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

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Abstract

We decompose euro area sovereign bond yields into five distinct components: *i*) expected future short-term risk-free rates and a term premium, *ii*) default risk premium, *iii*) redenomination risk premium, *iv*) liquidity risk premium, and a *v*) segmentation premium. Identification is achieved by modeling 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 (E.U.) fiscal policy announcements during the Covid-19 pandemic recession. We find that both monetary and fiscal policy announcements had a pronounced effect on yields, mostly through default, redenomination, and liquidity risk premia. While the ECB's unconventional monetary policy announcements benefited some (vulnerable) countries more than others, owing to unprecedented flexibility in implementing bond purchases, the E.U.'s fiscal policy announcements lowered yields more uniformly.

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

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1 Introduction

The outbreak of the novel Corona virus in the euro area in February 2020, commencing in northern Italy but quickly proliferating from there, forced governments to take drastic measures to contain the spread of Covid-19. The containment measures included restrictions on cross-border travel, shelter-in-place orders, and a reduction of public life to a minimum, thus contributing to unprecedented reductions in economic activity and coinciding with a widespread sell-off in financial markets. As a result of the pandemic, monetary and fiscal policy makers needed to step in to support firms, financial institutions, and households. Examples of such support include the European Central Bank (ECB)'s Pandemic Emergency Purchase Programme (PEPP), as announced in March 2020 and initially sized at €750 billion (bn), and the European Union (E.U.)'s Next Generation E.U. Fund, as announced in April 2020 and also sized at €750 bn. Both the outbreak of the Covid-19 pandemic, as well as the subsequent monetary and fiscal policy responses, had a pronounced impact on euro area sovereign bond yields (see e.g. Lane (2020) and Klose and Tillmann (2020)).

Sovereign bond yields comprise several components (see e.g. Duffie and Singleton (1999), Greenwood and Vayanos (2010), Renne and Monfort (2014), De Pooter et al. (2018), Krishnamurthy et al. (2018), De Santis (2019), and Schwarz (2019)). For example, today's five-year Italian sovereign bond yield could be thought of as containing expectations about future short-term risk-free interest rates, a term premium, a default risk premium, a redenomination risk premium, a liquidity risk premium, and, possibly, a segmentation (or convenience) premium. Which of these components explains what share of today's yield is unobserved and hard to ascertain. To our knowledge, there is currently no robust statistical framework that allows researchers and policy makers to decompose euro area sovereign bond yields into their underlying yield components, facilitating an assessment which of the above risk premia are currently the most dominant. This assessment, however, is often of considerable interest, for two main reasons. First, sovereign yields can play a key role in ensuring favorable financing conditions to all firms and households in an economy, as private borrowing and lending rates are often calculated from national sovereign yields as the relevant benchmark (see e.g. Eser et al. (2012) and ECB (2014)). In this way sovereign yields contribute to the future economic and inflation outlook. The optimal monetary policy response to a, say, 50 bps increase in all sovereign yields, however, likely depends on whether this increase is brought about by, for example, revised expectations about future short-term risk-free rates, redenomination risk premia, or liquidity risk concerns. Second, high and volatile yields in only a subset of countries can hinder an even transmission of the common monetary policy stance to all parts of the euro area. It is then of interest why exactly these yields are high and volatile, allowing policy makers to address the root causes.

This paper proposes a novel statistical 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*) a redenomination risk premium, *iv*) a liquidity risk premium, and *v*) a segmentation premium. We illustrate our approach for the four largest euro area countries: Germany, France, Italy, and Spain. Together, these countries represent approximately 67% of euro area gross domestic product (GDP) in 2019. Our approach can be implemented for other euro area countries as well, provided all necessary data are available.

Our starting point is the framework and empirical study of Krishnamurthy et al. (2018, KNV hereafter). KNV estimate latent yield components for Italian, Spanish, and Portuguese yields during the euro area sovereign debt crisis between 2010 and 2013. They do so using an unobserved component statistical model in state space form. Identification is achieved by modeling sovereign yields jointly with other rates, such as rates from Overnight Index Swaps (OIS), corporate bonds, and foreign-law sovereign bonds denominated in U.S. dollars. Doing so allowed them to study not only the response of sovereign yields to ECB monetary policy announcements, but also, crucially, which channels explained the observed impact on yields.

