Journal of Multinational Financial Management 68 (2023) 100800

Contents lists available at ScienceDirect

Journal of Multinational Financial Management

journal homepage: www.elsevier.com/locate/mulfin

Dynamic connectedness between credit and liquidity risks in euro area sovereign debt markets

Marta Gómez-Puig [a], Mary Pieterse-Bloem [b,*,1], Simón Sosvilla-Rivero [c]

[a] Department of Economics and Riskcenter, Universitat de Barcelona, 08034 Barcelona, Spain
[b] Section Finance in Business Economics, Erasmus School of Economics, 3062 PA, Rotterdam, and Rabobank, 3521 CB Utrecht, the Netherlands
[c] Complutense Institute for Economic Analysis, Universidad Complutense de Madrid, 28223 Madrid, Spain

ARTICLE INFO

JEL classification codes:
C22
C53
G12
G14
G15

Keywords:
Liquidity risk
Credit risk
Eurozone sovereign bonds
MTS bond market
Dynamic connectedness
Time-varying parameters

ABSTRACT

We examine the dynamic interconnections between sovereign credit and liquidity risks in ten euro area countries at the 5-year maturity with daily CDS data from IHS Markit and high-frequency data from MTS between 2008 and 2018 using the extended TVP-VAR connectedness approach of Antonakakis *et al.* (2020). We find that, for most of the period, net connectedness is from credit risk to liquidity risk, but this indicator is time-dependent, detecting some episodes where it goes from liquidity risk to credit risk. We set up an event study and discover that most of the latter episodes can be related to several unconventional monetary policy measures of the ECB. Then, we examine the drivers of the connectedness indicator using a Probit model. Our results suggest that a decline in global funding liquidity, monetary policy shocks and economic policy uncertainty increase the probability of risk transmission from liquidity to credit, while tensions in financial markets and the deterioration of fiscal sustainability are factors that reduce such a probability.

1. Introduction

In times of market distress extreme movements in bond markets are observed, as investors rebalance their portfolios, leading to a sharp rise in bond yield spreads, as was the case for example during the sovereign debt crisis in the euro area. This phenomenon is commonly referred to as “flight-to-safety”, which includes episodes that might be related, not only to “flights-to-quality”, but also to “flights-to-liquidity” (see Baele et al., 2019, García and Gimeno, 2014 or Beber et al., 2009). Changes in both the perceived default probabilities as well as in the capacity to undo positions at reasonable costs are issues that concern bond markets’ investors and are reflected in the respective yield’s premium. However, while the economic motives of these two phenomena are clearly distinct from each other, empirically disentangling a “flight-to-quality” from a “flight-to-liquidity” is difficult, because these two attributes of a fixed-income security (credit quality and liquidity) are usually highly correlated (see Ericsson and Renault, 2006 or Favero et al., 2010).

A decade after a fierce sovereign debt crisis in the euro area, the COVID-19 pandemic elevated the need for fiscal policy action to an unprecedented level amid pre-existing government debt-to-GDP ratios still above their pre-crisis levels, mainly in southern euro area

* Correspondence to: Section Finance in Business Economics, Erasmus School of Economics, E2–30, Burgemeester Oudlaan 50, 3062 PA, Rotterdam, Netherlands.

E-mail address: pietersebloem@ese.eur.nl (M. Pieterse-Bloem).

[1] The opinions and analyses expressed in this article are not those of the bank and remain the responsibility of the authors.

https://doi.org/10.1016/j.mulfin.2023.100800
Received 18 November 2022; Received in revised form 12 March 2023; Accepted 4 May 2023
Available online 5 May 2023

countries. Concretely, the aggregate debt-to-GDP ratio of the euro area, after reaching a peak of almost 100% in 2020, remains very high (94%) in 2022. And according to the European Commission's forecasts,[2] the European Union's (EU) aggregate debt ratio is set to remain above the pre-COVID-19 crisis level in 2024. Half of the member states will likely record debt ratios greater than 60% of GDP, with the debt ratios of Belgium, Greece, Spain, France, Italy, and Portugal expected to remain above 100% of GDP.

Moreover, a combination of factors is exerting upward pressures on prices (surging energy and food commodity prices and a host of supply and logistics bottlenecks – both originating from pandemic-induced adjustment but exacerbated by the outbreak of the war in Ukraine), leading to a record high in the annual inflation rate in the euro area of 8.6% in June 2022.[3] Intensifying and broadening inflationary pressures propelled a faster normalisation of monetary policy in the euro area and prompted the European Central Bank (ECB)'s first interest rate hike in eleven years on 21st July 2022 (50 bps.) which has been followed by four other hikes so far.

The increase in the cost of public debt and the ECB's monetary policy tightening, including the end of the vast ECB's sovereign bond purchasing programs, triggered a rise of euro area sovereign yield spreads in the early summer of 2022, especially in economies with the most debt-laden governments. To stem fragmentation in the euro area from diverging sovereign risk spreads, the ECB also approved the Transmission Protection Instrument (TPI) at its July meeting. This new policy instrument enables the ECB to purchase sovereign and near-sovereign bonds without restriction in the 1- to 10-year maturity from countries where financing conditions are deteriorating to an extent that is unwarranted by country-specific fundamentals. With the TPI, the ECB intends to expand its toolkit to act in the secondary market when it is firm in its decision to fight inflation but worries that credit risk dynamics in the euro area sovereign bond market inadvertently trigger a sovereign debt crisis in a highly indebted country, with all the subsequent contagion effects to other peripheral countries.

The current scenario of the ECB and other policymakers in Europe makes the studying of the dual interaction between the two main domestic components (credit risk and liquidity risk)[4] of sovereign yield spreads in the euro area and the unravelling of the drivers of bond price changes over time in the different countries of paramount importance. With better knowledge of the spillovers and contagion mechanism, policymakers can implement the appropriate policy decisions: if the increase in yield spreads reflects poor liquidity, policy actions should aim at improving market functioning, but if higher yields are largely attributable to a credit shock, then this may justify the use of the TPI as a quick-stop measure and argues for improving debtors' debt sustainability to abate fragmentation pressures in the longer run.

