and lending rates are often calculated from national sovereign yields as the relevant benchmark.

[2] A vast literature has documented that sovereign bond yields comprise several components. See for example Duffie and Singleton (1999), Greenwood and Vayanos (2010), Renne and Monfort (2014), De Pooter, Martin, and Pruitt (2018), Krishnamurthy, Nagel, and Vissing-Jorgensen (2018), De Santis (2019), and Schwarz (2019).

researchers to robustly decompose sovereign yields into their main components for the largest euro area countries. We illustrate our novel approach for four countries: Germany, France, Italy, and Spain. Together, these countries represent approximately 67% of euro area gross domestic product (GDP) in 2019.

Our starting point is the framework and empirical study of Krishnamurthy, Nagel, and Vissing-Jorgensen (2018, KNV hereafter). KNV estimate latent yield components for Italian, Spanish, and Portuguese yields during the euro area sovereign debt crisis between 2010 and 2012. They do so using an unobserved component model in state space form. They identify the default and redenomination risk premium by relying on corporate bonds that are assumed to have no exposure to their respective sovereign's default risk, and on foreign-law sovereign U.S. dollar-denominated bonds that are assumed to have only exposure to default risk. Unfortunately, the former are hard-to-impossible to find, and the latter are only available for very few euro area countries. To our knowledge, only Italy regularly issues a tiny number of U.S. dollar-denominated bonds, while France, Germany, and Spain only issue euro-denominated bonds. Partly owing to data availability issues, KNV end up relying on a different model specification for each country, complicating the interpretation of their empirical results. These drawbacks render their framework of limited use in practice.

We overhaul the KNV framework in (at least) two major ways. First, we identify the default risk and the redenomination risk premium relying on sovereign credit default swap spreads (CDS) with and without redenomination as a credit event feature. We identify the default risk premium from sovereign euro-denominated CDS spreads, and identify the redenomination risk premium using the so-called ISDA basis. The ISDA basis is the difference between sovereign CDS spreads under International Swaps and Derivatives Association (ISDA) contract terms (CT) CT2014 and CT2003. Following the euro area sovereign debt crisis, and particularly following the Greek credit event on 9 March 2012, the ISDA introduced new contract terms in September 2014. The new terms make a redenomination of debt securities issued by a country leaving the euro area into a new currency much more certain to trigger the new CDS contracts, as long as the redenomination is deemed detrimental to bondholders. The ISDA 2003 terms remained unchanged, and the CT2003 CDS contracts kept trading, at a discount to the CT2014 CDS contracts. A positive ISDA basis between ISDA CT2014 and CT2003 CDS spreads thus corresponds closely to risk perceptions that a government could, following a default, renounce the euro and redenominate its debt into a new currency at a depreciated exchange rate (see also Visco (2018), Balduzzi, Brancati, Brianti, and Schiantarelli (2020), and Kremens (2021)).[3] ISDA 2014 CDS spreads became available in October 2014, and were therefore not available to KNV when they conducted their study.

Second, we modify the KNV framework by including a country-specific liquidity risk premium. Liquidity risk premia can become important for euro area sovereign yields during times of financial turmoil (see e.g. ECB (2014), Renne and Monfort (2014), Pelizzon, Subrahmanyam, Tomio, and Uno (2016), Eser and Schwaab (2016), and De Pooter, Martin, and Pruitt (2018)). We identify liquidity risk premia from country-specific liquidity risk factors provided by Tradeweb, a leading electronic trading platform, and from the ten-year KfW-Bund spread. The former is a financial industry standard and a commercially-available measure of point-in-time market illiquidity (see e.g. De Renzis, Guagliano, and Loiacono (2018)), while the latter is a common measure of the price of liquidity risk at any time (see e.g. ECB (2009), Renne and Monfort (2014), and Schwarz (2019)).

We focus our empirical study on sovereign yields at the five-year maturity, owing to data availability and economic reasons discussed in the main text, and provide four main empirical results.

First, we find that all five yield components can become economically important, in the sense that their magnitudes are in the double-digit basis points at least occasionally. (Liquidity risk premia are the least important of the five, by that standard, in our sample.) The relative importance of each premium varies considerably across countries at any time, as well as within each country over time. For example, default and redenomination risk premia explain most of the Italian and Spanish yield, but are not as important for French and German yields. Instead, French and German yields are mostly explained by expectations about future short-term risk-free rates and a term premium, as well as segmentation premia. Liquidity risk premia increased considerably from before to after the onset of the Covid-19 pandemic, in all four countries, but overall remained contained.

Second, we document that all euro area sovereign bond yields in our sample contain a pronouncedly negative segmentation premium, which we interpret as a convenience yield. Convenience

[3]Caveats apply, and are discussed in the main text.

yields capture the extent to which investors value the non-pecuniary benefits of sovereign bonds (see e.g. Krishnamurthy and Vissing-Jorgensen (2012), Greenwood, Hanson, and Stein (2015), Del Negro, Giannone, Giannoni, and Tambalotti (2018), and Brunnermeier, Merkel, and Sannikov (2021)). Our segmentation premium estimates are most negative for German bonds, suggesting that these bonds are the most highly sought-after asset in our sample. We find that the segmentation premium became more negative following the ECB's PEPP announcement on 18 March 2020 for most countries. Our empirical results are in line with the theoretical predictions of Corradin and Maddaloni (2020) that the segmentation premium is pushed into more negative territory by the ECB purchasing large fractions of outstanding debt, thereby lowering euro area sovereign yields (see e.g. Koijen, Koulischer, Nguyen, and Yogo (2021) and Eser, Lemke, Nyholm, Radde, and Vladu (2019)), for example within the Public Sector Purchase Programme (PSPP) since March 2015 and the PEPP since March 2020.[4]

Third, we find that the ECB's PEPP-related unconventional monetary policy announcements had a beneficial, and economically large, impact on some sovereign yields, benefitting vulnerable countries hard-hit by Covid-19. For example, the ECB's initial PEPP-related announcement on 18 March 2020 led to a large reduction in Italian yields, and to a moderate reduction in Spanish yields. Specifically, five-year Italian yields peaked at 196 bps before the 18 March announcement, and then decreased by 78 bps over a two-day event window. Our statistical model attributes this decrease to a lower default risk premium (by 35 bps), redenomination risk premium (by 14 bps), and segmentation premium (by 16 bps). Spanish yields decreased by 11 bps, owing to a decrease in the segmentation premium (by 10 bps). By contrast, French and German yields increased by 10 and 24 bps, respectively.[5] As a second example, the ECB expanded its PEPP from €600 billion (bn) to €$1,350$ bn on 4 June 2020, decreasing Italian yields by an additional 17 bps, mainly owing to a

[4]Koijen, Koulischer, Nguyen, and Yogo (2021) and Eser, Lemke, Nyholm, Radde, and Vladu (2019) investigate how the ECB's asset purchase programs work by looking at yields and portfolio rebalancing jointly using data on security-level portfolio holdings for all major institutional investor sectors and for all countries in the euro area. He, Nagel, and Song (2021) document an unusual rise of U.S. Treasury yields relative to overnight indexed swap rates in March 2020, which they refer to as an inconvenience yield. They relate this finding to selling pressure originating from large holders of Treasuries and to regulatory constraints, both affecting primary dealers' balance sheet capacity. In response, the Federal Reserve first offered short-term financing to primary dealers and then started buying large amounts of Treasuries.

[5]These increases can in part be explained by an increase in expected future short-term risk-free rates and term premium. Some market participants may have been expecting a cut in the ECB's deposit facility rate at the time, to counteract the economic fallout of the Covid-19 pandemic, which did not happen. Instead, asset purchases became the preferred monetary policy instrument.

lower default risk premium (by 18 bps) and redenomination risk premium (by 6 bps). Spanish yields decreased by 5 bps, mainly owing to a lower default risk premium (by 5 bps) and redenomination risk premium (by 3 bps).

The asymmetric impact on yields on both 18 March and 4 June 2020 (Italian and Spanish yields down, French and German yields up) is probably attributable to the unprecedented flexibility built into the PEPP, granting the ECB substantial latitude in implementing asset purchases across euro countries, across asset classes, and over time, as deemed appropriate. In particular, within the PEPP, the ECB can deviate from the strict limits set by the ECB's capital key that had guided its net purchases until then.[6] Previous ECB asset purchase programs, including the PSPP, did not exhibit such flexibility.[7] As a result, the ECB's PEPP may have been understood as a signal of its willingness to provide a backstop to a potential national sovereign debt crisis, wherever it were to occur. In addition, the PEPP intervention might have lowered self-reinforcing tail risks, reducing the market price of risk, and might thus have increased debt sustainability in vulnerable countries (see e.g. Corsetti and Dedola (2016)).

Fourth, we find that the EU's main fiscal policy announcements also lowered sovereign yields, and more uniformly so across countries. At first glance, this is surprising because the EU's fiscal policies were all expansionary, adding new debt (guaranteed by EU member states) to the EU's balance sheet. For example, on 23 April 2020, EU heads of state agreed to put together a significant recovery package initially worth €540 bn. The package comprised a €100 bn program to mitigate unemployment risks (SURE), a €200 bn pan-European guarantee fund for loans to non-financial firms through the European Investment Bank (EIB), and a €240 bn crisis support credit line issued by the European Stability Mechanism (ESM) to European governments (see Section 3.2 for a discussion). It also announced a recovery fund of "a sufficient magnitude," with details to be worked out subsequently. Italian, Spanish, French, and German yields decreased by 23, 14, 11, and 5 bps, respectively, upon announcement. Our statistical model attributes the observed 23 bps decrease in Italian yields to lower risk premia across the board: the default risk premium (by 14 bps), the redenomination risk premium (by 3 bps), the segmentation premium (by 2 bps), the liquidity

[6] The ECB capital is held by euro area national central banks as shareholders. The capital key is set to reflect the member states' population and GDP.

[7] The announcement of the ECB's PSPP, on 15 January 2015, lowered sovereign yields more symmetrically for all four countries in our sample, including France and Germany.

risk premium (by 1 bps), as well as expected future short-term risk-free rates and term premium (by 5 bps). A similar pattern is observed for Spanish yields: all yield components decreased, by approximately proportionate amounts. Later, on 21 July 2020, EU heads of state reached an agreement fleshing out the technical details of its NGEU program. Also this announcement led to a uniform reduction in all yields. Italian, Spanish, French, and German yields then decreased by 8, 2, 3, and 3 bps respectively.

We interpret the uniform decline in yields following EU fiscal policy announcements as potentially reflecting market participants' assessment that expansive fiscal policy can play an important role in supporting monetary policy aimed at improving the economic outlook, which in turn improves debt sustainability (including debt-to-GDP metrics; see Bartsch, Benassy-Quere, Corsetti, and Debrun (2021)). In addition, the fiscal policy may have supported vulnerable countries by removing fiscal risk from weakened sovereign budgets onto shared budgets, facilitating lower default risk premia (in line with Augustin, Sokolovski, Subrahmanyam, and Tomio (2021)) and more negative convenience yields (Jiang, Lustig, Van Nieuwerburgh, and Xiaolan (2021)). Finally, the observed strong policy response at the European level may have contributed to lowering national political risks, rationalizing lower redenomination risk premia.

We proceed as follows. Section 2 presents our financial and statistical framework. Section 3 discusses our data and key policy announcements. Section 4 presents our main empirical results. Section 5 concludes. A Web Appendix provides further technical and empirical results.