We modify the KNV framework in two main ways. First, we identify the default risk and the redenomination risk premium differently, and, arguably, more straightforwardly. We identify the default risk premium from widely available sovereign credit default swap (CDS) spreads denominated in euro. Sovereign CDS denominated in euro have become much more liquid since the euro area sovereign debt crisis between 2010 and 2012, and now offer the most direct way to assess default risk as priced into euro area sovereign bond yields. We 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 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 2014. The new terms make a redenomination of debt securities issued by a country leaving the euro area into a new currency much more likely 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 with 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 et al. (2020), and Kremens (2020)). ISDA 2014 CDS spreads became available in October 2014, and were therefore not available to KNV when they conducted their study.[1]

Second, we modify the KNV framework by including liquidity risk premia. Liquidity risk premia can become important during times of financial turmoil, and have been pointed to in the past as an issue of concern for the ECB (see e.g. ECB (2014), Eser and Schwaab (2016), and De Pooter et al. (2018)). We identify country-specific liquidity risk premia from country-specific liquidity risk factors. Each liquidity risk factor is constructed as the geomet-

[1]KNV 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 no exposure to redenomination risk. Unfortunately, the former are hard-to-impossible to find, and the latter are only available for very few euro area countries, and much less liquid than euro-denominated bonds when available. These drawbacks complicate the interpretation of their empirical results. By relying on CDS spreads, we can apply our framework to euro area countries such as Germany and France.

ric average between, on the one hand, a proprietary country- and market-segment-specific liquidity measure provided by Tradeweb markets, a leading electronic trading network, and, on the other hand, 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 et al. (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)). Our liquidity risk premium estimate is given by the country-specific liquidity risk factor, scaled by a deterministic parameter to be estimated. We refer to the main text for details.

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 are economically important. Their relative importance, however, varies considerably across countries and over time. For example, default and redenomination risk premia explain the bulk of variation in Italian and Spanish yields, but are not dominant sources of variation for French and German yields. Instead, French and German yields are mostly driven by expectations about future short-term risk-free rates and term premium, as well as a segmentation premium.

Second, we document that all euro area sovereign bond yields in our sample contain a pronouncedly negative segmentation premium that we interpret as a convenience yield, capturing the extent to which investors value the non-pecuniary benefits of sovereign bonds (see e.g. Krishnamurthy and Vissing-Jorgensen (2012), Del Negro et al. (2018), and Brunnermeier et al. (2021)). Our segmentation premium estimates are most negative for German bonds, suggesting that these bonds are currently the most highly sought-after asset in our sample. Our empirical results are in line with the theoretical prediction of e.g. Eser et al. (2019) and Corradin and Maddaloni (2020) that the segmentation premium is made more negative by the ECB purchasing large fractions of outstanding sovereign debt, for example within the Public Sector Purchase Programme (PSPP) since March 2015 and the PEPP since March

2020, and by making euro area sovereign bonds eligible for large ECB credit market operations. For example, we find that the segmentation premium became more negative following the ECB's PEPP announcement on 18 March for most countries in our sample.

Third, we find that the ECB's unconventional monetary policy announcements in 2020 benefited some vulnerable countries more than others. For example, the ECB's PEPP announcement 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. Five-year Italian yields peaked at 1.96% before the 18 March announcement, and then decreased by 78 bps over a two-day event window. We attribute 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. These increases are in part 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 effects of the Covid-19 pandemic, which did not happen.

The PEPP's total envelope was extended by €600 billion to €1,350 billion on 4 June 2020. The 4 June announcement led to a similar pattern than the initial PEPP announcement on 18 March: a reduction in Italian and Spanish yields, and an increase in German yields. The PEPP extension decreased Italian yields by an additional 17 bps, mainly owing to a 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 can be attributed to the unprecedented flexibility built into the PEPP, granting the ECB flexibility in implementing asset purchases across euro countries, across asset classes, and over time. Importantly, within PEPP the ECB can deviate from the strict limits set by the ECB's capital key that had guided its net purchases until then.[2] Previous ECB asset purchase programs, including the PSPP, did not have such flexibility. 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 E.U.'s main fiscal policy announcements, in contrast to the ECB's PEPP announcements, lowered sovereign yields more uniformly across countries. On 23 April 2020, E.U. heads of state agreed to assemble a €750 bn Next Generation E.U. Fund. In addition, they established a €540 bn safety net comprising the €100 bn program to mitigate unemployment risks, 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). Italian, Spanish, French, and German yields subsequently decreased by 23, 14, 11, and 5 bps respectively. Our estimates attribute 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 risk premium (by 1 bps), as well as expected future short-term risk-free rates and term premium (by 5 bps) all declined. A similar pattern is observed for Spanish yields: all yield components decreased, by approximately proportionate amounts. Later, on 21 July 2020, E.U. heads of state reached an agreement fleshing out the technical details of its Recovery Fund Next Generation E.U. 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 E.U. fiscal policy announcements as potentially reflecting market participants' assessment that expansive fiscal policy can play

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

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 et al. (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. Finally, the observed strong policy response at the European level may have contributed to lowering national political risks, rationalizing lower redenomination risk premia.