However, despite its relevance, the interaction between credit and liquidity risks in the euro area sovereign bond market is an understudied phenomenon. To the best of our knowledge, the only exceptions are Pelizzon et al. (2016) and O'Sullivan and Papavassiliou (2020). Both use Credit Default Swap (CDS) spreads to measure credit risk and high-frequency data from the Mercato Telematico dei Titoli di Stato (MTS) to derive liquidity risk from. Pelizzon et al. (2016) find in the case of Italy that credit risk, on average, Granger-causes liquidity risk, and that market stress reinforces this relation. O'Sullivan and Papavassiliou (2020) find in their comparison of core and periphery countries in the euro area that liquidity risk has a significant impact on perceived creditworthiness in both the pre-crisis and crisis periods.

So, an empirical analysis of the interaction between credit and liquidity risks of each euro area country on a case-by-case basis and of a time-varying nature is needed to provide more in-depth verification. We design our study to infer country-specific relations. We aim to determine whether the evolution of bonds' yields principally originates from a change in liquidity or a change in default risk, and to study whether the driver changes across euro area countries and over time. We will examine the interconnection between these two sources of risk in ten[5] euro area countries for the period January 2008 and December 2018, which incorporates both the global financial crisis (GFC) and the Eurozone sovereign debt crisis and the various measures that policymakers took to stem these crises, among them most prominently the ECB. We obtain high-frequency quote data from MTS, allowing us to construct sophisticated liquidity measures, which we aggregate to a daily level to match the highest available frequency of the CDS data from IHS Markit that we use to proxy credit risk.[6] We use the extension of the time-varying parameter vector autoregressive (TVP-VAR) connectedness approach of Antonakakis et al. (2020) to characterize the dynamic connectedness between these credit and liquidity measures from the secondary market. Subsequently, once a time-varying net measure of interdependence between liquidity and credit risks is computed

[2] See European Commission's summer and autumn 2022 forecasts (European Commission, 2022a and 2022b, respectively).

[3] It peaked at 10.6% in October 2022.

[4] See Codogno et al. (2003), Baele et al. (2004), or Gómez-Puig (2006, 2008), to name a few.

[5] Our analysis is focused on the countries that joined the euro in 1999–2002 except for Luxembourg and Greece (the great number of missing values is the reason why we had to drop the latter country from the study).

[6] One would like to conduct a study on the dual interaction of credit and liquidity risk at the highest possible frequency, as the incorporation of new information into bond prices is often very rapid. Several papers demonstrate that the use of MTS data for intra-day variation in euro area sovereign bond liquidity can better capture the effect of sudden liquidity spirals (e.g., Scheider et al., 2018) and ECB interventions (under its SMP program) to sudden and strong price deteriorations (e.g., Ghysels et al., 2017) and are able to better establish the link between liquidity and tail returns (Clancy et al., 2019). These studies are, however, exceptional in their use of intra-day data, as either their data source is limited to MTS or is supplemented with time-stamped interventions. The majority of studies that examine the role of liquidity risk in relation to credit risk in Eurozone government bond returns and similarly use CDS spreads and MTS three-best quotes data for their liquidity measure, also typically use a daily frequency (e.g.: Eijsing and Sihvonen, 2009; Beber et al., 2009; Favero et al., 2010; Coppola et al., 2013; Caporale and Girardi, 2013; Dufour et al., 2017; Schwarz, 2019; Buis et al., 2020). Pelizzon et al. (2016) combine some elements of intraday and daily data, but use for their main analysis and results, a liquidity measure that is a daily average over five-minute intervals per bond and is then averaged across bonds. All these studies demonstrate through their significant results that the new information incorporated into bond returns sufficiently extends beyond one day to render empirical research at a daily frequency on this topic meaningful.

for each of the ten countries in our sample, we will turn to our second objective and examine the drivers of the evolution of our dynamic indicator.

Concretely, our study contributes to the existing literature in four ways. First, we go beyond the traditional notion that liquidity risk is essentially the difference between the offered and demanded price of sovereign bonds in the secondary market (known as the bid-ask spread) and add important insights to it by using a slope measure recently proposed by Buis et al. (2020) that includes both price and volume information. To our knowledge, this is the first paper to use this slope measure to examine the interrelation between liquidity risk and sovereign credit risk. Therefore, our paper proposes to use a measure of liquidity (the slope measure) that encompasses two of its main dimensions: tightness and depth.

Our second contribution is that we separately analyse ten euro area countries to examine whether there are differences across them. Our sample encompasses six central countries (Austria, Belgium, Finland, France, Germany, and the Netherlands) and four peripheral countries (Ireland, Italy, Portugal, and Spain).

Thirdly, in contrast to earlier studies, our methodology is not based on a Granger-causality test (Granger, 1969). Following Fernández et al. (2015, 2016), we make use of the connectedness approach to analyse the dynamic spillovers between credit and liquidity risks. This approach, initially developed by Diebold and Yilmaz (2012, 2014), goes beyond the pair-wise independence analysis of Granger-causality and facilitates the measurement of interdependence across a network of variables. The connectedness approach thus offers a framework for evaluating both an idiosyncratic influence and a non-idiosyncratic influence by other variables based upon the estimation of the forecast error variance decompositions that derive from a VAR model. In particular, we apply the extension of the TVP-VAR connectedness approach of Antonakakis et al. (2020) to characterize dynamic connectedness. This advanced methodological framework captures possible changes in the underlying structure of the data more flexibly and robustly than the Granger-causality methodology. The measure of net interdependence directly assesses not only the direction but also the strength of the linkages among the variables under study, which in turn helps attain a better understanding of the underlying dynamics and facilitates the formulation of policy implications. Therefore, in contrast with previous studies, the methodology used in this paper allows us to compute a time-varying net measure of interdependence between credit and liquidity risks and to examine whether the direction of this relation changes over time.