2 Financial framework

2.1 Sovereign yield components

Following KNV, we consider the yield on a euro-denominated sovereign bond issued by country c observed at time t with remaining time-to-maturity τ,

$$\begin{aligned} r^c_{t,t+\tau} = \frac{1}{\tau}\int_t^{t+\tau} \mathbb{E}[i_s]\mathrm{d}s + \text{Term Premium}_{t,t+\tau} \\ + \text{Default Risk Premium}^c_{t,t+\tau} + \text{Redenomination Risk Premium}^c_{t,t+\tau} \\ + \text{Liquidity Risk Premium}^c_{t,t+\tau} + \text{Segmentation Premium}^c_{t,t+\tau} + u^c_{t,t+\tau}. \end{aligned} \tag{1}$$

Equation (1) decomposes the bond yield $r^c_{t,t+\tau}$ into several distinct terms. We now address each in turn. The first and second term (top line) are not dependent on the identity of the country c. Denote by i_t the overnight interest rate at time t on a safe and liquid contract, such as the EONIA overnight rate. Thus, the first term reflects the expectation hypothesis of interest rates. The second term reflects a term (or duration risk) premium. Longer-term bonds carry interest rate risk, and therefore contain a term premium to compensate investors for bearing that risk. As in KNV, we do not separately identify the first two terms. Instead, we identify both terms, as one latent component, from EONIA OIS rates,

$$\text{EONIA OIS rate}_{t,t+\tau} = \frac{1}{\tau}\int_t^{t+\tau} \mathbb{E}[i_s]\mathrm{d}s + \text{Term Premium}_{t,t+\tau},$$

where the equality is approximate if the EONIA OIS rate is subject to measurement error, and exact otherwise (see Section 2.2).

The next five terms are country-specific. The third term, Default Risk Premium$^c_{t,t+\tau}$, reflects the premium for default risk. In bond pricing models this premium is driven by the probability of default, the loss-given-default, and the economic market-price-of-risk associated with default states (see e.g. Duffie and Singleton (1999)).

If investors are concerned that, in addition to defaulting on (all or parts of) its obligations, the government will also re-denominate its debt into a new local currency at a depreciated exchange rate, effectively exiting the euro area, then investors will demand a positive Redenomination Risk Premium$^c_{t,t+\tau}$ (our fourth term; see also ECB (2014), De Santis (2019), and Kremens (2021)).

A Liquidity Risk Premium$^c_{t,t+\tau}$ (fifth term) arises from the potential difficulty that investors may have in selling the bond before its redemption. Such difficulties typically arise in distressed market conditions, when it is harder to find a counterparty for a trade relatively quickly. While liquidity risk premia are typically negligible in deep sovereign bond markets, they became economically significant during the global financial crisis between 2008 and 2010 and the euro area sovereign debt crisis between 2010 and 2012 (see e.g. Renne and Monfort (2014), Pelizzon, Subrahmanyam, Tomio, and Uno (2016) and De Pooter et al. (2018)).

We identify a Segmentation Premium$^c_{t,t+\tau}$ as the remaining persistent component (sixth term).

It is called a segmentation premium because it can arise with some limits to arbitrage (see e.g. Gromb and Vayanos (2002), Duffie (2010)) and in the presence of a large buyer such as a central bank (Corradin and Maddaloni (2020)). In Gromb and Vayanos (2002)'s setting, the bond price reflects the valuation of only a subset of investors because some investors are constrained from fully participating in the market, for example owing to country-specific regulatory hurdles or home biases. The bond yield can then embed a segmentation premium relative to its frictionless price. This segmentation premium is negative if the first set of investors benefit from owning the bond above and beyond the utility they derive from receiving its cash flows (Krishnamurthy and Vissing-Jorgensen (2012), Del Negro, Giannone, Giannoni, and Tambalotti (2017), and Brunnermeier, Merkel, and Sannikov (2021)). The segmentation premium can therefore also be referred to as a convenience yield. In the euro area setting, investors could be willing to pay a premium to hold government bonds instead of central bank reserves, particularly when large-scale central bank asset purchase programs are active and the latter are subject to penalty (negative) interest rates. In addition, current banking sector liquidity regulations compel banks to hold sovereign bonds, as so-called high-quality liquid assets, regardless of their yields, to meet their liquidity coverage ratio requirements.

Finally, independently-distributed noise terms $u^c_{t,t+\tau}$ capture one-off effects. Such one-off effects are typically small. Trading around key policy announcements can, however, lead to transitory market pressures related to dealer inventory effects (see e.g. Greenwood and Vayanos (2010), Eser, Carmona Amaro, Iacobelli, and Rubens (2012), and Eser and Schwaab (2016)). In addition, one-off effects can be present when a newly-issued bond becomes the new benchmark bond.

We focus our analysis on the five-year maturity throughout this paper for two main reasons. First, the sovereign CDS contracts used to identify default and redenomination risk premia are the most liquid at this maturity. Second, the weighted average maturity of the outstanding sovereign debt for the euro area countries in our sample is approximately six years. This is closer to the five year maturity than, say, the two or ten year maturity, and therefore the most relevant economically.

2.2 Statistical model

This section presents our statistical model in state space form. The measurement and state equations are given, respectively, by

$$y_t = Z\alpha_t + \epsilon_t, \quad \epsilon_t \sim \mathrm{N}(0, H_t), \tag{2}$$

$$\alpha_{t+1} = T\alpha_t + \eta_t, \quad \eta_t \sim \mathrm{N}(0, Q), \tag{3}$$

where y_t is the data vector, $t = 1, \ldots, T$, Z is a loading matrix, α_t is the state vector, ϵ_t is the measurement error, H_t is the measurement error covariance matrix, T is the state transition matrix, η_t is the state equation error, and Q is the state equation error covariance matrix. Matrices H_t and Q are symmetric and positive definite. The error terms ϵ_t and η_t are assumed to be normally distributed. This is mainly for simplicity. The Kalman filtering and smoothing recursions continue to provide attractive (i.e., minimum-variance linear unbiased) estimates of the state vector α_t even if ϵ_t and η_t were not normally distributed; see e.g. Durbin and Koopman (2001, Ch. 4.3).

The $[7 \times 1]$-dimensional data vector y_t contains bond yields, CDS spreads, and a liquidity risk factor. The $[6 \times 1]$-dimensional state vector α_t contains the unobserved risk premia of interest. We focus on the five-year maturity throughout this paper. Section 2.4 explains in detail which data in y_t are used to identify which risk premium in α_t. For now, we preview the data vector y_t and state vector α_t as

$$y_t = \begin{bmatrix} \text{5y benchmark bond yield, Bloomberg} \\ \text{5y benchmark bond yield, Reuters} \\ \text{5y OIS EUR rate} \\ \text{5y CDS EUR ISDA CT2003} \\ \text{5y CDS USD ISDA CT2014} \\ \text{5y CDS USD ISDA CT2003} \\ \text{5y Tradeweb liquidity indicator} \\ \quad \times\text{KfW-Bund spread} \end{bmatrix}, \quad \alpha_t = \begin{bmatrix} \text{expected future average short-rate} \\ \quad \text{and term premium} \\ \text{default risk premium} \\ \text{redenomination risk premium} \\ \text{filtered CDS USD CT2003} \\ \text{liquidity risk premium} \\ \text{segmentation premium} \end{bmatrix}$$

and defer a full discussion of our identification approach to Section 2.4 and of data specificities to Section 3. The loading matrix Z relates the observations y_t to the latent risk premia in α_t, allowing us to identify the latter from the former.[8] The measurement error variance matrix H_t can be made time-varying as suggested by KNV. Both matrices are then given by

$$Z = \begin{bmatrix} 1 & \beta_1 & \beta_2 & 0 & \beta_3 & 1 \\ 1 & \beta_1 & \beta_2 & 0 & \beta_3 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}, \qquad H_t = \begin{bmatrix} \gamma_1^2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \gamma_2^2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \gamma_3^2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \gamma_4^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \gamma_5^2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \gamma_6^2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \gamma_7^2 \end{bmatrix} \cdot \begin{pmatrix} 1 \\ 1 \\ 1 \\ y_{4,t-1} \\ y_{5,t-1} \\ y_{6,t-1} \\ y_{7,t-1} \end{pmatrix},$$

where $\beta = (\beta_1, \beta_2, \beta_3)'$ and $\gamma = (\gamma_1, \ldots, \gamma_7)'$ collect deterministic loading and standard deviation parameters.[9] The time-varying covariance matrix H_t allows measurement errors to be more dispersed if the lagged data are higher at the time. This specification requires the respective elements of y_{t-1} to be non-negative, however. While CDS spreads and liquidity measures are always non-negative, sovereign yields and euro area OIS rates are not. We therefore use time-varying measurement error variances only for the CDS spreads and the liquidity measure, and use time-invariant ones for sovereign yields and OIS rates.[10]

The state equation transition matrix is given by $T = I_6$, where I_6 denotes the $[6 \times 6]$ identity matrix. Each risk premium therefore evolves as a random walk, reflecting their association with

[8]The fourth element of α_t ("filtered CDS USD CT2003") is not of primary interest. Our model obtains the ISDA basis as the difference between the *filtered* CDS USD CT2014 swap rate and *filtered* CDS USD CT2003 swap rate, see the fifth row of matrix Z below. Each CDS spread $y_{4,t}$, $y_{5,t}$, and $y_{6,t}$ is subject to its own measurement error (see Equation (2)).

[9]The default risk premium $\alpha_{2,t}$ could, in principle, also be made sensitive to the two CDS spreads $y_{5,t}$ and $y_{6,t}$. We do not do so because the latter two CDS contracts also insure against a devaluation of the euro against the U.S. dollar should a sovereign credit event occur. These contract spreads are thus sensitive to risks beyond "pure" default risk; see also Section 2.4 below.

[10]The empirical results reported in Section 4 are not particularly sensitive to adopting an entirely time-invariant measurement error variance matrix H_t because the estimated measurement errors are small. Our results are also not sensitive to making all diagonal elements of H_t time-varying, using an exponential link function for sovereign yields and OIS rates. If only a part of H_t is time-varying, then the lagged data y_{t-1} can be re-scaled to a unit mean to facilitate the interpretation of all elements of γ as standard deviation parameters. We do so for our empirical work in Section 4.

financial market prices (for example, CDS spreads).[11] The state error variance matrix is given by $Q = \mathbb{E}[\eta_t \eta_t'] = DCD$, where $D = \mathrm{diag}(\delta_1, \ldots, \delta_6)$ is a diagonal matrix containing state error volatility parameters $\delta = (\delta_1, \ldots, \delta_6)'$, and C is a symmetric and positive-definite correlation matrix with ones on the diagonal and correlation parameters $\rho = (\rho_1, \ldots, \rho_{15})'$ off the diagonal. Non-zero on-diagonal elements in D imply time-variation in risk premia. Non-zero off-diagonal elements in C allow for contemporaneous correlation between the state errors η_t.

The state vector α_t is initialized with a diffuse prior distribution.[12] This reflects the random walk character of the unobserved components in α_t (see also Durbin and Koopman (2001, Ch. 5.2) and KNV).