Section 2 presents our statistical model. Section 3 discusses our data and key policy announcements. Section 4 presents our main empirical results. Section 5 concludes.

2 Statistical model

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,

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

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. Then 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) and De Santis (2019).

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) and De Pooter et al. (2018)).

We identify a Segmentation Premium$^c_{t,t+\tau}$ as the remaining and residual autocorrelated component (sixth term). It is called a segmentation premium because it cannot arise without some limits to arbitrage (see e.g. Gromb and Vayanos (2002), Duffie (2010), and Corradin and Maddaloni (2020)). In Gromb and Vayanos (2002)'s setting, the bond price reflects the valuation of only a subset of the 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 (Del Negro et al. (2017), Brunnermeier et al. (2021)). In the euro area setting, investors could be willing to pay a premium to store excess central bank reserves in safe assets, particularly when large-scale central bank asset purchase programs are active. 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 banks' 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 induced by dealer inventory effects (see e.g. Greenwood and Vayanos (2010), Eser et al. (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 ($\tau = 60$ months), 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 Model in state space form

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.[3] The measurement error variance matrix

[3]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 (2).

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 to be estimated.[4] 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.[5]

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 financial market prices (for example, CDS spreads).[6] The state error variance matrix is given by $Q = \mathbb{E}[\eta_t \eta_t'] = DCD$, where $D = \text{diag}(\delta_1, \ldots, \delta_6)$ is a diagonal matrix

[4] 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.

[5] 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.

[6] 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 et al. (2018), and references therein). Each latent component can evolve flexibly, conditional on the data at hand, to match a multitude of potential patterns.

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.[7] 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). For parameter estimation, we maximize the sum over all four country-specific log-likelihoods. This implies that the loading, volatility, and correlation parameters in ψ are pooled across countries. 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 necessary because, for example, our German data are fairly uninformative about default and redenomination risk premia, and liquidity risk premia are only weakly identified at the country level. The pooling of country-specific parameters in ψ 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 $\hat{\alpha}_t = \mathbb{E}[\alpha_t | y_1, \ldots, y_T; \psi]$ are obtained from the Kalman filter and smoother as in KNV.[8]

[7] 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 identical parameter and state vector estimates.

[8] For compactness we omit superscripts to indicate country data. 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, unwieldy, model would produce. The two quantities coincide, however, if the measurement error covariance matrix of the larger model remained diagonal and the state error covariance matrix had a (country-)block structure.

In principle, the loading parameters β could alternatively be estimated by a (restricted) least squares regression of sovereign yields on the other financial instruments' rates. The associated regression residual could then be interpreted as a segmentation premium. The advantages of a Kalman filtering approach over this simpler regression approach are (at least) twofold. First, all variables in y_t are subject to measurement error. For example, what the five-year Italian yield is today depends on which exact ISIN is tracked as the relevant benchmark bond. The sovereign yields can differ by up to 20 bps across data sources as a result. Similarly, all CDS spreads are subject to a bid-ask spread. Errors-in-variables (Davidson and MacKinnon (2004, Ch. 5.1)), however, 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 our filtering approach, leading to consistent parameter estimates. Second, such a regression specification would implicitly push the segmentation premium into the regression residual. Persistent regression residuals, however, can give rise to spurious regression results. Differencing the data can mitigate this problem to some extent, but leads to a loss of (level) information, and makes the β estimate dependent on whether e.g. daily, weekly, or monthly differences are considered. Our filtering approach, by contrast, distinguishes the persistent segmentation premium from serially uncorrelated yield measurement errors, and allows all risk premia to be non-stationary.[9]

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

[9]The filtering and smoothing recursions, log-likelihood evaluation, and state vector estimation for non-stationary time series models in state space form are by now well understood (Koopman (1997)). The filtering approach also allows us to put appropriate standard error bands around each filtered component. These, however, are not the primary focus of the empirical results presented in Section 4.