Finally, we determine the main drivers of the evolution of the dynamic indicator of connectedness between credit and liquidity risks in each of the ten countries in our sample, paying special attention to the impact of the ECB's unconventional monetary policy (UMP) interventions on their evolution.

With these goals in mind, we combine two datasets from two secondary markets for euro area sovereign risk. First, CDS premia are used as the most direct measure of the size of the credit risk component in euro area government bonds. We obtain the single-name CDS premia for each of the ten euro area sovereigns from IHS Markit for this purpose. Our study focuses on the 5-year maturity, since CDS contracts, single-name contracts including, at this maturity record the largest trading volume.[7] Not only are CDS prices in the 5-year maturity the least influenced by liquidity risk, they also provide the highest informative content to our analysis. Secondly, we use quote data from the largest inter-dealer secondary market electronic bond trading platform, MTS, to measure market liquidity. On MTS, dealers provide quotes for all sizeable euro area sovereign bonds that are firm and can be immediately executed, the total of which is like a giant order book. We use a record from MTS of the three best bid and ask quotes that have been posted by all dealers' intra-day at the 5-year maturity to construct liquidity measures on a daily basis to match the frequency of the CDS spreads for the ten euro area sovereigns included in this study. Our liquidity measure captures this daily variation for these different sovereign issuers between January 2008 and December 2018 at the 5-year maturity.

Our paper provides new insights into the dual interaction between liquidity and credit risks for the European sovereign debt markets that allows us to reconcile the findings of Pelizzon et al. (2016) and O'Sullivan and Papavassiliou (2020), since our empirical evidence indicates that the interconnection between credit and liquidity risks is time dependent. So, although, on average over the period 2008–2018, credit risk drives liquidity risk, we identify the changing transmitters of risk shocks and detect episodes where liquidity is a net trigger of risk. In our empirical analysis we also find that monetary policy shocks, a decrease in global funding liquidity and economic policy uncertainty increase the probability of risk transmission from liquidity to credit. Moreover, we uncover tensions in financial and sovereign bond markets and deteriorations of fiscal sustainability as factors that reduce such a probability.

The rest of the paper is organized as follows. Section 2 reviews the related literature. Section 3 introduces the econometric methodology. Section 4 describes the data and measures used in the analysis. Empirical results are presented in Section 5. Finally, some concluding remarks and policy implications are offered in Section 6.

2. Literature review

In the academic literature, most papers that explicitly study the interaction between liquidity and credit risks are focused on

[7] BIS securities data on OTC Credit Default Swaps by remaining maturity (https://stats.bis.org/statx/srs/table/d10.3) show that the USD amount outstanding of single-name CDS contracts have over our sample period on average been 7.6 times larger in the 1- to 5-year maturity than in the over 5-year maturity. This ratio grew from 2.5 in the 1 H 2008–9.0 in 2 H 2018, having peaked at 12.2 in 2 H 2015. This fact is elucidated in the BIS Quarterly Review of June 2018 on developments in the size and structure of the CDS market over the decade since the GFC (see Aldasoro and Ehlers, 2018) by the statement that the market has become increasingly standardized, with contract maturities concentrating around the 5-year mark, also referencing Abad et al. (2016) in this respect. That the 5-year CDS is the most frequently traded is echoed by major participants in the fixed-income market (such as PIMCO for example: https://nl.pimco.com/en-nl/resources/education/understanding-credit-default-swaps/).

corporate bonds, subscribing to the importance of liquidity deemed for corporates' bond returns.[8] From the long list of studies in this field, those that stand out are those that examine liquidity in terms of access to (re)financing in the primary market or in terms of the presence of a time-varying liquidity premium in corporate bond spreads.

Either way, liquidity risk (i.e., the lack of liquidity) is a substantial factor in a company's default risk and probability. Ericsson and Renault (2006) are an early example of a structural bond pricing model with liquidity and credit risk determining not only their relative contribution but also their interactive contribution to default probability. Reduced form models, which take information from the CDS market to obtain direct measures of the size of the default component in corporate bond spreads, also establish a history of including liquidity risk early on (see, e.g., Longstaff et al., 2005). As the breadth of studies increases, the dual and interactive role of liquidity and credit risk is maintained, for example in models that determine causes of default through rollover risk (He and Xiong, 2012) and models that study the effect of (endogenous) liquidity on corporate bond prices in the secondary market (He and Milbradt, 2014). Studies on the determinants of corporate bond yields or spreads itself also assess the role of both liquidity and credit risk.[9] Furthermore, most of these studies find that liquidity risk impacts credit risk in a negative sense, meaning to say that it acts to amplify the credit risk component, especially in times of stress.

While there is much to learn from these studies on corporate bond returns, we are interested in those of sovereign bonds and then specifically in the euro area. In the early years of the Economic and Monetary Union, the euro area sovereign bond markets attracted attention from academics interested in the extent and speed of financial integration. Euro area sovereign spreads were typically explained through their two main domestic components of market liquidity and credit risks, in combination with an international risk factor [see, e.g., Codogno et al. (2003), Baele et al. (2004), Geyer et al. (2004), Gómez-Puig, and (2006, 2008, 20109) or Pagano and von Thadden (2004)]. In these studies, liquidity risk, often estimated through rather crude volume-based measures such as the size of the respective sovereign bond market, plays a side role. This is presumably because of the hitherto correct observation that countries always have access to bond financing in the primary market and that the price of it is determined by the international risk conditions and their individual credit risk component. Liquidity risk shows up as a significant, but economically small, component of intra-euro sovereign spread differentials in the secondary market, translating to equally small differences in the primary market.