2.3 Parameter and state vector estimation

All deterministic parameters are stacked into $\psi = (\beta', \gamma', \delta', \rho')'$ to be estimated numerically by maximum likelihood methods (see Hamilton (1994, Ch. 13.4) and Durbin and Koopman (2001, Ch. 7)), or to be calibrated to fixed values based on non-sample information (see Section 4.1 below). For parameter estimation, we maximize the average (or sum) over all four country-specific log-likelihoods. This implies that the loading, volatility, and correlation parameters in ψ are restricted to be the same across countries. The state space of each model remains $[6 \times 1]$-dimensional. In this way, a large amount of time series data is brought to bear for inference on ψ, facilitating precise estimates and a robust convergence to the global maximum. The pooling of country-specific parameters is advantageous because, for example, our German or French data are fairly uninformative about default, redenomination, and liquidity risk premia. The pooling restriction does not imply that the estimated random walk components in α_t are in any way similar across countries; see Section 4. Full-sample estimates of the state vector $\hat{\alpha}_t = \mathbb{E}[\alpha_t | y_1, \ldots, y_T; \psi^{(\mathrm{common})}]$ are obtained from the Kalman filter and smoother as in KNV.[13]

[11] The random walk specification for latent components is a common choice in the applied literature using time-varying parameter models (see e.g. Primiceri (2005), Eickmeier et al. (2015), Krishnamurthy, Nagel, and Vissing-Jorgensen (2018), and references therein). Each latent component can evolve flexibly, conditional on the data at hand, to match a multitude of potential patterns.

[12] This means that, roughly, $\alpha_1 \sim \mathrm{N}(0, \kappa \cdot I_6)$ with $\kappa \to \infty$. Koopman (1997) provides exact Kalman filtering and smoothing recursions for non-stationary time series models with diffuse initial conditions, which we use. State initialization with a finite $\kappa = 10$, however, lead to virtually identical parameter and state vector estimates.

[13] For compactness we omit country superscripts to indicate country data in (2) – (3). To clarify, when estimating French yield components, say, the state vector estimate is $\hat{\alpha}_t^{\mathrm{FR}} = \mathbb{E}[\alpha_t^{\mathrm{FR}} | y_1^{\mathrm{FR}}, \ldots, y_T^{\mathrm{FR}}; \psi]$. This quantity does not necessarily coincide with $\hat{\alpha}_t^{\mathrm{FR}} = \mathbb{E}[\alpha_t^{\mathrm{FR}} | y_1^{\mathrm{DE}}, \ldots, y_T^{\mathrm{DE}}, y_1^{\mathrm{FR}}, \ldots, y_T^{\mathrm{FR}}, y_1^{\mathrm{ES}}, \ldots, y_T^{\mathrm{ES}}, y_1^{\mathrm{IT}}, \ldots, y_T^{\mathrm{IT}}; \psi]$ that a much larger,

The loading parameters β could alternatively be estimated by a (restricted) least squares regression of sovereign yields on the other financial instruments' rates. Estimates of the state vector α_t, and of the remaining parameters in ψ, could then be obtained in a second step conditional on that estimate of β. Web Appendix A provides the details of such a regression-based approach to decomposing euro area sovereign yields, and demonstrates that the empirical outcomes are quantitatively similar.[14] The Kalman filtering approach is our preferred approach, however, for three reasons. First, all variables in y_t could be subject to at least some measurement error. If so, errors-in-variables (see e.g. Davidson and MacKinnon (2004, Ch. 5.1)) could imply that the least squares estimator is subject to a bias of unknown sign and magnitude. By contrast, measurement errors are explicitly taken into account in a filtering approach, leading to reliable, one-step, and consistent parameter and state vector estimates. Second, the filtering approach allows us to put full-sample standard error bands around each filtered component. Finally, the regression-based approach implicitly pushes the segmentation premium into the regression residual, effectively merging the last two terms in Equation (1). This decreases the precision with which the segmentation premium is measured.

2.4 Identification

This section explains in detail how each risk premium is identified. As in KNV, the expected average future short-term risk-free rate over the next five years and the five-year term premium are identified jointly, as one component, from five-year EONIA OIS rates. This first component is common to all euro area countries. The remaining four premia are country-specific, and unobserved, and therefore need to be inferred from additional financial instruments. We depart from KNV's analysis by using a different set of financial instruments to identify country-specific default, redenomination, and liquidity risk premia. Web Appendix B provides two tables that contrast KNV's approach with our approach.

unwieldy, model (that we do not estimate) would produce. In practice, if the measurement error variances are small, then each state vector is almost perfectly observed, and the smoothing recursions would only be minimally influenced by other countries' data.

[14]The least squares approach does not pool over γ, δ, and ρ parameters. The empirical outcomes are similar, suggesting that pooling these parameters across countries is not restrictive.

2.4.1 Default risk premium

We identify the default risk premium based on sovereign CDS spreads denominated in euro under ISDA 2003 contract terms (CT2003). Such CDS contracts protect the insurance owner from a sovereign default, but not necessarily from a redenomination of sovereign debt into another currency (as explained below). In addition, such CT2003 CDS contracts denominated in euro do not protect the protection buyer from a devaluation of the euro should a sovereign credit event occur. In place of CDS spreads, KNV use U.S. dollar-denominated sovereign bonds to identify the default risk premium, assuming that these cannot be redenominated through changes in domestic law (see Chamon et al. (2018)). KNV argue that the yields of these bonds, when adjusted by the U.S. dollar OIS rate for the corresponding maturity, should contain the default risk premium.

A crippling limitation of KNV's identification approach is that very few euro area countries actually issue U.S. dollar-denominated bonds. We observe that, for the four countries in our sample, only Italy has two U.S. dollar-denominated bonds outstanding for which daily price quotes are available.[15] As a result, KNV's decomposition approach is not feasible for the largest euro area countries, particularly Germany and France.

Web Appendix C compares the two approaches for Italian data. The two measures of the default risk premium are highly correlated, with a correlation coefficient of approximately 83%. Web Appendix C also compares the market liquidity of Italy's two U.S. dollar-denominated bonds to that of the corresponding CT2003 CDS contract. The CT2003 CDS contract is more liquid than the two U.S. dollar-denominated bonds, with an average bid-ask spread of 8 bps vs. 11 and 12 bps, respectively.

KNV argue against using CDS spreads to infer default risk premia in their sample, for two reasons. First, during the euro area sovereign debt crisis between 2010 and 2012, market participants were uncertain whether CT2003 CDS contracts referencing euro area countries would be triggered in all default-related scenarios. For example, there was considerable uncertainty in late 2011 whether the "voluntary" asset-swap involving Greek debt would indeed trigger the corresponding CDS contract. This uncertainty was ultimately resolved, on 9 March 2012, when the relevant

[15] To assess the availability of U.S. dollar-denominated bonds issued by the central government we use the ECB's Centralized Security Database (CSDB), containing information on all active debt securities issued by euro area issuers.

ISDA-committee ruled that this would be the case. At around the same time, it also became clear that CT2003 CDS contracts might not provide effective protection should a large euro area country, such as Italy, decide to leave the euro area and redenominate its debt. This uncertainty was also ultimately resolved, when the ISDA updated its credit terms in September 2014, introducing new CDS contracts to trade in parallel to the older CT2003 contracts. As a result, there is substantial more clarity today, compared to 2011, regarding which events each CDS contract insures against.

Second, KNV argued in their study that CDS spreads might be "distorted" by ECB bond purchases, and as result could underestimate the default risk premium. For example, market participants might be less willing to pay for CDS protection if they believed that the ECB would always intervene to keep sovereign yield spreads below a certain threshold. That this has ever been the case, however, is not obvious, and not in line with the ECB's communication. And even then, the CDS spread would still reflect the appropriate (lower) default risk premium at the time.[16] We conclude that, for our sample, CDS spreads provide the most available, direct, and liquid measure of a sovereign's default risk.

2.4.2 Redenomination risk premium

We identify the redenomination risk premium from the difference between five-year sovereign CDS spreads quoted in U.S. dollars under ISDA CT2014 and CT2003 terms. This difference is also known as the ISDA basis among central bankers and academics (see e.g. Visco (2018), Balduzzi, Brancati, Brianti, and Schiantarelli (2020), and Kremens (2021)). In 2014, following the euro area sovereign debt crisis and the Greek credit event on 9 March 2012, the ISDA introduced new credit terms making a redenomination of debt much more likely to trigger the revamped CDS contracts. A positive ISDA basis between ISDA 2014 and ISDA 2003 CDS spreads, when quoted in the same currency and referencing the same euro area sovereign, is therefore indicative of a perceived risk that the sovereign could renounce the euro and subsequently redenominate its debt.

Web Appendix D.1 describes in detail the differences between the ISDA 2014 and 2003 credit

[16] Eser and Schwaab (2016) study the impact of bond purchases under the ECB's Security Market Program (SMP) on sovereign yields between 2010 and 2012. The SMP covered five euro area countries at the time – Greece, Ireland, Portugal, Spain, and Italy. The authors document that SMP purchases had an impact on CDS spreads in addition to bond yields, but that the impact on CDS spreads was much lower than that on the corresponding bond yields. As a result, bond purchases did not distort countries' CDS-bond bases, but, through their impact on yields, instead helped restore them to more common, positive levels.

terms. We here summarize the main distinctions. In principle, the possibility of redenomination is also covered in the 2003 credit terms. In addition, however, the 2003 terms also contain fine print that effectively removes protection against redenomination risk, at least for some countries. Specifically, Group of 7 (G7) countries — including France, Germany, and Italy —, as well as OECD countries with a AAA/Aaa rating, are treated differently, in that these countries could issue a new "permitted currency." As a result, France, Germany, and Italy could redenominate their existing debt into a new permitted currency, without triggering the ISDA 2003 contract terms. Around 2010 it became apparent (and widely-discussed in the financial press) that CT2003 CDS contracts do not provide effective protection against redenomination risk for France, Germany, and Italy; see e.g. Kaminska (2010).

In our study we also use the ISDA basis to measure the redenomination risk premium for Spain. At first glance, this seems strange, since Spain is not a G7 country. We proceed nevertheless, with two justifications in mind. First, during the euro area sovereign debt crisis there was a substantial discussion that, if either Spain or Italy were to redenominate their debt, then they might exit the euro jointly and adopt a, say, "southern states euro." Given that this new currency would then also be legal tender in Italy, a G7 country, the Spanish CT2003 CDS might not be triggered in this case.[17] Second, the ISDA 2003 terms put the responsibility on an ISDA committee to determine whether a deterioration in the creditworthiness, or the financial condition, of the reference sovereign has occurred prior to redenomination. That decision, however, would not necessarily be straightforward (or timely). Nevertheless, we acknowledge that using the ISDA basis to infer the Spanish redenomination risk premium is less clear cut than for the other three (G7) countries, and note that the reader is free to refer to the sum of the Spanish redenomination risk premium and default risk premium collectively as Spanish "credit-related premia." Our main empirical results, as presented in Section 4, are only minimally affected by such an alternative interpretation.

In contrast to the ISDA 2003 credit terms, the ISDA 2014 terms were drafted with the existential euro area sovereign debt crisis in mind. The redenomination-related clauses were significantly reworded, and any reference to G7 membership was removed. Now, if a debt obligation "is rede-

[17]See e.g. https://www.isda.org/a/sFiDE/icm-21318534-v8-memo-to-kirsty-taylor.pdf. A potential joint exit with Italy, a G7 country, can also explain observed positive ISDA bases for other euro area countries such as e.g. Portugal or Ireland; see e.g. Kremens (2021, Figure 1b). ISDA bases for non-euro area countries (such as Japan or the U.K.) tend to be tiny (single digit basis points).

nominated into a currency other than that of Canada, Japan, Switzerland, the UK, the US dollar and the euro," then this can trigger a restructuring credit event. The ISDA 2014 terms also removed the requirement that a restructuring event would be triggered "only in the case of a deterioration in the creditworthiness or financial condition of the sovereign" that exits the euro, which, as argued above, could be difficult to prove in practice. Instead, the 2014 terms introduced a rule: the restructuring credit event would be triggered by *any* redenomination into a new currency, as long as a haircut or market loss occurs to existing bondholders. This is a much more straightforward criterion, and easier to ascertain.