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. The default risk premium is identified 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 explicitly from a redenomination of sovereign debt into another currency. In addition, such contracts do not protect the owner from a devaluation of the euro against the U.S. dollar should the 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)). As a result, the yields of these bonds, when adjusted by the U.S. dollar swap rates of similar maturity, should contain the default risk premium of the sovereign bond yield. A major limitation of this identification approach is that very few euro area countries regularly issue U.S. dollar-denominated bonds. In addition, these bonds are usually much less frequently traded than comparable euro-denominated bonds issued by the same country.

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 financial sector and central bank practitioners (see e.g. Visco (2018), Kremens (2020)). In 2014, following the euro area sovereign debt crisis and the Greek credit event on 9 March 2012, the ISDA introduced new definitions making a redenomination of debt from a currency leaving the euro area much more likely to trigger CDS contracts, as long as this act is detrimental to bondholders. By contrast, the ISDA 2003 terms remained unchanged and unclear in this regard. A positive ISDA basis between ISDA 2014 and ISDA 2003 CDS spreads, when quoted in the same currency for euro area sovereigns, is therefore indicative of a perceived risk from renouncing the euro and subsequently redenominating debt obligations (see also Balduzzi et al. (2020) and Kremens (2020)). Instead of relying on CDS spreads, KNV rely on corporate bond yields to infer the redenomination risk premium, arguing 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-impossible to find, and their yields are in any case subject to company-specific pricing effects.

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 constructed 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 et al. (2018)). 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.

We close 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 (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 December 2017 and Credit Market Analysis (CMA) DataVision from January 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 (www.tradeweb.com) and Bloomberg.

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 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.

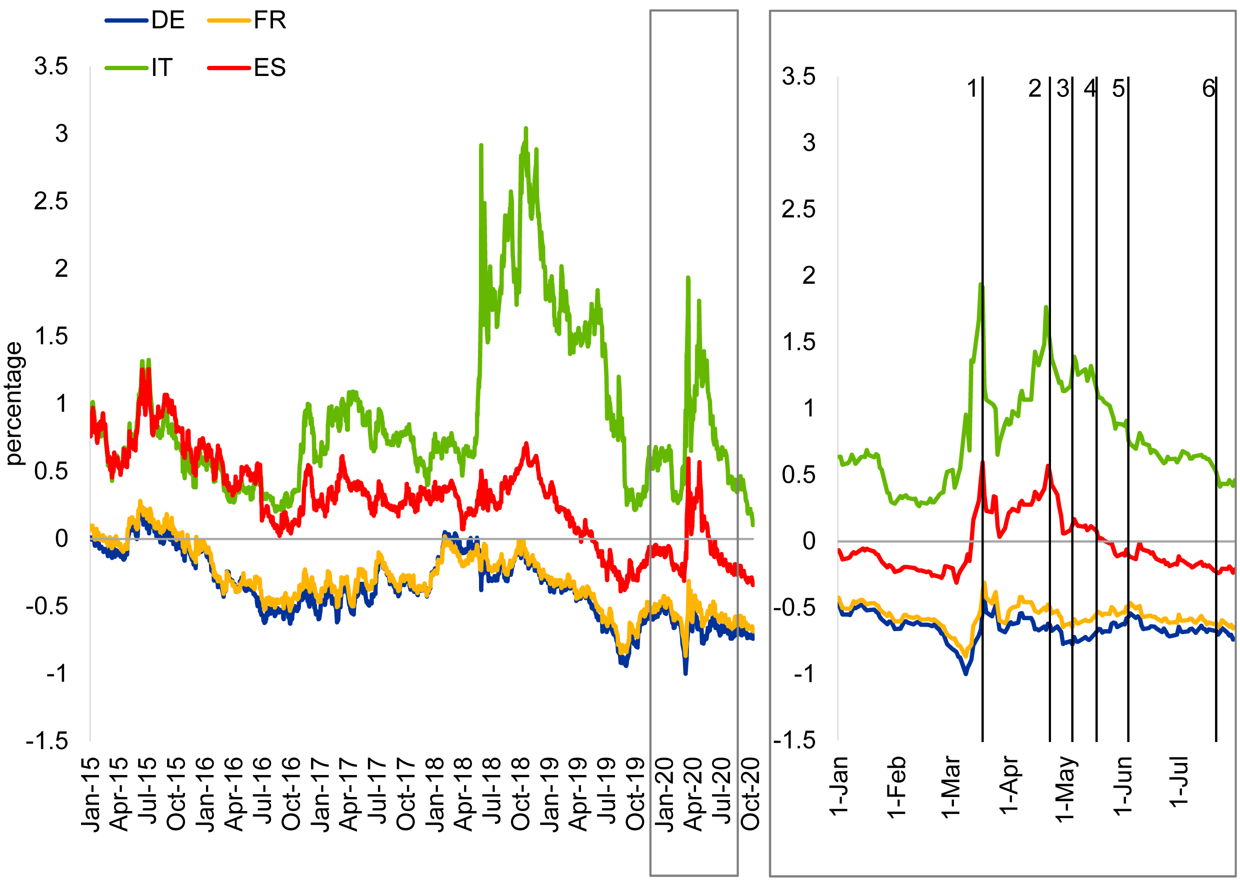
The right panel of Figure 1 contains vertical lines indicating key monetary and fiscal policy announcements. Section 4.4 studies the impact of these announcements in detail.