Interest in the determinants of euro area sovereign bond spreads surged after the GFC when spreads rise significantly and reach first-time highs in the European sovereign debt crisis. Many studies, trying to explain the behaviour of euro area bond yields during and after this turbulent period, find evidence of the link with market volatility and adverse investor sentiment conditions, reinforcing the (sovereign) credit risk component [see, e.g., Palladini and Portes (2011), Favero and Missale (2012), Aizenman et al. (2013), Beirne and Fratzscher (2013) and Georgoutsos and Migiakis (2013)]. Apart from the set of papers that focus on the macroeconomic fundamental linkages between the credit risk component and country risk,[10] another set is focusing on the financial market linkages.[11] In those latter studies liquidity risk features, more prominently, as an independent risk factor, spurred by the observation in the European sovereign debt crisis that a liquidity crisis can turn into a solvency crisis. This crisis, culminating in the default of Greece in 2010 and the near defaults of other sovereigns in the periphery of Europe, clearly demonstrates that access to the primary bond market can be jeopardized for some sovereigns and is available in differing degrees for others.

Credit risk in those studies takes on different forms, increasingly moving from traditional macroeconomic indicators of the sovereign's debt dynamics to the credit ratings and CDS premia as financial market indicators of the same sovereign's probability or default. Liquidity risk in those studies also takes on different forms, pertaining to the liquidity of the sovereign itself as well as to the funding liquidity in their domestic banking sector and that of the euro area as a whole. The first is now also typically captured through price-based rather than volume-based measures, with more refined liquidity measures beyond that of the simple bid-ask spread of sovereign bonds, constructed from the sovereign-guaranteed agency yield differential (see Schwarz, 2019) or the price-volume slope in the limit order book (see Eijsing et al., 2015). These studies invariably find that credit and liquidity risks are individually significant and time-varying and are independently exacerbated by global market risk and macroeconomic risk factors. Buis et al. (2020), link the liquidity, or market access of euro area sovereigns in the primary market to the incentives that primary dealers have and the risk that they are prepared to take as market makers in the secondary market, which is, among others, influenced by the sovereign's credit risk.

The dual interaction of liquidity and credit risks is, however, in contrast to the corporate bond literature, still not explicitly incorporated into studies on the determinants of euro area sovereign bond yields. Favero et al. (2010) do interact liquidity risk, however not with the sovereign's credit risk but with an international bond risk factor to determine yield differentials among euro area sovereign bonds. Their result testifies to a negative interaction term, such that liquidity differentials among the sovereigns only become significant when this interaction term is included.

Pelizzon et al. (2016) and O'Sullivan and Papavassiliou (2020) are, to our knowledge, the only studies to explicitly include the dual interaction of liquidity and credit risks of the sovereign itself and identify the directionality of the relation. Among the many studies

[8] There are nowadays even papers that focus exclusively on liquidity risk for asset pricing implications of corporate bonds (see, e.g., Bongaerts et al., 2017).

[9] The evidence from corporate commercial paper (see, e.g., Covitz and Downing, 2007), longer-dated corporate bonds [see, e.g., Nashikkar et al. (2011), Dick-Nielsen et al. (2012), Helwege et al. (2014), Wang and Wu (2015) or Chen et al. (2018), to name a few] and microfinance company loans (Jarrow and Protter, 2020) is that credit risk is the larger component, but that liquidity risk, while smaller, is also statistically and economically significant.

[10] See Barrios et al. (2009), Allen et al. (2011), Bolton and Jeanne (2011) or Acharya et al. (2014).

[11] See Manganelli and Wolswijk (2009), Afonso et al. (2014), D'Agostino and Ehrmann (2014), Gómez-Puig et al. (2014), Eijsing et al. (2015) and Schwartz (2019).

that confirm that credit quality matters the most for bond valuation, there are several that point to the importance of liquidity risk and its potential to create spillover effects. Clancy et al. (2019) demonstrate that liquidity risk can influence tail risk in returns of Spanish, Italian and German government bonds, providing evidence that liquidity risk can be the instigator or source of risk in times of high volatility. Baele et al. (2020) show that flights-to-liquidity take place in an international bond-stock context and Beber et al. (2009) show that in the euro area sovereign bond market flights-to-liquidity also take the upper hand over flights-to-quality among investors. Nevertheless, while Beber et al. (2009) demonstrate that Italy is benefitting from flight-to-liquidity flows, De Santis (2014) show that after controlling for bond-specific liquidity and credit risks, it is rather Germany that is benefitting from those flows. Moreover, both García and Gimeno (2014) and De Santis (2014) singularly focus on flight-to-liquidity flows through agency-sovereign bond spreads and find that such flows contribute significantly to explain the widening of sovereign spreads within the euro area in stressful periods. These results are corroborated by Schwarz (2019) who finds that liquidity risk, measured by a German agency-sovereign bond spread, is overall a much more important driver of euro area sovereign bond yield spreads in the GFC period than credit risk, though not in the European sovereign debt crisis period when credit risk remained the more important driver. While all these studies lend substantial evidence to the interaction of liquidity and credit risks, which may be reinforced or reversed in times of market stress, they are inconclusive on the direction of this relation and between individual countries in the euro area.

In this context, the analysis in our paper tries to shed further light on this scarcely explored and still an open debate in the literature by using a methodology that allows for time dependency in the interconnection between sovereign credit and liquidity risks and an examination of the drivers of its evolution over time.

3. Econometric methodology

In this section, we describe our methodology for constructing dynamic interconnectedness measures via an extension of the time-varying parameter vector autoregressive (TVP-VAR) connectedness approach, and through which methodologies we subsequently determine the main drivers of these measures.

3.1. Assessing interconnections between credit and liquidity risks

We employ the connectedness approach initially proposed by Diebold and Yilmaz (2012, 2014) to examine the interconnection between sovereign credit and liquidity risks. This approach has certain advantages relative to the Granger-causality framework. First, the connectedness approach establishes the bilateral linkages for all pairs of variables in the multivariate system, making it possible to assess variables' comparative importance for others in the network. This is because the approach, based on variance decompositions and using publicly available market data, in essence, measures the future expected variation in each variable accounted for by a standard deviation shock to another variable. Secondly, the connectedness approach quantifies directionality in the network spillover effects from one variable to another variable, making it possible to identify through the net pairwise connectedness which variable is receiving or triggering the spillover and where a 'trigger' is dominant in the information transmissions between two variables. This is because the linkages are not bilaterally equal, but rather capture the asymmetry in connectedness among financial assets. Thirdly, as Arsov et al. (2013) point out, the connectedness approach is highly adaptive to data changes, making its predictive power one of the highest among other indicators.