We conclude this section by discussing potential objections against using the ISDA basis as a measure of redenomination risk in our sample. First, a straightforward objection could be that CT2003 CDS contracts are less liquid than the more current CT2014 CDS contracts. In fact, however, the difference in market liquidity is barely noticeable.[18]

Second, the ISDA basis could, in principle, also reflect another change in 2014 credit terms, revolving around a new "Asset Package Delivery" (APD) clause. Web Appendix D.2 explains the new APD clause in detail. In short, the APD clause was a direct response to the Greek debt restructuring of 2012. It clarifies which assets are taken into account when calculating a bond's recovery value at default. We argue that the new APD clause is unlikely to lead to an economically significant pricing differential between CT2003 and CT2014 contracts in our sample because the magnitude of the recovery value matters most when countries are close to default.[19] This is not the case in our sample. If the APD clause led to a constant level shift in the spread between 2003 and 2014 contracts, our redenomination risk premium estimates would be too high (by a constant). Our segmentation premium estimates would then be too negative, and our event study results in Section 4.4 would remain unaffected.[20]

[18] For example, the bid-ask spread for the five-year CDS contract referencing Italy – the country with the maximal CDS spread in our sample, at approximately 180 bps – is 6 bps for the CT2014 CDS contract, and 8 bps for the CT2003 CDS contract, on average between 1 May 2018 and 9 October 2020.

[19] For example, Pan and Singleton (2008) argue that they cannot reliably identify CDS recovery values from a term structure of CDS spreads at low default risk premia, and apply their method to emerging markets (Mexico, Turkey, and Korea) for this reason. In our euro area sample, the maximally observed CDS spread is approximately 180 bps (for Italy, in Spring 2020).

[20] Kremens (2021) discusses two ways to "clean" the ISDA basis from effects potentially related to the APD clause. While we are sympathetic to such an attempt in principle, we see no obvious way to ascertain whether the procedure works reliably. We therefore proceed with using the raw ISDA basis, as e.g. in the speech by Visco (2018), but allowing for measurement errors associated with both the CT2003 and the CT2014 CDS spreads, and thus also with the ISDA basis.

Finally, using the ISDA basis to infer the redenomination risk premium is, arguably, superior to its two main alternatives. First, one alternative is to follow KNV's approach, when feasible. KNV rely on corporate bond yields and corporate CDS spreads. They argue that both the yield of euro-denominated local-law sovereign bonds and euro-denominated local-law corporate bonds of the same maturity should be equally affected by the risk of redenomination. A major limitation here is that the corporate bonds should be issued by a non-financial corporation for which the default risk is very low and, crucially, not linked to the default risk of the sovereign. Such bonds are difficult to find, and their yields are in any case subject to company-specific pricing effects. Similarly, euro-denominated single-name CDS referencing euro area non-financial corporations are rare and illiquid.

Second, the literature has proposed an alternative measure of country-specific euro area redenomination risk. De Santis (2019) measures redenomination risk based on the difference between a country's Quanto CDS spread and the Quanto CDS spread for Germany. Quanto CDS spreads are differences in CDS spreads associated with the same reference entity but denominated in different currencies (e.g., U.S. dollars and euro). We do not use this measure in our study, for two reasons. First, it would then be unclear whether measured redenomination risk moves because of developments in the country of interest, or in Germany. Second, the measure risks conflating states of the world with default scenarios that foresee and do not foresee debt redenomination. Quanto CDS spreads reflect the expected depreciation of the exchange rate in the event that CDSs are triggered (a sovereign default) and the covariance between the exchange rate and default risk (Augustin, Chernov, and Song (2020), Monfort, Pegoraro, Renne, and Roussellet (2020)).[21]

2.4.3 Liquidity risk premium

We extend the KNV framework by explicitly incorporating a liquidity risk premium. The liquidity risk premium is identified from a (scaled) country-specific liquidity risk factor. This factor is con-

[21]The ISDA basis based on U.S. dollars-denominated CDS spreads under ISDA CT2014 and CT2003 could also reflect a potential depreciation of the euro against the U.S. dollar in the event of a return to a national currency of the underlying sovereign reference entity. The alternative would be to compute the ISDA basis on euro-denominated CDS spreads. We prefer the ISDA basis obtained from CDS spreads denominated in U.S. dollars because of the higher market liquidity of the underlying CDS contracts. In any case, the difference between the U.S. dollars and euro-denominated ISDA basis is small in our sample: 2 bps for France on average, 1 bps for Germany, 10 bps for Italy, and 5 bps for Spain.

structed as the geometric average between *i*) a country- and market-segment-specific proprietary liquidity measure provided by Tradeweb markets, and *ii*) the ten-year KfW-Bund spread. Tradeweb liquidity indicators are commercially available and measure the point-in-time market illiquidity of a small basket of similar bonds relative to ten-year German sovereign bonds (see e.g. De Renzis, Guagliano, and Loiacono (2018), and Web Appendix E for time series data plots). Ten-year Bunds are considered the most liquid bond in the euro area, and are therefore a natural point of comparison. The KfW-Bund spread is a common measure of the price of liquidity risk (see e.g. ECB (2009) and Renne and Monfort (2014)). The liquidity risk premium is given by the country-specific liquidity risk factor times a deterministic parameter (β_3) to be estimated (see Section 2.2).

2.4.4 Final remarks

We conclude this section with two remarks. First, we do not seek to further disentangle each risk premium estimate into a quantity-of-risk and a price-of-risk subcomponent. Doing so would require additional identification assumptions, and may not be straightforward. Second, the risk premia could, in principle, be subject to a complicated nonlinear dependence structure. In that case the linear Gaussian state space model as presented in Section 2.2 would be misspecified. A fat-tailed multivariate density could then be used for η_t in Equation (3), for example, at the cost of a significantly increased computational burden. A mild nonlinear dependence among the state variables, however, should not materially affect our approach to in-sample signal extraction (see e.g. Durbin and Koopman (2001, Ch. 4.3)).

3 Data and event timeline

3.1 Data sources

Five-year sovereign benchmark bond yields for Germany (DE), France (FR), Italy (IT), and Spain (ES) are obtained from Bloomberg and Thomson Reuters. Bloomberg and Thomson Reuters data can differ at times in their assessment which bond (ISIN) is the relevant five-year benchmark bond to track. Including both data sources into our statistical model allows us to be robust to such differences.

Sovereign CDS spreads are obtained from Thomson Reuters between January 2015 and April 2018 and Credit Market Analysis (CMA) DataVision from May 2018 onwards. Thomson Reuters takes CDS spread quotes each day from several contributors and combines them into end-of-day data. CMA collects its data from a slightly larger consortium of hedge funds, asset managers, and major investment banks. Thus, we prefer the CMA data for our study at hand, but splice them with Thomson Reuters data for the earlier years for data availability reasons. CMA reports bid, ask, and mid quotes allowing us to cross-check the CDS market liquidity. The bid-ask spreads for five-year CDS contracts are typically below ten basis points, including during the Covid-19 pandemic recession in early 2020.

Our country-specific liquidity risk factors combine data from Tradeweb[22] and Bloomberg. We use the euro area sovereign Tradeweb liquidity indicators that use executed prices and volume data from the Tradeweb platform comparing the executed price to the mid price at security level. The distance from the mid price is used as a bond market liquidity measure: values further away from the mid price are seen as less liquid. A weighted liquidity measure for each security country and maturity bucket is provided by Tradeweb.[23] We use the bucket $2 - 5.5$ year bucket for France, Germany, Italy and Spain.

3.2 Euro area sovereign bond yields and event timeline

This section discusses the sovereign yields which we decompose into their respective risk premia below. We focus on Germany, France, Italy, and Spain because they constitute the four largest euro area countries, representing approximately 67% of euro area GDP in 2019. Our approach can be implemented for other euro area countries as well, provided full sets of data are available, including ISDA CT2014 and CT2003 CDS spreads.

Figure 1 plots our sample of five-year sovereign bond yields between 2 January 2015 and 9 October 2020. The figure suggests a salient downward trend for all countries. A potential contributor to this downward trend may have been purchases of euro area sovereign bonds within the ECB's PSPP

[22] See www.tradeweb.com.

[23] Each index is derived from the duration weighted yield (in basis points) difference from Tradeweb composite mid prices across all trades. The Germany $5.5 - 11.5$ year bucket is selected as the liquidity benchmark. This bucket is defined as 1 at the start of the index on 2 January 2008. On the same date a multiplier is calculated on all other bucket indexes to reflect their relative liquidity level.

that started in March 2015. Figure 1 also suggests that significant fluctuations in yields can occur as a result of political developments. For example, the Italian yield displays a pronounced spike in mid-2018. The spike coincides with two euro-skeptical parties, Lega and Movimento Cinque Stelle, first forming a coalition and ultimately a government. Italian yields declined in September 2019 when the populist government ended, but have remained higher than those of Germany, France, and Spain since then. We return to this issue when discussing redenomination risk premia (see Section 4 below).

The severity of the economic and financial implications from the Covid-19 pandemic has become increasingly apparent since February 2020 (see the right panel of Figure 1). Since late April 2020, however, all sovereign yields have stabilized and resumed their gradual downward trend.

The right panel of Figure 1 contains vertical lines indicating key monetary and fiscal policy announcements in the euro area. Section 4.4 studies the impact of these announcements in detail. We do not consider announcements by other central banks, or other fiscal policy makers, as these were probably less important for euro area sovereign yields at the time.[24]

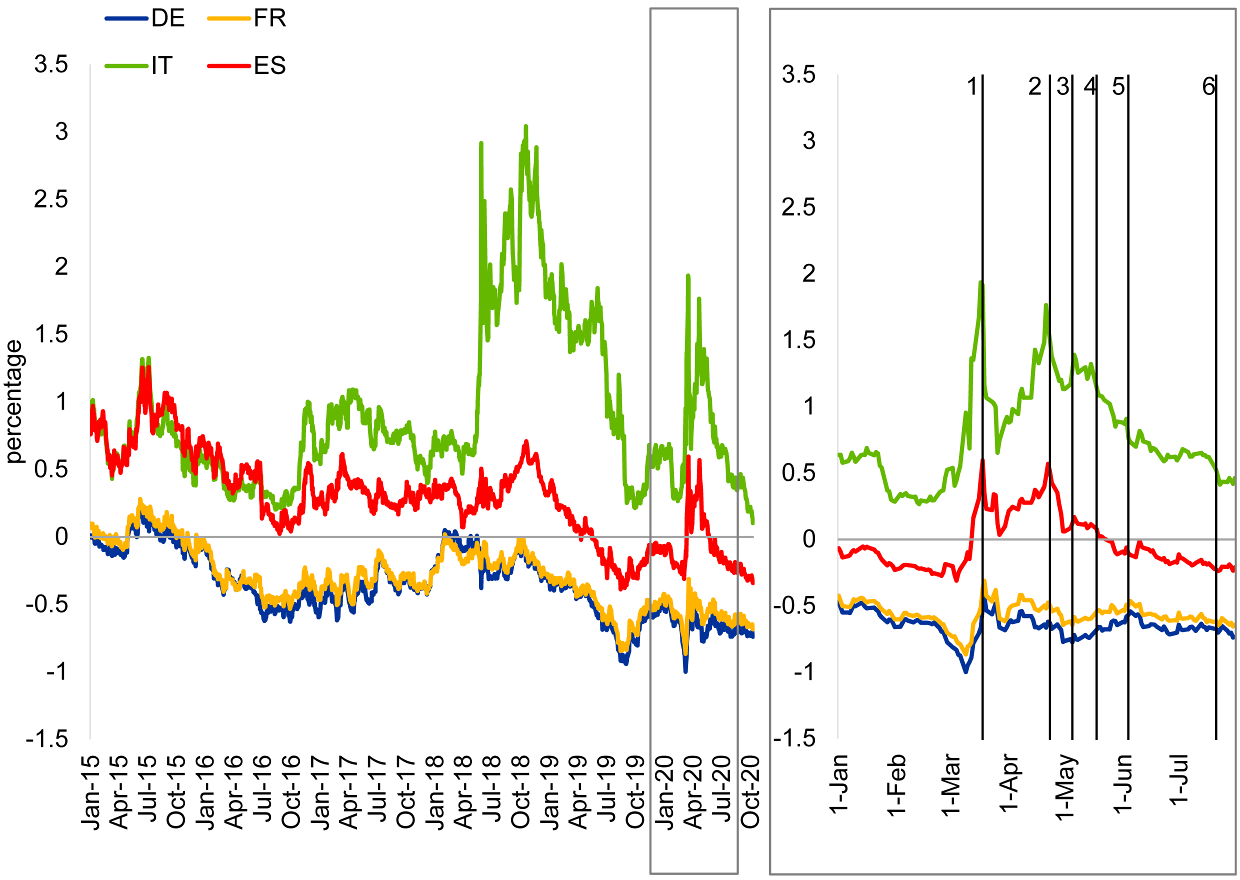
The outbreak of Covid-19 caused asymmetric responses across sovereign yields. Sovereign yields started to diverge in February 2020, mainly driven by Italian and Spanish yields. Italian yields more than doubled in the month preceding 18 March 2020. To improve the economic and inflation outlook, and to stabilize markets, the ECB announced its PEPP on 18 March 2020 (first line). On 5 May 2020 (third line), the German Federal Constitutional Court ruled on the compatibility of the ECB's earlier PSPP (not PEPP) with German constitutional law. The ruling was interpreted at the time to possibly constrain the ECB's latitude regarding future sovereign bond purchases, and could be interpreted as a contractionary unconventional monetary policy shock. On 4 June 2020 (fifth line), the ECB decided to increase the PEPP envelope by €600 bn to a total of €1,350 bn.[25]