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 vertical 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.

In April 2020 a common fiscal policy response to the Covid-19 pandemic recession was initiated by E.U. heads of state to complement the ECB's strongly accommodative monetary

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 E.U. announced its €750 bn Next Generation E.U. emergency fund; 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 billion European recovery programme; 5) on 4 June 2020 the ECB announced the expansion of the PEPP from €750 billion to €1,350 billion; and 6) on 21 July 2020 E.U. leaders reached an agreement on details regarding its Recovery Fund Next Generation E.U.



policy. On 23 April 2020 (second vertical line), E.U. leaders agreed to assemble a €750 bn emergency fund, labeled the Next Generation E.U. Fund. Three additional support measures were also endorsed at that time: a 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. On 18 May 2020 (fourth line), the German chancellor Angela Merkel and French president Emmanuel Macron announced their joint proposal for a €500 bn European recovery program. On 21 July 2020 (sixth line), E.U. heads of state reached an agreement on the technical details of their Next Generation E.U. Fund.

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 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 early 2020? Finally, which channels explain most of the announcements' impact?

4.1 Model selection and parameter estimates

This section first discusses parameter restrictions that we impose when fitting the general model (2) – (3) to the empirical data at hand. We then discuss the resulting parameter estimates. The parameter estimates are statistically significant at the 5% level unless otherwise indicated.

We restrict the loading coefficients $\beta_1 = \beta_2 = 1$ following preliminary data analyses and likelihood ratio tests. 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 are subject to measurement error. Second, we restrict $\gamma_1 = \gamma_2$, 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 further set $\gamma_3 = 0$. This ensures that the first, euro-area-wide component (expected future short-term risk-free rates and term premium) is numerically identical for all countries. Finally, we set $\gamma_4 = \gamma_5 = \gamma_6 = 4$ bps and $\gamma_7 = 2$ bps. These choices are approximately in line with the observed bid-ask spreads for CDS spreads in the CMA subsample of our data, and with observed bid-ask spreads for German KfW bonds. 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 (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 yields empirically given the data at hand.

We now discuss our parameter estimates. The state error standard deviation parameters $\delta_1, \ldots, \delta_6$ are estimated to lie between 0.8 bps (liquidity risk premium) and 2.3 bps (redenomination risk premium), suggesting economically significant time series variation for all risk premia.[10] The yield measurement error standard deviation parameters $\gamma_1 = \gamma_2$ are estimated at ≈ 4 bps, implying a small but non-negligible role for one-off market pressures. The correlation estimates in C point to a moderate correlation between the default and redenomination risk premium (-0.58), the redenomination and liquidity risk premium (-0.28), the default and liquidity risk premium (0.24), and the redenomination risk premium and segmentation premium (0.22). Overall, the moderate magnitude of the correlation parameters suggests that each risk premium captures a distinct source of economic risk.

The loading on the country-specific liquidity risk factor (β_3) is estimated at approximately 0.26, with a sizeable standard error (4.19). This parameter estimate is thus only weakly empirically identified from our data at hand. Our sample of sovereign bonds is highly liquid, at least during normal times, with only a minor role for time series variation in liquidity risk

[10] If $\delta_i = 0$, then the corresponding risk premium is constant; see (3). Standard t- and LR-tests are not appropriate for these parameters (Andrews and Ploberger (1994)). Information criteria strongly prefer model specifications with $\delta > 0$.

premia. We keep β_3 at its estimated value, after comparing the magnitude of our liquidity risk premium estimates with those in the relevant literature (e.g., Renne and Monfort (2014) and De Pooter et al. (2018)).

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 can explain the bulk of the observed variation. We first discuss the variation in risk premia across countries and over time. We then turn to redenomination 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 associated summary statistics. 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 above-mentioned risk premia are economically important. 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 five bps between 2015 and 2019. 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 e.g. Renne and Monfort (2014) and De Pooter et al. (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 et al. (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. 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 (2020) 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 a segmentation premium.