The methodological framework of our study for constructing connectedness measures follows the lines of Antonakakis et al. (2020). These authors suggest a TVP-VAR method that extends the originally proposed connectedness approach of Diebold and Yilmaz (2012, 2014) by allowing the variance-covariance matrix to vary via a Kalman filter estimation with forgetting factors in the spirit of Koop and Korobilis (2014). The TVP-VAR framework substantially improves Diebold and Yilmaz's (2012, 2014) connectedness approach, since there is no need to arbitrarily set the rolling window size and hence, there is no loss of observations. In addition, it adjusts immediately to events, incorporating the market responses to shocks hitting the financial system.

The TVP-VAR(p) model can be written as follows:

$$Y_t = \beta_t Y_{t-1} + \varepsilon_t \quad \varepsilon_t \sim N\left(0, \sum\right) \tag{1}$$

$$\beta_t = \beta_{t-1} + \upsilon_t \upsilon_t \sim N(0, R_t) \tag{2}$$

where β_t is an NxN_p dimensional time-varying coefficient matrix and $\varepsilon_t$is an Nx1 dimensional error-disturbance vector with an NxN time-varying variance-covariance matrix,Σ_t, and F_{t-1} is the given information through time t-1. The parameters β_t follow a random walk and depend on their own lagged values β_{t-1} and on an NxN_p dimensional matrix with an N_pxN_p variance-covariance matrix,R_t.[12]

Using series data up to and including time t, and the time-varying coefficients β_t and variance-covariance matrix Σ_t we obtain an H period-ahead forecast (up to time $t+H$) and decompose the error variance of the forecast for each component with respect to shocks from the same or other components at time t using the generalized forecast error variance decomposition (GFEVD) proposed by Koop et al. (1996) and Pesaran and Shin (1998), which is invariant to ordering, as well as the dynamic H-step GFEVD matrix:

[12] Following Koop and Korobilis (2014), we use the same non-informative initial conditions in the Kalman filter, a decay factor of 0.96 and a forgetting factor of 0.99. Without loss of generality, we normalize the series, Y_t, to get a faster convergence in the Kalman filter and smoother.

$$d_{i,j,t}^{gH} = \frac{\sigma_{jj,t}^{-1} \sum_{h=0}^{H-1} \left(e_i' \Theta_{h,t} \Sigma_t e_j\right)^2}{\sum_{h=0}^{H-1} \left(e_i' \Theta_{h,t} \Sigma_t \Theta_{h,t}' e_i\right)} \tag{3}$$

where e_j is a vector with jth element unity and zeros elsewhere; $\Theta_{h,t}$ is the coefficient matrix in the infinite moving-average representation from VAR; Σ_t is the covariance matrix of the shock vector in the non-orthogonalized-VAR, σ_{jj} being its jth diagonal element. In this GFEVD framework, the lack of orthogonality means that the rows of $d_{i,j,t}^{gH}$ do not have sum unity and, in order to obtain a generalized connectedness index $\widetilde{D}_t^{g^H} = [\widetilde{d}_{i,j,t}^{g^H}]$, the following normalization is necessary: $\widetilde{d}_{i,j,t}^{g^H} = \frac{d_{i,j,t}^{g^H}}{\sum_{j=1}^{N} d_{i,j,t}^{g^H}}$, where by construction $\sum_{j=1}^{N} \widetilde{d}_{i,j,t}^{g^H} = 1$ and $\sum_{i,j=1}^{N} \widetilde{d}_{ij}^{g^H} = N$.

The matrix $\widetilde{D}_t^{g^H} = [\widetilde{d}_{ij,t}^{g^H}]$permits us to define the dynamic *total directional connectedness*, *net total directional connectedness*, and *total connectedness.*

The off-diagonal entries of $\widetilde{D}_t^{g^H}$ are the parts of the N forecast-error variance decompositions of relevance from a connectedness perspective. In particular, the *gross pairwise directional connectedness* from j to i at time t is defined as follows:

$$C_{i\leftarrow j}^{H} = \widetilde{d}_{i,j,t}^{g^H} \tag{4}$$

Since in general $C_{i\leftarrow j}^{H} \neq C_{j\leftarrow i}^{H}$, the *net pairwise directional connectedness* from j to i, can be defined as:

$$C_{ij}^{H} = C_{j\leftarrow i}^{H} - C_{i\leftarrow j}^{H} \tag{5}$$

Note that the net pairwise directional connectedness directly measures not only the time-varying direction but also the strength of dynamic linkages among the variables under study, allowing for distinguishing between net shock transmitters and net shock receivers. In particular, if $C_{ij}^{H} > 0 (C_{ij}^{H} < 0)$the variable i is dominating (dominated by) variable j which means that variable i influences (is influenced by) variable j more that being influenced by (influences) it. In our empirirical study, variable i is our measure of credit risk and the variable j is our indicator of liquidity risk.

Notice finally that the net pairwise directional connectedness is calculated considering all other pairwise directional connectedness with the remaining credit and liquidity risk indicators under study. This therefore provides an interconnection measure that controls for possible cross-country relations between credit and liquidity risks that allows us to uncover the propagation of risk shocks between them, identifying the direction and magnitude of market shocks transmitted.