[24] Hartley and Rebucci (2020) provide international evidence of QE announcements made by 21 central banks on local sovereign bond yields and bilateral U.S. dollar exchange rates in March and April 2020. Using an event study approach, they find that the Fed's policies may have affected international (mostly emerging markets') yields and played an important role in addressing the global dollar shortage triggered by the outbreak of Covid-19. Individual countries' QE announcements contributed significantly to stabilizing local yields even after controlling for the Fed's and other central banks' announcements.

[25] We leave aside the ECB's Governing Council decision on 12 March 2020 because this announcement did not mention PEPP. Web Appendix F studies the ECB's decisions on 7 and 22 April 2020 to temporarily relax its collateral requirements.

Figure 1: Sovereign bond yields and major policy events

Yields-to-maturity of five-year sovereign benchmark bonds for France (FR), Germany (DE), Italy (IT) and Spain (ES). Data are daily between 2 January 2015 and 9 October 2020. The right panel magnifies the period between 31 January 2020 and 31 July 2020. Vertical time lines indicate the following policy announcements. 1) On 18 March 2020 the ECB announced its Pandemic Emergency Purchase Programme (PEPP); 2) on 23 April 2020 the EU announced a recovery package worth €540 bn; 3) on 5 May 2020 the German Federal Constitutional Court addressed the compatibility of the Public Sector Asset Purchase Program (PSPP) launched by the ECB in March 2015 with German constitutional law; 4) on 18 May 2020 German Chancellor Angela Merkel and French President Emmanuel Macron announced their joint proposal for a €500 bn European recovery fund; 5) on 4 June 2020 the ECB announced the expansion of the PEPP from €750 bn to €1,350 bn; and 6) on 21 July 2020 EU leaders reached an agreement on details regarding its NGEU program.



In April 2020, a common fiscal policy response to the Covid-19 pandemic recession was initiated by EU heads of state to complement the ECB's strongly accommodative monetary policy. On 23 April 2020 (second line), EU leaders agreed to assemble a €540 bn recovery package, comprising three support measures, which would later evolve into the EU's temporary program to mitigate unemployment risks (SURE), a loan guarantee scheme by the European Investment Bank, and a credit line to governments from the European Stability Mechanism. The announcement also called for an EU recovery fund of “sufficient magnitude” that was “needed and urgent”. On 18 May 2020 (fourth line), the German chancellor Angela Merkel and French president Emmanuel Macron announced their joint proposal for a €500 bn EU recovery fund, in line with the 23 April announcement. On 21 July 2020 (sixth line), EU heads of state reached an agreement on the technical details of their new NGEU initiative, embedding the EU recovery fund into an even larger, €750 bn “resilience and recovery” plan.

4 Empirical results

Our empirical study is structured around five interrelated questions. Which underlying risk premia explain the bulk of the observed variation in euro area sovereign bond yields? How do these premia vary across countries and time? Which risk premia explain the observed divergence of sovereign yields at the onset of the Covid-19 pandemic recession? How successful were monetary and fiscal policy announcements in stabilizing yields in the first half of 2020? Finally, which channels explain most of the policy announcements' impacts?

4.1 Model specification and parameter estimates

This section discusses model choice and the resulting parameter estimates. We first discuss parameter restrictions that we use when fitting the statistical model proposed in Section 2.2 to the data discussed in Section 3 and Web Appendix E. We then turn to the parameter estimates.

We chose the loading coefficients $\beta_1 = \beta_2 = 1$ following our discussion in Section 2.4 and in line with preliminary data analyses. This implies that the default risk premium is approximately equal to the CDS EUR CT2003 rate, and that the redenomination premium is approximately equal to the ISDA basis between the CT2014 and CT2003 CDS spreads (see Section 2.4 for details). The equality is approximate since all yields and CDS spreads can be subject to measurement error. Second, we chose $\gamma_1 = \gamma_2$, implying that the yield data obtained from Bloomberg and Thomson/Reuters are equally informative. This implies that the model seeks to fit the midpoint between the two yield measurements, facilitating the economic interpretation of the estimation outcomes. We then set $\gamma_3 = 0$, implying that the first euro-area-wide component (the expected future short-term risk-free rates and term premium) is numerically identical for all countries. Finally, we chose $\gamma_4 = \gamma_5 = \gamma_6 = \gamma_7 = 4$ bps. These choices are approximately in line with the observed bid-ask spreads for CDS spreads and for German KfW bonds, but the exact calibration is immaterial, as other choices yield similar risk premium estimates.[26] The off-diagonal elements of the state error correlation matrix C are not restricted in our baseline specification. This allows the innovation terms to all risk premia ($\Delta\alpha_{t+1} = \eta_t$ in Equation (3)) to be mutually correlated. Using this specification, we combine model parsimony with the ability to study the impact of a rich set of monetary and fiscal policy announcements on sovereign yields empirically given all the financial data at hand.

We now discuss our parameter estimates. All estimates discussed below are statistically significant at the 5% level.

The state error standard deviation parameters δ indicate how volatile each risk premium component is. The δ parameters are estimated to be, in ascending order, 0.8 bps (for the liquidity risk premium), 1.0 bps (redenomination risk premium), 1.8 bps (segmentation premium), 1.9 bps (default risk premium), and 2.1 bps (expected future short-term risk free rates and term premium), all estimated with small standard errors (below 1 bps), suggesting pronounced time series variation for all risk premia.[27] The yield measurement error standard deviation parameter γ_1 is estimated at 3.6 bps, implying a moderate-to-small role for the noise term in (1). The loading on the country-specific liquidity risk factor (β_3) is estimated at approximately 0.25, implying country-specific liquidity risk premium estimates ($\hat{\beta}_3 \times \hat{\alpha}_{6,t}$) that are, on average over time, similar to those reported in Renne and Monfort (2014) and De Pooter, Martin, and Pruitt (2018).

Likelihood-based information criteria (AIC, BIC) prefer a full specification of the state covariance matrix Q over a more parsimonious diagonal specification.[28] Seven statistically significant correlation estimates in C point to, in descending absolute magnitude, a correlation between the

[26]The empirical results discussed in Sections 4.2 – 4.4 remain virtually identical if, say, $\gamma_4 = \gamma_5 = \gamma_6 = \gamma_7 = 8$ bps is chosen instead. If estimated, these measurement error variance parameters converge to zero, increasing the noise in the two residual terms (the segmentation premium and the one-off effects), which may be unwelcome; there are no material effects on the other parameters.

[27]If $\delta_i = 0$, then the corresponding risk premium would be constant; see (3). Standard t- and LR-tests are not appropriate for these parameters (Andrews and Ploberger (1994)), but likelihood-based information criteria (AIC, BIC) strongly prefer a model specification with $\delta > 0$.

[28]On the other hand, imposing a diagonal Q is of little consequence for the empirical results as discussed in Sections 4.2 – 4.4, given that most measurement errors are small (in the single digit basis points) and each country's state vector is thus almost fully observed.

innovations to the default and redenomination risk premium (0.58), redenomination and liquidity risk premium (0.27), default and liquidity risk premium (0.23), redenomination risk premium and segmentation premium (-0.21), expected rates and redenomination risk premium (-0.14), expected rates and default risk premium (-0.13), and expected rates and liquidity risk premium (-0.09). Overall, the moderate-to-small magnitudes, and intuitive signs, of the correlation estimates suggest that each risk premium captures a distinct source of economic risk.

4.2 Risk premia before the Covid-19 pandemic

This section discusses longer-term developments in euro area sovereign yields, with a focus on which underlying premia explain most of the observed variation. We first discuss the variation in risk premia across countries and over time. We then turn to discussing redenomination risk and segmentation premia in more detail.

Figures 2 – 3 plot five-year sovereign bond yields for Italy, Spain, France, and Germany, along with full-sample and country-specific estimates of the default, redenomination, liquidity risk premium and segmentation premium. Table 1 provides summary statistics (sample means and standard deviations) for all five risk premium estimates. Our empirical results are presented and discussed in the order that each country's yields were negatively affected by the Covid-19 pandemic (Italy first, Germany last).

All five above-mentioned risk premia are economically important (in the sense that their magnitude is in the double-digit basis points; with liquidity risk premia being the least economically important by that standard). Their relative importance, however, varies considerably over time and across countries. As a key finding, default and redenomination risk premia explain the bulk of variation in Italian and Spanish yields, but are less important for French and German yields. This is immediately visible: the predominant colors in Figure 2 are red and brown (for default and redenomination risk premia), while the predominant colors in Figure 3 are green and beige (for expected future short-term risk-free rates and term premium, and the segmentation premium). Figure 2 suggests that default and redenomination risk premia are the main drivers of Italian bond yields during our sample. This is intuitive, given a relatively high level of outstanding sovereign debt (at approximately 138% of GDP at the end of 2019, compared to approximately 86% for the euro area), and a relatively low average annual nominal GDP growth rate (of 1.1% between 2010 and 2019, compared to 2.4% for the euro area over the same period). This finding is also in line with the evidence provided by KNV that Italian yields can be explained to a large extent by default and redenomination risk premia (although their study covers a different period, January 2010 to January 2013). Liquidity risk premia are estimated to be minor for most yields, and rarely exceed 5 bps between 2015 and 2019; see Table 1. Liquidity risk premia are lowest on average in Germany, and highest in Italy, with France and Spain as intermediate cases. This is in line with Renne and Monfort (2014) and De Pooter, Martin, and Pruitt (2018). Finally, all countries exhibit an economically significant negative segmentation premium.