Figure 2: Yield decomposition results for Italy and Spain

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.

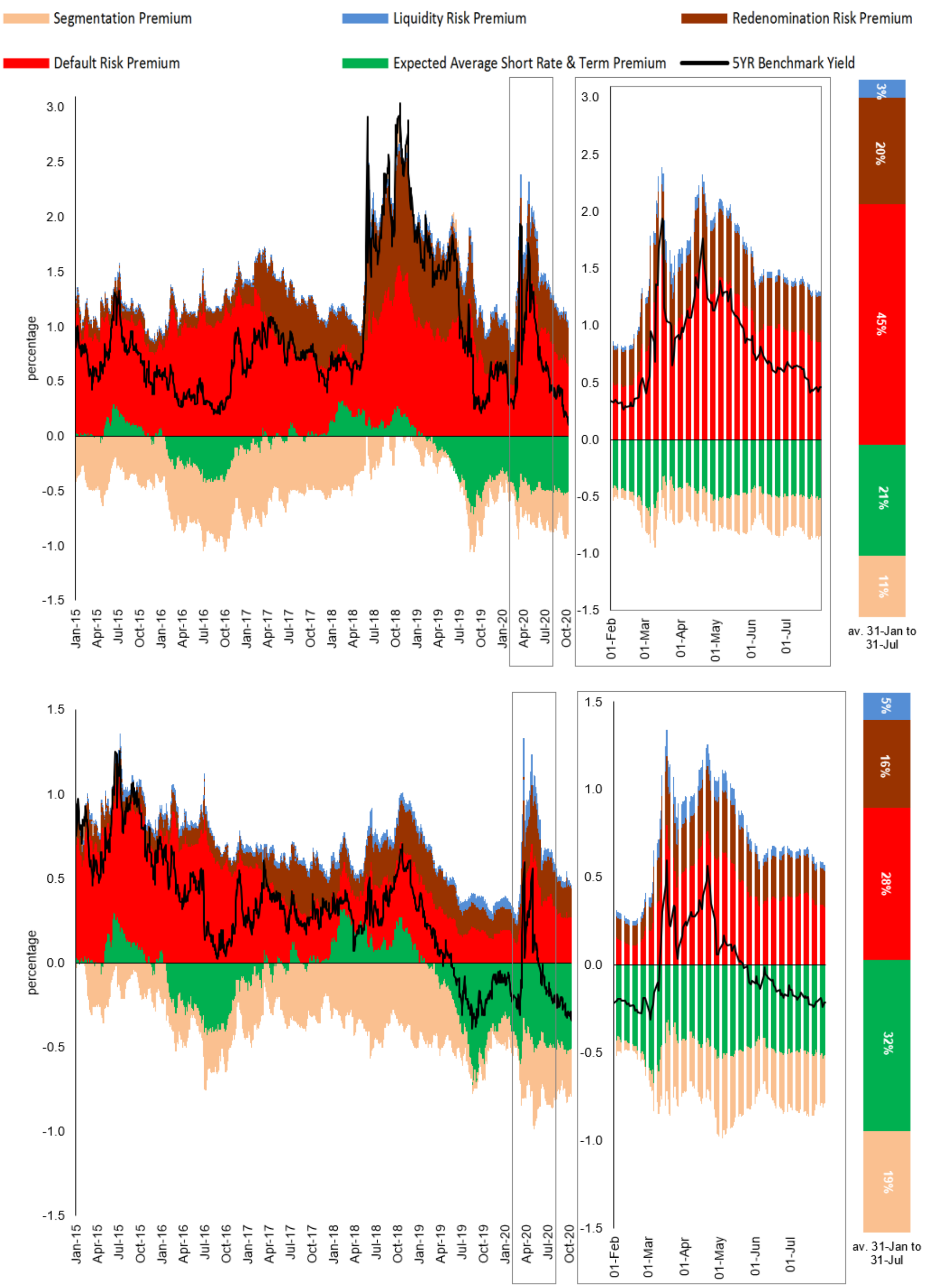


Figure 3: Yield decomposition results for France and Germany

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.