3.2. Assessing the role of ECB unconventional monetary policies

Extensive research shows the impact of the ECB's UMP on euro area government bond yields [see, Rogers et al. (2014), Altavilla et al. (2016), Krishnamurthy et al. (2017), Jäger and Grigoriadis (2017), Rostango et al. (2019) and Farinha and Vidrago (2021), among others]. We use an 'event study' approach to explore the role of the UMP measures implemented by the ECB since 2008 in the dynamic evolution of the estimated net pairwise directional connectedness. To this end we estimate the following regression:

$$npdc_t^c = \kappa_0^c + \kappa_1^c D_t + \zeta_t^c \tag{6}$$

where $npdc_t^c$is the net pairwise directional connectedness for country c at time t, following Hofmann et al. (2020), D_t is a dummy variable associated with major ECB UMP news measures and announcements (it takes the value of one on the day of each announcement and two days around it, and zero elsewhere),[13] κ_0^c and κ_1^c are a constant and a slope parameter to be estimated, and ζ_t^c is the error term. In particular, κ_1^c measures the impact of each monetary policy decision. To ensure that the announcement dummies do not pick up the effects of other monetary measures nor macroeconomic or financial risk,[14] we introduce several control variables in the model. The change in the main refinancing operations (ΔMRO) rate[15] is used to capture conventional monetary policy measures; stock market volatility (VOL)[16] is introduced as an indicator of general economic conditions[17]; the TED spread (TED), which is the difference between the three-month Treasury bill and the three-month LIBOR based in U.S. dollars[18] proxies global funding liquidity risk; whilst bond market volatility (MOVE) is used as a measure of Treasury rate volatility through options pricing.

3.3. Assessing the determinants of the detected subperiods of risk transmission from liquidity risk to credit risk

As further analysis, we use Probit models to examine the determinants of the detected subperiods of risk transmission from liquidity to credit. To that end, we define a new dependent variable (y) that takes the value one if we have detected such subperiods and zero otherwise. The goal is to quantify the relation between a set of potential instruments (X) and the probability of occurrence of such an event (y).

Concretely, we adopt a specification designed to handle the requirements of binary dependent variables, modelling the probability of observing a value of one as:

$$\Pr\,(y = 1 | X, \beta) = 1 - \Phi(-X'\beta) = \Phi(X'\beta) \quad (7)$$

where Φ is the cumulative distribution function of the standard normal distribution. As can be seen, we adopt the standard simplifying convention of assuming that the index specification is linear in the parameters so that it takes the form $X'\beta$.

Regarding X, we comprehensively analyse the most prominent factors proposed in the literature, considering a set of explanatory variables that not only capture fundamental economic variables and economic agents' expectations, but also indicators of the monetary policy stance and of uncertainty and risk. These variables are explained in Section 4.3.

4. Data and measures

In this section, we describe the credit measures based on the CDS premia from IHS Markit and the liquidity measure that we construct from the MTS bond data. For each, we provide a summary of descriptive statistics. In addition, we also describe the explanatory variables used in the probit analysis to examine the drivers of the spillovers from liquidity to credit risk.

4.1. Measuring credit risk

For our credit risk measures, we use the information from secondary market trading in credit default swaps (CDS) to obtain a direct real-time market measure of the size of the default component. With a CDS, the protection buyer pays a fee to the protection seller in return for the right to receive a payment conditional upon the occurrence of a credit event by the reference obligation or the reference entity. The fee is determined by the CDS premium that is traded in the CDS market and reflects the probability of a credit event, i.e., a default occurring. CDS premia are known to incorporate counterparty risk, which is the risk that the bank acting as the financial intermediary in the CDS with the end-investor fails on its obligations (Giglio, 2016). However, regulators took their lessons from the GFC and acted to reduce systemic financial risk by insisting, among others, on the interposition of a central clearing party as a

[13] The empirical literature on event studies points out that it is necessary to assume that markets are information-efficient, which means, in our case, that most cases when unconventional ECB policies have impact on the net pairwise directional connectedness happen when market expectations are formed about these measures and not when the operations are carried out. Therefore, it is important to choose an event window that is both short enough to cut down on noise from irrelevant information and long enough to pick up on potential delayed or anticipated responses from market participants. By extending the event window to two days, we allow for possible anticipated and delayed reactions to the news by market participants. We also considered a three-day window around the UMP events. The results are qualitatively similar but quantitatively smaller, suggesting the impact is better captured through the two-day window.

[14] We are grateful to an anonymous referee for suggesting the use of macroeconomic and financial variables as additional control variables. Their selection has been conditioned to their availability in daily frequency, though.

[15] Recall that the MRO is a key ECB interest rate that provides the bulk of liquidity to the banking system.

[16] Following Parkinson (1980), we estimate the daily variance for each national stock market indices using daily high and low prices. For market i on day t we have $\tilde{\sigma}_{it}^2 = 0.36[\ln(P_{it}^{MAX}) - \ln(P_{it}^{MIN})]^2$, where P_{it}^{MAX} it is the maximum (high) price in market I on day t, and P_{it}^{MIN} is the daily minimum (low) price. Given that $\tilde{\sigma}_{it}^2$ is an estimator of the daily variance, the corresponding estimate of the annualized daily per cent standard deviation (volatility) is $\hat{\sigma}_{it}^2 = 100\sqrt{365\tilde{\sigma}_{it}^2}$.. We use the following indices: ATX for Austria, BEL20 for Belgium, OMX for Finland, CAC for France, DAX for Germany, FTSE MIB for Italy, AEX for the Netherlands, PSI 20 for Portugal, and IBEX 35 for Spain.

[17] Numerous scholars have been interested in the use of the stock market as a leading indicator of economic activity due to the significant research that has been done on the relationship between economic activity and the stock market (see, Fama and French, 1989; Cutler et al., 1989; Chen, 1991; and Cheung and Ng, 1998; among others).