Continuing with Figure 2 and Italian yields, significant fluctuations can occur in redenomination risk premia as a result of domestic political developments. Specifically, the redenomination risk premium displays a pronounced spike in mid-2018, ultimately reaching values of approximately 90 bps. The upward jump coincides with the start of a coalition government between the Lega and Movimento Cinque Stelle (Balduzzi, Brancati, Brianti, and Schiantarelli (2020)). This coalition government was widely perceived as in contempt of the European Stability and Growth Pact and fundamentally euro-sceptical. In mid-2018 the redenomination risk premium accounts for approximately one third of the Italian five-year yield.

The bottom panel of Figure 2 suggests that, overall, Spanish yields share common dynamics with Italian yields, in the sense that both tend to rise and fall together. Time-variation in the redenomination risk premium, however, plays a less pronounced role for Spanish yields than for Italian yields.

Variation in the redenomination risk premium is not only relevant for Italian yields. The French redenomination risk premium became economically significant in early 2017 when the candidate of Front National, Marine Le Pen, featured highly in the polls for the French presidential election (see the top panel of Figure 3, and also Kremens (2021) for a discussion). The French redenomination risk premium increased to approximately 30 bps in the run-up to the May 2017 election, accounting for approximately one third of French yields at the time. By contrast, redenomination risk premia are minor for German yields during our sample. German yields are almost completely explained by variation in the OIS EUR rate and the segmentation premium.

Figures 2 - 3 and Table 1 suggest that euro area sovereign bond yields contain a substantial and negative segmentation (convenience) premium. The German segmentation premium is the most negative, at approximately -36 bps on average over the full sample. This suggests that the German sovereign bond is the most highly sought-after bond in our sample, and the de-facto safe asset benchmark. Interestingly, German, French, and Italian convenience yields were similar between 2015 and 2019 before the onset of the Covid-19 pandemic (after accounting for term, default, redenomination, and liquidity risk premia), before diverging to some extent during the pandemic recession. This is in line with the ECB's PSPP, as announced on 15 January 2015, acquiring these bonds in approximately similar amounts (in accordance with the ECB's capital key, see our discussion in Section 4.4 below), and with their symmetric treatment in the ECB's collateral framework and banking sector liquidity regulation.

In our framework, a consistently negative segmentation premium means that investors are willing to accept a lower return from sovereign bonds compared to holding an alternative position that has the same (or similar) payoffs. In particular, investors prefer sovereign bonds over a long position in the five-year OIS contract and a short position in a CDS contract that protects against default and redenomination risk.[29]

The segmentation premium is possibly made more negative by the ECB purchasing substantial fractions of outstanding sovereign debt within its PSPP since March 2015. As discussed in Corradin and Maddaloni (2020), the central bank is a buy-and-hold investor and effectively decreases asset supply over time because the purchased asset becomes locked away in its portfolio.[30] If the ECB lends only a marginal fraction of the purchased bonds back to the market through repurchase transactions, then individual bonds can become scarce and more valuable for the bond holders. As a result, the bond price increases and the yield decreases. The impact of central bank purchases on bond prices is even larger when bond markets are also segmented (see e.g. Gromb and Vayanos (2002), Duffie (2010)), implying that the central bank purchases are absorbed by a group of market

[29]The extent to which investors value the non-pecuniary benefits of bonds is usually referred to as a convenience yield; see, for example, Krishnamurthy and Vissing-Jorgensen (2012). Del Negro, Giannone, Giannoni, and Tambalotti (2017, 2018) provide convenience yield estimates for U.S. Treasuries.

[30]Corradin and Maddaloni (2020) extend the search-based dynamic model by Vayanos and Weill (2008) in which assets with identical cash flows can trade at different prices in spot and repo markets by introducing the central bank as a key player. Our argument is also in line with standard reasoning on the transmission channels of quantitative easing (see e.g. Eser, Lemke, Nyholm, Radde, and Vladu (2019) and Bernanke (2020) and the references therein).

participants because other investors are not active in the same market. This causes the segmentation premium to become even more negative. Euro area sovereign bond markets were arguably well-integrated prior to the global financial crisis (see e.g. Pagano and Von Thadden (2004)), but saw a substantial re-fragmentation during the euro area sovereign debt crisis, leading to a persistent increase in investor home bias (see Ehrmann and Fratzscher (2017) and Koijen, Koulischer, Nguyen, and Yogo (2021)).

4.3 Risk premia during the Covid-19 pandemic

This section discusses our risk premium estimates since the onset of the Covid-19 pandemic in early 2020. To this end we focus on the right panels of Figures 2 and 3. The right panels magnify the six months between 31 January and 31 July 2020. On 30 January 2020, the World Health Organization declared that the Covid-19 outbreak constitutes a "public health emergency of international concern," sometimes also referred to as a pandemic.

Italian and Spanish sovereign yields started to increase at the end of February 2020, while German and French yields increased by much less. The increase in yields was most notable for Italy, where yield rose from 0.37% to 1.96% just before the ECB's PEPP announcement on 18 March 2020. The increase is mainly attributed to the default and redenomination risk premium, which both increased during the Covid-19 pandemic. The Italian default risk premium increased by 110 bps. The Italian redenomination risk premium increased by 29 bps, but remained lower than what was observed in 2018. The Italian liquidity risk premium was economically small between 2015 and 2019, but became more important during the early phase of the Covid-19 pandemic at approximately 15 bps before 18 March 2020.

Figure 2: Yield decomposition results for Italy (top) and Spain (bottom)

Yield decomposition results for Italian and Spanish five-year sovereign benchmark bonds. Data are daily between 2 January 2015 and 9 October 2020. The right panel magnifies the period between 31 January and 31 July 2020. The rightmost bars visualize the relative importance of each risk premium between 31 January and 31 July 2020. The reported percentages refer to the share of each component in the sum over (the absolute value of) all risk premia, averaged over all trading days between 31 January and 31 July 2020.

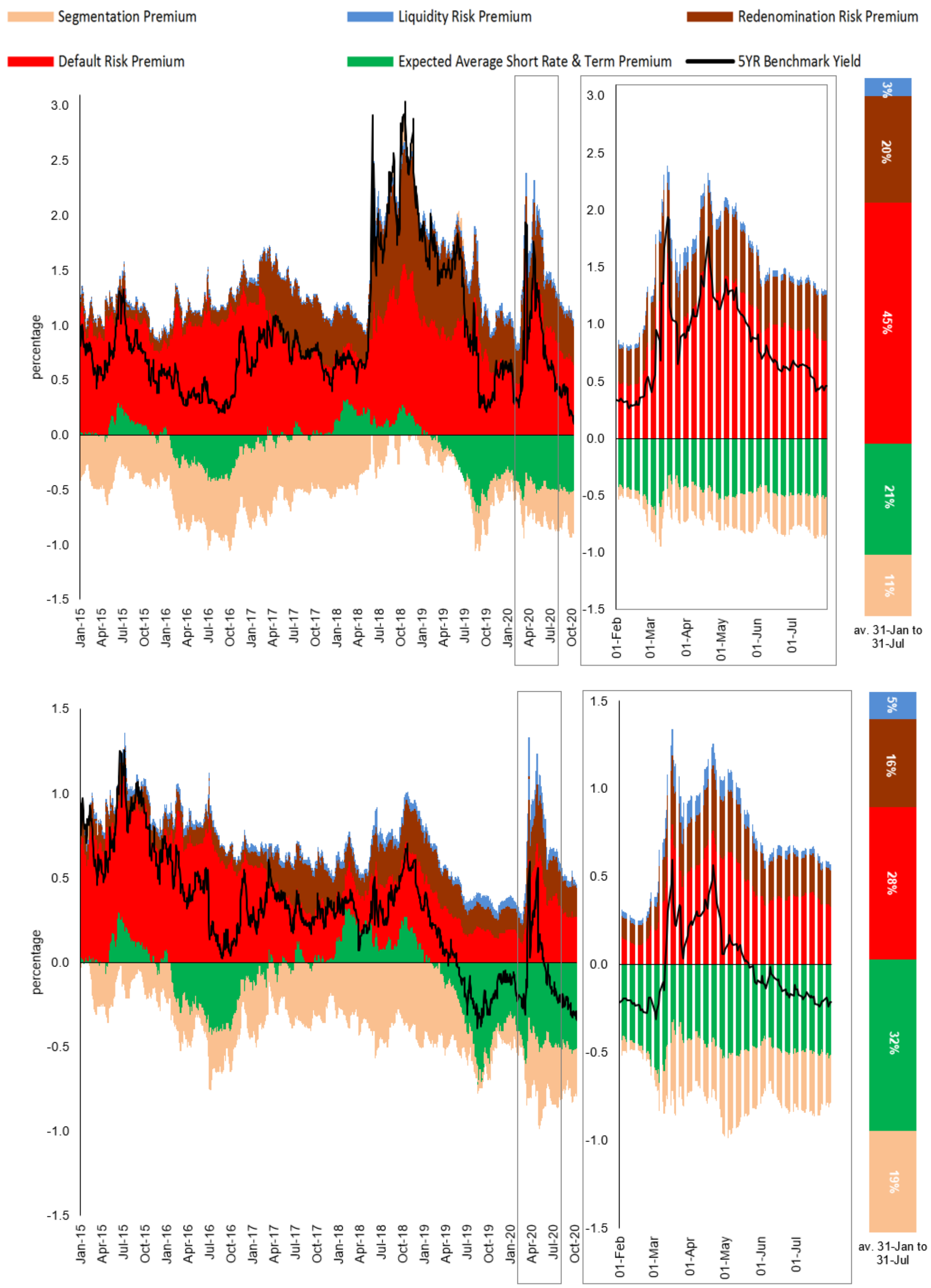


Figure 3: Yield decomposition results for France (top) and Germany (bottom)

Yield decomposition results for French and German five-year sovereign benchmark bonds. Data are daily between 2 January 2015 and 9 October 2020. The right panel magnifies the period between 31 January and 31 July 2020. The rightmost bars visualize the relative importance of each risk premium between 31 January and 31 July 2020. The reported percentages refer to the share of each component in the sum over (the absolute value of) all risk premia, averaged over all trading days between 31 January and 31 July 2020.