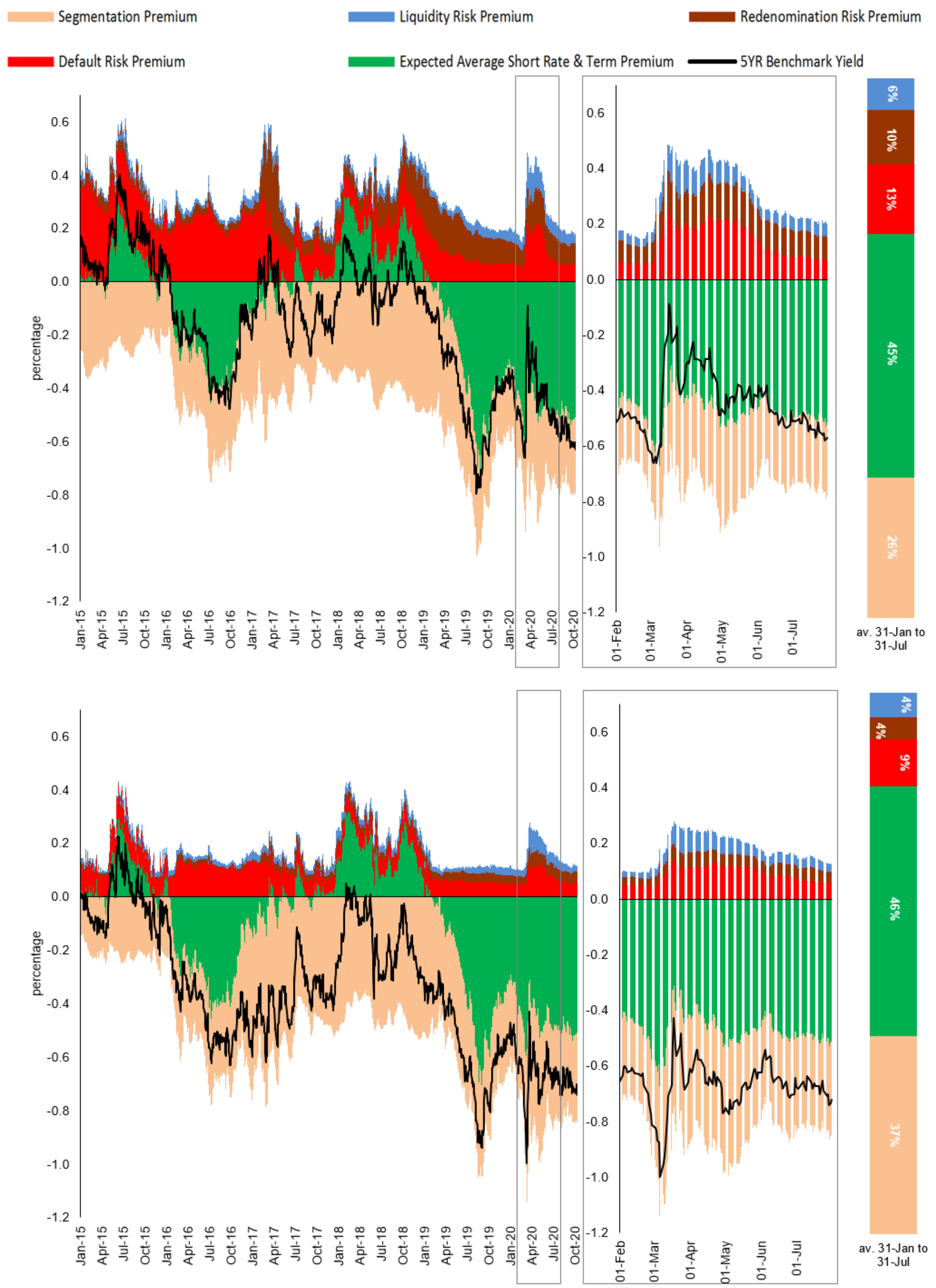


Table 1: Bond premia descriptive statistics

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 sample ranges from 01 January 2015 to 30 January 2020 (left panels in Figures 1 to 3). The Covid sample refers to the zoomed-in period between 31 January 2020 and 31 July 2020 (right panels in Figures 1 to 3). The final column refers to the complete sample from 01 January 2015 to 09 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	Covid	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)

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 among euro area sovereign bonds, and the de-facto safe asset benchmark. Interestingly, German and Italian convenience yields were similar before the onset of the Covid pandemic (after accounting for term, default, redenomination, and liquidity risk premia), before diverging to some extent during the pandemic recession.

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.[11]

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.[12] 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, implying that the central bank purchases are absorbed by a group of market participants because other investors are not active in the same

[11]The extent to which investors value the non-pecuniary benefits of bonds is often referred to as a convenience yield. For example, Krishnamurthy and Vissing-Jorgensen (2012) and Del Negro et al. (2017, 2018) provide convenience yield estimates for U.S. Treasuries.