[18] Although we are aware of the existence of a series of fraudulent actions connected to the setting of the LIBOR rate, following the empirical literature, we use the TED spread defined in this way as a proxy for funding illiquidity (see, e.g., Brunnermeier, 2009 and Bianchi et al., 2010).

counterparty between banks. CDS premia are also known to incorporate regulatory risk, as regulators also insisted that banks receive higher capital charges for uncollateralised derivatives transactions, giving rise to a phenomenon such as safe-haven CDS premia (Klingler and Lando, 2018). However, the rise of central clearing parties and the increased standardisation in the CDS market in the decade following the GFC, which have in turn facilitated the netting of exposures among banks, has arguably decreased both counterparty and regulatory risk in CDS premia.[19] The CDS premia are, therefore, the best available proxy for the credit risk in bonds. This is also corroborated by the frequent use of CDS premia in studies that aim to empirically disentangle credit and liquidity risk in euro area sovereign bond yields or spreads [see, e.g., Beber et al. (2009), Ejsing et al. (2015), Pelizzon et al. (2016), Dufour et al. (2017), Schwartz (2019) or O'Sullivan and Papavassiliou (2020), to name a few][20] as well as in several contagion studies of these bonds in stress periods.[21] Furthermore, several empirical studies show that the liquidity premium in CDS spreads is lower than in bond spreads.[22] This holds in particular for fixed maturity CDS, especially the 5-year CDS. Studies that consider the lead-lag in the price discovery process for euro area sovereign risk document that CDS spreads lead government bond prices in normal times in the case of peripheral countries with mixed evidence for core countries, and that the CDS lead is weakened and the relation may reverse in flight-to-liquidity episodes, or at times when the ECB provides ample liquidity though it's UMPs, especially in the periphery [see, e.g., Coudert and Gex (2013), Gyntelberg et al. (2018), Anelli et al. (2021), or Anelli and Patanè (2022)]. Agiakloglou and Deligiannakis (2020) find that the relation between EU government bond yields and their associated CDS spread is time-varying and that a significant credit event can alter it. These various results provide a strong hint to the time-varying and country-varying interplay of liquidity and volatility with credit risk in euro area sovereign bond yields.

We take the CDS data for the contracts where each of our ten euro area sovereigns is the single-name reference entity in the swap contract. There is ample liquidity in single-name euro area sovereign CDS, particularly at the 5-year maturity.[23] We take the series that string together the premia for the 5-year for our sample period. The CDS spreads are available to us on a daily basis from IHS Markit, which is the market's most extensive source of CDS data. Table 1 presents the descriptive statistics of our credit measure based on this CDS data, organized by country.

Differences in CDS spreads are high in the euro area over our sample period. This is not only obvious from the mean (ranging from 312.92 bps for Portugal to 29.35 bps for France) and the median (ranging from 208.21 bps for Portugal to 22.03 bps for Germany), but also from various volatility indicators such as the max-min (ranging from 1563.06 bps to 89.72 between Portugal and France) and the standard deviation in CDS spreads (ranging from 296.07 and 17.57 between Portugal and France). In particular, Table 1 shows that the difference between the maximum and minimum values is elevated at the 5-year maturity for Ireland, Italy, Portugal and Spain and the standard deviation is also high for those countries as well as, marginally so, for Belgium. This suggests that investors' concerns in times of stress are decidedly expressed in the near term (5-year maturity) for the lower credit-rated countries with a weaker fiscal stance.

4.2. Measuring liquidity

We take our bond price information from the MTS secondary market inter-dealer trading platform.[24] Dunne et al. (2006), Coluzzi et al. (2008) and Buis et al. (2020) describe MTS as the leading interdealer electronic trading platform for euro area sovereign and quasi-sovereign bonds. Since the quotes that are posted by the dealers on the platform are immediately tradeable and can be executed instantly, MTS is essentially an order-driven market [see e.g., Cheung et al. (2005), Caporale and Girardi (2013) or Darbha and Dufour (2013)]. A record of the high-frequency quotes and trading data is one of a very large centralized transparent electronic limit order book for euro area sovereign bonds. Dufour and Skinner (2004) give a comprehensive description of the MTS high-frequency data. We obtain the record for the three best bid and ask prices for all individual straight fixed coupon bonds from ten euro area sovereigns quoted MTS intra-day with the accompanying volumes between January 2008 and December 2018.[25]

[19] The BIS Quarterly Review of June 2018 on the CDS market (see Aldasoro and Ehlers, 2018) reports that the share of outstanding amounts cleared via central counterparties has risen rapidly, from 17% in mid-2011–55% at end- 2017, while the share of inter-dealer trades has fallen, from 53% to 25%.

[20] The choice of CDS spreads as a proxy for sovereign credit risk is a much better option than yields' spreads, which are likely to be highly connected to the bond quote and transaction prices that are also used to calculate our liquidity measure based on the slope. Therefore, we follow common practice in the literature that empirically tries to differentiate between credit and liquidity risk in euro area sovereign yields and use CDS premia as a proxy of credit risk.

[21] See Beirne and Fratzscher (2013) or Caporin et al. (2018) among them.

[22] See, e.g., Longstaff et al. (2005), Cossin and Lu (2005), Crouch and Marsh (2005) or Zhu (2006).

[23] The BIS Quarterly Review of June 2018 on the CDS market (see: Aldasoro and Ehlers, 2018) reports that outstanding notional amounts on sovereign entities increased substantially in the aftermath of the GFC and during the euro area crisis, from around USD 1.6 trillion (3.4% of the market) in mid-2007 to around USD 3.3 trillion (13.3%) at mid-2013, pointing to the role of growing solvency concerns in the euro area in late 2011 and the first half of 2012. A ban on short sales of European sovereign debt, introduced by Germany in May 2010 and permanently adopted by the European Union in November 2012, may have nudged investors towards replicating these exposures by buying CDS contracts instead. The share of sovereign reference entities in the overall market continued to rise, reaching around 16% at end-2017, even though gross notional amounts declined.

[24] García and Gimeno (2014), De Santis *et al.* (2014) and Schwarz (2019) proxy liquidity risk with an agency-sovereign bond spread. These are however not available for all euro area countries in our sample.

[25] The euro area countries in our dataset are Austria (AT), Belgium (BE), Finland (FI), France (FR), Germany (GE), The Netherlands (NL), Ireland (IE), Italy (IT), Portugal (PT), and Spain (SP).

Table 1
Descriptive statistics of our credit measure (CDS).