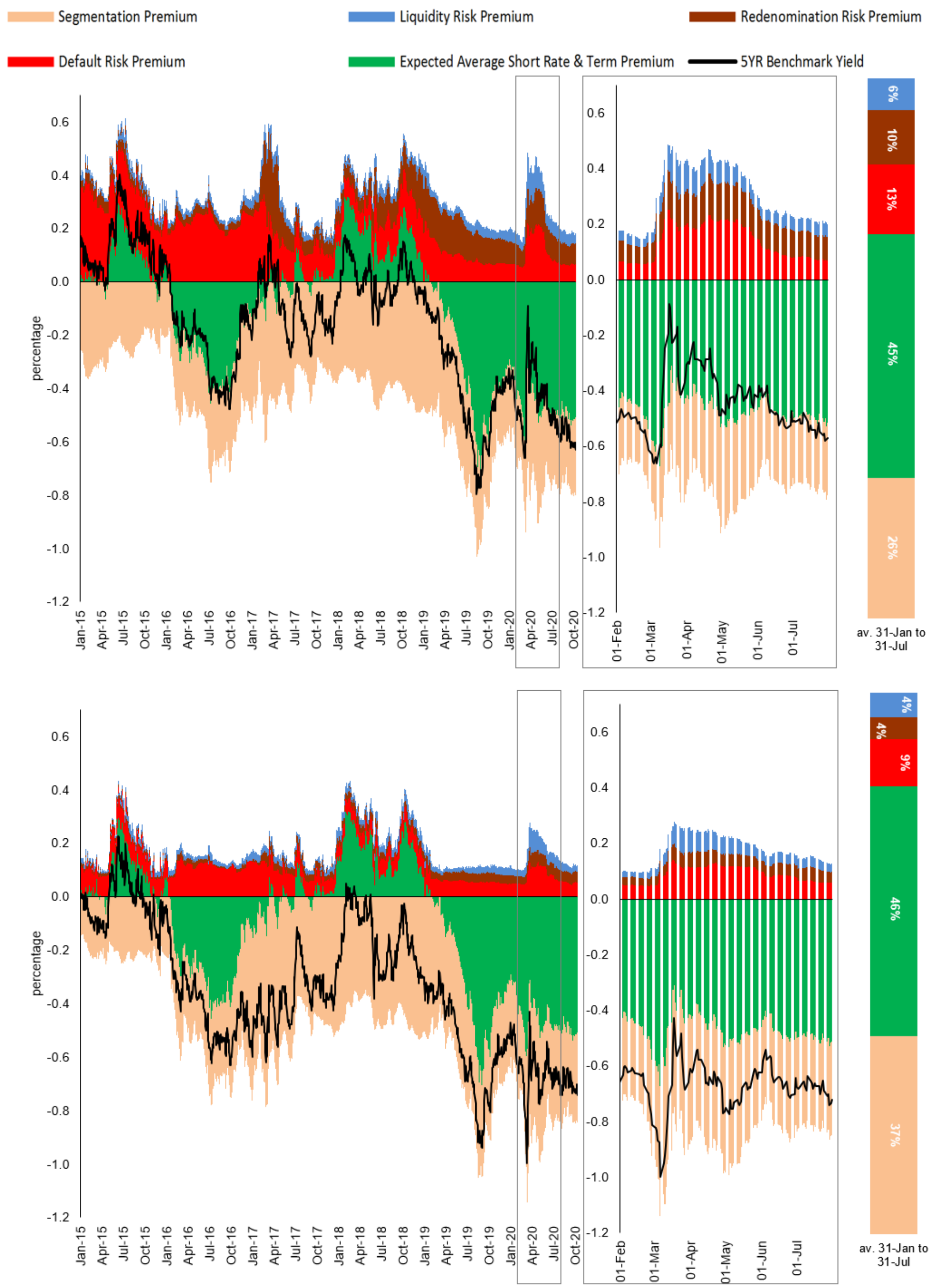


Table 1: Bond premia descriptive statistics

Sample means (first row) and standard deviations (second row, in brackets) associated with risk premium estimates as reported in Figures 2 and 3. Entries are in percentage points. The pre-Covid-19 sample ranges from 1 January 2015 to 30 January 2020. The Covid-19 sample refers to the zoomed-in period between 31 January 2020 and 31 July 2020. The final column refers to the complete sample from 1 January 2015 to 9 October 2020. The first component (expected future short-term risk-free rates and term premium) is identical across countries, and therefore only reported once.

	Pre-Covid-19	Covid-19	Full Sample
Italy			
$\mathbb{E}$[short rate] & term premium	-0.065	-0.472	-0.115
	(0.231)	(0.056)	(0.256)
Default risk premium	0.920	1.030	0.923
	(0.219)	(0.299)	(0.229)
Redenomination risk premium	0.396	0.452	0.401
	(0.289)	(0.088)	(0.273)
Liquidity risk premium	0.029	0.077	0.033
	(0.019)	(0.042)	(0.026)
Segmentation premium	-0.357	-0.261	-0.348
	(0.202)	(0.082)	(0.193)
Spain			
Default risk premium	0.470	0.421	0.460
	(0.215)	(0.176)	(0.211)
Redenomination risk premium	0.150	0.243	0.159
	(0.063)	(0.077)	(0.068)
Liquidity risk premium	0.030	0.075	0.034
	(0.013)	(0.040)	(0.021)
Segmentation premium	-0.239	-0.280	-0.243
	(0.124)	(0.121)	(0.122)
France			
Default risk premium	0.164	0.135	0.158
	(0.075)	(0.063)	(0.076)
Redenomination risk premium	0.074	0.105	0.077
	(0.055)	(0.024)	(0.053)
Liquidity risk premium	0.022	0.061	0.026
	(0.009)	(0.025)	(0.016)
Segmentation premium	-0.315	-0.272	-0.309
	(0.086)	(0.045)	(0.083)
Germany			
Default risk premium	0.077	0.089	0.077
	(0.026)	(0.029)	(0.027)
Redenomination risk premium	0.021	0.042	0.024
	(0.010)	(0.009)	(0.012)
Liquidity risk premium	0.017	0.046	0.020
	(0.006)	(0.020)	(0.012)
Segmentation premium	-0.360	-0.374	-0.360
	(0.119)	(0.064)	(0.113)

The right-hand-side bars in Figures 2 and 3 indicate the relative importance of each risk premium between 31 January and 31 July 2020. The percentages refer to the share of each component in the sum over the absolute values of all components, subsequently averaged over all trading days between 31 January and 31 July 2020. (For each components' magnitudes in basis points, see Table 1.) Between 31 January and 31 July 2020 the default risk premium accounts for 45% of the Italian "yield" (total), and for 28% of the Spanish "yield." The redenomination risk premium accounts for 20% of the Italian "yield" (total), and for 16% of the Spanish "yield." Both default and redenomination risk were thus dominant risk premia for these countries following the outbreak of the Covid-19 pandemic.

The right-hand-side bars in Figure 3 suggest that default, redenomination, and liquidity risk premia continued to play a minor role for French and German yields between 31 January and 31 July 2020. Instead, French and German yields are mostly explained by expected future short-term risk-free rates and a term premium (45% and 46% of total), and a segmentation premium (26% and 37% of total).

4.4 Event study results

The extracted yield premia can be studied further based on event study regressions that allow us to disentangle the channels through which ECB monetary policy and EU fiscal policy announcements affected sovereign yields. We estimate the regression specification

$$\Delta r_t^c = \kappa_0^c + \kappa_1^{c\prime}\,\mathrm{D}_t + u_t^c, \tag{4}$$

where Δr_t^c is the daily change in the five-year yield (or, alternatively, the daily change in a certain yield component) associated with country c at time t, D_t is a vector of dummy variables associated with certain ECB monetary policy and EU fiscal policy announcements, κ_0^c and κ_1^c are a constant and slope parameters to be estimated, and u_t^c is the usual regression error term. The impact coefficient κ_1^c measures the surprise component in each announcement.[31] We estimate the parameters in

[31] The dummy variables in D_t are set to 0.5 on the event day and the following day, in line with the two-day event window approach of KNV. As a result, the least squares estimate of $\kappa_{\cdot}$ is approximately equal (not exactly equal, owing to the constant) to the sum of the two observations following the respective event day.

(4) by simple least squares, and report Newey and West (1987) standard errors.[32] Our event study regression results are reported in Table 2, distinguishing between monetary policy (top rows in each country panel) and fiscal policy announcements (bottom rows). We first discuss the monetary policy-related announcements, and then turn to the fiscal policy-related announcements.

4.4.1 Monetary policy announcements

This section focuses on the ECB's PEPP-related unconventional monetary policy announcements. All announcements in this section are expansionary (with the exception of the 5 May 2020), pointing to a later increase in the size of the Eurosystem's consolidated balance sheet. Such announcements could be expected to decrease term premia (Eser et al. (2019)), possibly decrease credit-related premia (Calvo (1988); Eser and Schwaab (2016)), decrease liquidity risk premia (De Pooter et al. (2018)), and possibly decrease segmentation premia as well (Corradin and Maddaloni (2020)).

Table 2 suggests that the ECB's PEPP announcements on 18 March 2020 led to a large reduction in Italian yields, to a moderate reduction in Spanish yields, and to an increase in French and German yields. On 18 March 2020, Italian yields first reached 196 bps and then decreased by 78 bps over the next two days. Our statistical model attributes this decrease to a lower default risk premium (by 35 bps), redenomination risk premium (by 14 bps), and segmentation premium (by 16 bps). Spanish yields decreased by 11 bps, brought about by a lower segmentation premium (by 10 bps). French and German yields increased by 10 bps and 24 bps, respectively. Our model assigns the increase in French and German yields to higher than expected future short-term risk-free (monetary policy) rates and term premium. Most probably, market participants had expected a cut in the ECB's deposit facility rate to counteract the effects of the Covid-19 pandemic, which did not happen. Instead, additional bond purchases became the instrument of choice.[33]

[32] Estimating the parameters by seemingly unrelated regression instead would not lead to more efficient estimates because the right-hand-side variables would then be common across countries; see e.g. Greene (2003, Chapter 14) for a discussion.

[33] Around 18 March, the U.S. Federal Reserve bought a substantial amount of U.S. Treasury bonds to support Treasury bond market functioning; see e.g. He et al. (2021). In principle, these purchases could have affected euro area sovereign yields as well. We would not expect these spillovers to be large, however, as, to our knowledge, the Federal Reserve did not buy any euro-denominated bonds at the time, and markets can become less tightly integrated across borders in times of stress (Ehrmann and Fratzscher (2017) and Koijen, Koulischer, Nguyen, and Yogo (2021)).

Table 2: Event study parameter estimates

Impact estimates from the event study regression (4). The event dates are given in Section 3.2 (see also Figure 1). We consider two-day event windows. P-values are based on Newey and West (1987) HAC standard errors with a one lag bandwidth.