[12]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 et al. (2019) and Bernanke (2020) and the references therein.

market. This causes the segmentation premium to become even more negative. Euro area sovereign bond markets were arguably well-integrated prior to the great 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 e.g. Ehrmann and Fratzscher (2017) and Koijen et al. (2020)).

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 remained approximately stable. 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 basis points. The Italian redenomination risk premium increased by 29 basis points, but remained lower than what was observed in 2018. Italian liquidity risk premia were negligible 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.

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. These percentages allow us to study the relative magnitudes. Between 31 January and 31 July 2020 the default risk premium accounts for 45% of the Italian yield, and for 28% of the Spanish yield. The redenomination risk premium accounts for 20% of the Italian yield, 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. The default risk premium accounts for 13% of the French yield, and for 9% of the German yield. The redenomination risk premium accounts for 10% of the French yield, and for 4% of the German yield. Instead, French and German yields are mostly explained by expected future short-term risk-free rates and a term premium (45% and 46%), and a segmentation premium (26% and 37%).

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 E.U. 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 E.U. 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.[13]

Our event study regression results are reported in Table 2, distinguishing between mon-

[13] 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 $\kappa.$ is approximately (owing to the constant) equal to the sum of the two observations following the respective event day.

etary 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.

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 1.96% and then decreased by 78 bps (two-day change). 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 attributes the increase in French and German yields to higher than expected future risk-free (monetary policy) rates and the term premium. This is intuitive. Market participants may have been expecting 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.

The asymmetric impact on yields (ES and IT down, DE and FR up) can be attributed 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."* 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.[14]

On 4 June 2020 the PEPP's total envelope was extended by €600 billion to €1,350 billion. 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. We attribute this decrease mainly to a 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 increase in French and German yields is mainly attributed to a slight increase in future expected short-term risk-free rates and term premium.

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. 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 attributed to the same channels, which, however, are not statistically significant in this instance.

We now turn to our E.U. fiscal policy announcements. On 23 April 2020, E.U. heads of state agreed to assemble a €750 bn Next Generation E.U. Fund (see Section 3.2 for a discussion). In addition they announced a Covid-19 pandemic rescue package, establishing a €540 billion safety net comprising the €100 billion SURE program, a €200 billion pan-

[14] 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).

European guarantee fund for loans to companies by the EIB, and a €240 billion pandemic crisis support credit line by the ESM.

Table 2 suggests that the E.U.'s common fiscal response to the Covid-19 crisis led to a large and approximately uniform reduction in all yields. On 23 April 2020, 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 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 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). 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.

On 21 July 2020, E.U. heads of state reached an agreement fleshing out the technical details of its Next Generation E.U. recovery fund. 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).

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 one lag.

	(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)
05-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)
04-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)
E.U. 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)
05-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)
04-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)
E.U. 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)
05-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)
04-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)
E.U. 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)
05-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)
04-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)
E.U. 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)

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 in Bartsch et al. (2021)). In addition, the fiscal policy supported vulnerable countries by removing risk from weakened sovereign budgets, facilitating lower default risk premia. Finally, the strong policy response at the European level may have lowered political risks in vulnerable countries, facilitating lower redenomination risk premia.

As a caveat, however, not all supranational fiscal policy announcements led to a uniform reduction in yields. On 18 May 2020, the German chancellor Angela Merkel and French president Emmanuel Macron announced a joint proposal for a €500 billion European recovery programme. 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). We attribute 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 segmentation premia (by 1 and 3 bps).

5 Conclusion

We proposed a novel framework to decompose euro area sovereign bond yields into their most dominant risk premia. Our framework can be used to monitor sovereign yields in the context of regularly recurring monetary policy assessments, as well as for financial integration monitoring. The identification of each risk premium is achieved by modeling sovereign yields jointly with other instruments' rates in an unobserved components model in state space form.

We applied our model to study the impact of ECB monetary policy and E.U. fiscal policy announcements on sovereign yields during the Covid-19 pandemic recession. Both ECB monetary and E.U. fiscal announcements had a pronounced impact on yields, mainly by affecting default, redenomination, and liquidity risk premia. The ECB's unconventional monetary policy announcements benefited some countries more than others, owing to unprecedented flexibility when implementing bond purchases. The E.U.'s fiscal policy announcements, by contrast, lowered yields more uniformly. The latter points to E.U. fiscal policy supporting national budgets by moving risks onto shared budgets, mitigating political (redenomination) risks by decisive action at the European level, and, possibly, to synergies between accommodative monetary and fiscal policies to improve the economic outlook.

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