	(1) 5Y bond yield	(2) Short rate & term premium	(3) Default risk premium	(4) Redenomination risk premium	(5) Liquidity risk premium	(6) Segmentation premium
Italy						
Monetary policy						
18-Mar-20	-77.59**	13.29***	-34.64***	-14.21***	2.51***	-16.47***
	(36.60)	(5.10)	(12.92)	(5.07)	(0.11)	(4.16)
5-May-20	22.39***	2.68	9.62***	2.91***	-0.61*	2.88***
	(0.42)	(1.90)	(1.99)	(0.90)	(0.34)	(0.26)
4-Jun-20	-17.36***	3.38***	-18.31***	-6.25***	-0.27**	2.55***
	(5.85)	(0.37)	(0.69)	(0.20)	(0.11)	(0.86)
EU fiscal policy						
23-Apr-20	-22.62***	-5.23***	-13.55***	-3.43***	-0.59**	-1.65***
	(1.80)	(1.55)	(1.23)	(0.31)	(0.28)	(0.36)
18-May-20	-23.42***	2.38***	-11.70***	-4.76***	-0.17	-4.91***
	(6.07)	(0.86)	(0.46)	(0.09)	(0.13)	(0.79)
21-Jul-20	-7.80***	-2.03***	-2.50***	-0.27**	0.16***	-2.91***
	(1.27)	(0.12)	(0.41)	(0.11)	(0.03)	(0.12)
Spain						
Monetary policy						
18-Mar-20	-10.60	13.29***	-3.60	-5.35	0.49**	-9.51***
	(19.27)	(5.10)	(10.01)	(3.52)	(0.24)	(1.46)
5-May-20	8.47***	2.68	2.11	0.64	-0.69	1.02
	(0.54)	(1.90)	(1.46)	(0.80)	(0.50)	(0.64)
4-Jun-20	-5.45***	3.38***	-5.19***	-3.27***	-0.62***	1.24***
	(1.67)	(0.37)	(0.12)	(0.05)	(0.01)	(0.28)
EU fiscal policy						
23-Apr-20	-14.11***	-5.23***	-7.41***	-1.22***	-0.19***	-0.66
	(1.48)	(1.55)	(0.54)	(0.10)	(0.02)	(0.49)
18-May-20	-9.40***	2.38***	-8.42***	-2.91***	-0.60***	0.77***
	(1.09)	(0.86)	(0.52)	(0.25)	(0.05)	(0.14)
21-Jul-20	-1.64***	-2.03***	-2.70***	-0.77***	-0.17	2.59***
	(0.28)	(0.12)	(0.15)	(0.19)	(0.23)	(0.18)
France						
Monetary policy						
18-Mar-20	9.52	13.29***	-2.90**	-1.32***	1.18***	-2.36***
	(5.89)	(5.10)	(1.44)	(0.23)	(0.31)	(0.68)
5-May-20	5.41	2.68	-0.16	-0.01	-0.53	1.85**
	(4.66)	(1.90)	(0.10)	(0.20)	(0.36)	(0.84)
4-Jun-20	-0.99	3.38***	-2.32***	-0.89**	0.08	-0.17
	(1.91)	(0.37)	(0.38)	(0.38)	(0.40)	(0.40)
EU fiscal policy						
23-Apr-20	-10.81***	-5.23***	-1.66***	-1.03***	-0.83***	-0.85
	(0.67)	(1.55)	(0.63)	(0.14)	(0.22)	(0.61)
18-May-20	2.11	2.38***	-1.65**	-0.54***	-0.54***	1.25***
	(1.90)	(0.86)	(0.68)	(0.16)	(0.11)	(0.34)
21-Jul-20	-2.90*	-2.03***	-0.51**	-0.38**	-0.18	0.32
	(1.51)	(0.12)	(0.24)	(0.17)	(0.26)	(0.54)
Germany						
Monetary policy						
18-Mar-20	24.18***	13.29***	0.29	0.94***	2.01***	2.49***
	(3.02)	(5.10)	(0.56)	(0.10)	(0.36)	(0.38)
5-May-20	3.25	2.68	-0.07	-0.22	-0.54**	0.63
	(3.83)	(1.90)	(0.08)	(0.16)	(0.23)	(0.53)
4-Jun-20	3.90***	3.38***	-1.48***	-0.12	-0.18*	1.29***
	(0.77)	(0.37)	(0.33)	(0.15)	(0.09)	(0.11)
EU fiscal policy						
23-Apr-20	-5.31***	-5.23***	0.09***	-0.10***	-0.52***	1.27***
	(1.76)	(1.55)	(0.03)	(0.02)	(0.09)	(0.18)
18-May-20	6.96***	2.38***	-0.10	-0.03**	-0.34***	2.54***
	(1.33)	(0.86)	(0.14)	(0.01)	(0.09)	(0.25)
21-Jul-20	-2.90**	-2.03***	-0.27***	-0.29***	-0.28***	0.34
	(1.36)	(0.12)	(0.01)	(0.02)	(0.04)	(0.25)

The asymmetric impact on yields (ES and IT down, DE and FR up) may be attributable to the unprecedented flexibility of the PEPP. The press release from the ECB stated that *"For the purchases of public sector securities, the benchmark allocation across jurisdictions will continue to be the capital key of the national central banks. At the same time, purchases under the new PEPP will be conducted in a flexible manner. This allows for fluctuations in the distribution of purchase flows over time, across asset classes and among jurisdictions."*[34] As a result, within the PEPP, the ECB can deviate from the country-limits set by the ECB's capital key that had guided the cross-country allocation of purchases under the PSPP. This means that the ECB is allowed to overweight, at least temporarily, certain sovereign bonds relative to others in its purchases. In addition, the PEPP framework grants the ECB additional latitude regarding the pace of the purchases over time, as well as regarding which asset classes are acquired (e.g., sovereign bonds vs. corporate bonds). Finally, there are no a-priori purchase limits within the PEPP framework. Such purchase limits apply to the PSPP, where they are aimed at avoiding that the ECB becomes a predominant creditor of euro area countries.[35]

Previous ECB asset purchase programs, including the PSPP, did not have the PEPP's flexibility. Web Appendix F presents event study results for the ECB's initial announcement of its PSPP on 15 January 2015. This announcement led to a symmetric reduction in all four countries' yields. The reductions were primarily brought about by lower expected future short-term risk-free rates and term premium, as well as lower default risk premia for Italy and Spain. The symmetry of the yield responses on 15 January 2015 is thus in contrast to the asymmetry of yield responses observed on 18 March 2020 (and 4 June 2020).

On 4 June 2020, the PEPP's total envelope was extended by €600 bn to €1,350 bn. Table 2 suggests that the PEPP extension led to a further reduction in Italian and Spanish yields, to no significant change in French yields, and to an increase in German yields. Italian yields decreased by an additional 17 bps. Our statistical model attributes this decrease mainly to a lower default risk premium (by 18 bps) and redenomination risk premium (by 6 bps). Spanish yields decreased by 5

[34] See ECB press release on 18 March 2020 https://www.ecb.europa.eu/press/pr/date/2020/html/ecb.pr200318_1~3949d6f266.en.html.

[35] So-called issuer limits refer to the maximum share of an issuer's outstanding debt securities that the Eurosystem may buy. Issue limits refer to the maximum share of a single PSPP-eligible security that the Eurosystem may hold. Within the PSPP, the Eurosystem can buy only up to 33% of a country's outstanding securities (issuer limit) and up to 33% of any particular bond series as identified by its ISIN code (issue limit).

bps, mainly owing to a lower default risk premium (by 5 bps) and redenomination risk premium (by 3 bps).

On 5 May 2020, the German Federal Constitutional Court (GFCC) ruled on the compatibility of the ECB's PSPP with German constitutional law. The ruling was interpreted at the time to potentially constrain the ECB's latitude regarding future sovereign bond purchases, and is thus similar to a contractionary unconventional monetary policy shock. The GFCC's ruling led to a substantial increase in Italian and Spanish yields by 22 and 8 bps respectively. The increase in French and German yields (by 5 and 3 bps) is less pronounced and not statistically significant. Our statistical model attributes the increase in Italian yield to an increased default risk premium (by 10 bps), redenomination risk premium (by 3 bps), and segmentation premium (by 3 bps). The increase in Spanish yield is assigned to the same channels, which, however, are not statistically significant in this instance.

4.4.2 Fiscal policy announcements

We now turn to our EU fiscal policy announcements. All fiscal announcements studied below are expansionary, adding debt to the EU's balance sheet. Such announcements could be expected to decrease expected future short-term risk-free interest rates, for example if market participants perceived the central bank to be subject to fiscal dominance (see e.g. Reinhart and Sbrancia (2015); Schnabel (2020)). Alternatively, such announcements could also increase expected future short-term risk-free interest rates, for example if additional fiscal stimulus were perceived as inflationary (Blanchard (2016)). Expansionary fiscal announcements could be expected to increase the default risk premia of the sovereigns that guarantee the EU's new debt (Calvo (1988)), or to decrease them if the new funds were perceived as supporting sovereigns' economic outlook and thus help increase debt sustainability. The announcements could also be expected, possibly, to increase (to less negative values) the German segmentation premium if market participants perceived the new EU debt as a competing euro area-wide safe asset (Brunnermeier et al. (2021)).

On 23 April 2020, EU heads of state agreed to assemble a €540 bn recovery package and a recovery fund of "sufficient magnitude" (see Section 3.2 for a discussion). Table 2 suggests that the EU's fiscal response to the Covid-19 crisis led to a large and approximately uniform reduction in all yields. Italian, Spanish, French, and German yields decreased by 23, 14, 11, and 5 bps, respectively. The symmetric impact of the fiscal policy announcement on sovereign yields is in stark contrast to the asymmetric impact of the ECB's PEPP announcements on 18 March and 4 June 2020 as studied above. While the monetary policy announcements benefited some vulnerable countries more than others, the fiscal announcement lowered euro area bond yields more uniformly. We attribute the observed 23 bps decrease in Italian yields on 23 April 2020 to lower risk premia across the board — the default risk premium (by 14 bps), future short rates and the term premium (by 5 bps), the redenomination risk premium (by 3 bps), the segmentation premium (by 2 bps), and the liquidity risk premium (by 1 bps) all decreased. The same pattern is observed for Spanish yields: all yield components decreased simultaneously. French and German yields decreased amid lowered expectations of future short-term risk-free rates and term premium.[36]

On 21 July 2020, EU heads of state reached an agreement fleshing out the technical details of its NGEU program. Also this announcement led to a uniform reduction in all yields. Italian, Spanish, French, and German yields decreased by 8, 2, 3, and 3 bps, respectively. The decrease in Italian yields is mainly attributed to a decrease in the default risk premium (3 bps) and segmentation premium (3 bps).

We interpret these findings as reflecting market participants' assessment that expansive fiscal policy can play an important role in supporting the central bank's monetary policy to improve the economic outlook in a coordinated fashion, as e.g. argued by Bartsch, Benassy-Quere, Corsetti, and Debrun (2021). In addition, the common EU fiscal policy supported vulnerable countries by removing risk from weakened sovereign budgets, facilitating lower default risk premia and higher convenience yield premia. In line with this interpretation, Augustin, Sokolovski, Subrahmanyam, and Tomio (2021) find a positive and significant sensitivity of sovereign CDS spreads to the intensity of the Covid-19 spread for fiscally constrained governments, suggesting that sovereign resilience to external shocks was impaired. Finally, the strong policy response at the European level may have lowered political risks in vulnerable countries, facilitating lower redenomination risk premia.

[36] On 22 April 2020, one day before the EU's announcement of its recovery package on 23 April, the ECB announced that it would ease its collateral requirements, increasing the amount of liquidity banks can obtain. At the time, Italy was at risk of losing its investment grade credit rating. In principle, some of the yield response attributed to EU's 23 April announcement in Table 2 could be due to a delayed response to the ECB's announcement one day before. Web Appendix F studies this issue and concludes that this unlikely to be the case.

As a final caveat, not all EU fiscal policy announcements led to a uniform reduction in sovereign yields. On 18 May 2020, the German chancellor Angela Merkel and French president Emmanuel Macron announced a joint proposal for a €500 bn European recovery fund. Table 2 suggests that their bilateral announcement led to a sizable reduction in Italian and Spanish yields (by 23 and 9 bps), while moderately increasing French and German yields (by 2 and 7 bps). Our statistical model attributes the decrease in Italian and Spanish yields to lower default risk, redenomination risk, and segmentation premia. By contrast, French and German yields increased moderately amid rising expectations of future short-term risk-free rates and term premium (by 2 bps) and less negative segmentation premia (by 1 and 3 bps).

5 Conclusion

We propose a novel modeling framework to decompose euro area sovereign bond yields into their most dominant risk premia, building upon key ideas in Krishnamurthy et al. (2018). The identification of each risk premium is achieved by modeling sovereign yields jointly with other instruments' rates in an unobserved components model. Our framework can be used to study sovereign yields in detail in the context of regularly recurring monetary policy decisions, as well as, potentially, to monitor euro area financial integration over time.

We apply our model to study the impact of ECB unconventional monetary policy and EU fiscal policy announcements on euro area sovereign yields during the Covid-19 pandemic recession. Both ECB monetary and EU fiscal policy announcements had a pronounced impact on sovereign yields, mainly by affecting default, redenomination, and segmentation premia. The ECB's unconventional monetary policy announcements particularly benefited vulnerable countries hard-hit by Covid-19, owing to unprecedented flexibility when implementing bond purchases. The EU's fiscal policy announcements also stabilized sovereign yields, and uniformly so across countries, possibly by moving fiscal risks onto a shared budget, by lowering political (redenomination) risks through unprecedented collective action at the European level, and by complementing the ECB's monetary policy aimed at improving the economic outlook and therefore debt sustainability.

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