5-year maturity										
	ATCDS	**BECDS**	**FICDS**	**FRCDS**	**GECDS**	**IECDS**	**ITCDS**	**NLCDS**	**PTCDS**	**SPCDS**
Mean	55.60	77.07	59.63	29.35	31.02	196.11	181.27	39.20	312.92	158.51
Median	31.35	46.86	42.85	25.00	22.03	76.26	146.31	30.50	208.21	97.11
Maximum	273.00	405.85	250.34	93.92	121.51	1195.57	594.66	137.49	1581.66	642.42
Minimum	6.00	11.60	6.70	4.20	4.50	17.50	22.00	6.50	18.60	17.10
Std. Dev.	50.70	73.66	48.85	17.57	23.87	226.22	114.25	29.12	296.07	128.28
Skewness	1.61	1.76	1.77	1.69	1.54	1.54	1.50	1.45	1.70	1.43
Kurtosis	5.10	5.35	5.68	5.39	4.78	4.25	5.00	4.48	5.22	4.37
Jarque-Bera	1676.99	2034.95	2235.22	1936.78	1442.04	1259.04	1479.30	1196.94	1867.88	1140.55
p-value	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Observations	2721	2725	2725	2722	2725	2722	2725	2722	2725	2725

Note: AT, BE, FI, FR, GE, IE, IT, NL, PT and SP stand for: Austria, Belgium, Finland, France, Germany, Ireland, Italy, The Netherlands, Portugal and Spain.

Our sample period includes the nadir of the GFC in 2008, the European sovereign debt crisis that started in 2009, and the UMPs implemented or announced by the ECB to contain this crisis in this and the following years. Those policies are presented in Appendix 1.

We follow Coluzzi et al. (2008), Ejsing and Sihvonen (2009) and Buis et al. (2020) in the selection of the three most commonly used liquidity measures from the MTS limit order book. These three measures are based on the bid-ask spread representing the tightness of liquidity, on the volumes quoted with these prices representing the depth of the liquidity, and on a slope measure from price and volume quotes representing the breadth of liquidity. However, price (e.g., bid-ask spreads) or volume (e.g., quoted volume) based liquidity measures focus on a single dimension of liquidity. While both are frequently used in the literature, they allow for the limit case of a very tight spread but virtually no tradeable volume. Conversely, the posted volume could be copious at an unreasonably large spread. In either limit case, such liquidity measures would contradict. For this reason, the selected measure of liquidity in our analysis will be the liquidity slope measure (LSM) since it encompasses both price and volume information. The LSM is formulated as volume by price. In other words, one can think of the slope as, very roughly, the bid-ask divided by the volume.

In following Wuyts (2008) and Buis et al. (2020), we define the LSM as:

$$l_{\tau,LSM} = \frac{1}{n}\sum_{i=1}^{n}\frac{\left(p_{i,\tau,a} - \frac{1}{2}\left(p_{1,\tau,b} - p_{1,\tau,a}\right)\right)}{\sum_{k=1}^{i} V_{k,\tau,a}} + \frac{1}{n}\sum_{i=1}^{n}\frac{\left(\frac{1}{2}\left(p_{1,\tau,b} - p_{1,\tau,a}\right) - p_{i,\tau,b}\right)}{\sum_{k=1}^{i} V_{k,\tau,b}}, \quad (8)$$

where $p_{i,\tau,b} = p_{1,\tau,b}, \ldots, p_{n,\tau,b}$ is defined as the set of n bid prices at time τ, which in the order book is uniquely mapped to their quoted volumes $V_{i,\tau,b}$ and $V_{i,\tau,a}$ respectively via their rank i. Similar to Pelizzon et al. (2016) and Buis et al. (2020), we only take quotes inside the 09:00–17:00 time interval. Like Buis et al. (2020), we take the average slope of the price increments from the midpoint over the cumulative limit order book volume posted and aggregate the slopes on the bid- and ask-side. To prevent that premium' bonds are penalized, the LSM is scaled by the mid-price. The resulting LSM can be interpreted as an elasticity of supply and demand.

When creating our liquidity measures for the individual bonds, we aggregate the high-frequency data to the daily level, to match the frequency of our CDS spreads. Similar to Buis et al. (2020), we create a time-weighted measure in interval t for the LSM measure and the Υ_t snapshot in time that the measure uniquely belongs to, by:

$$l_{t,LSM} = \frac{\sum_{\tau=1}^{\Upsilon_t} \omega_{t,\tau} l_{t,\tau,LSM}}{\sum_{\tau=1}^{\Upsilon_t} \omega_{t,\tau}} \quad (9)$$

where $\omega_{t,\tau}$ is defined as the length of time where the order book remains constant.

From the liquidity measures of all individual bonds, we then construct liquidity measures for each sovereign k where $k = 1, \ldots, 10$ for maturity m, being $m =$ 5-years in our study. We string together the respective liquidity measure belonging to the bond of the same sovereign k that is at each daily observation the closest to but does not exceed maturity m. This method has the effect of always relying on the bond with the so-called benchmark status at the 5-year maturity for the calculation of the liquidity risk and is the preferred method for our analysis. The $l_{t,k,m,LSM}$ based on the nearest-to-maturity bond, combining price and volume aspects for the benchmark bond, is the selected liquidity measure that we will use in our study. Table 2 presents the descriptive statistics of this liquidity measure organized by country.[26]

Table 2 shows that differences in liquidity measured by the slope measure (LSM) are significant in the euro area over our sample period. Peripheral countries' sovereign bond markets turn out to be the least liquid on this measure and market liquidity present the highest volatility, while central countries' markets are the most liquid with lower volatility. Concretely, Ireland appears as the least

[26] Note that low liquidity is associated with liquidity risk, as it signals the lack of marketability of an investment that cannot be traded quickly enough in the market without impacting the market price.

Table 2
Descriptive statistics of our liquidity measure (LSM).

5-year maturity										
	ATLSM	**BELSM**	**FILSM**	**FRLSM**	**GELSM**	**IELSM**	**ITLSM**	**NLLSM**	**PTLSM**	**SPLSM**
Mean	4.47E-08	1.88E-08	4.48E-08	1.89E-08	2.53E-08	3.86E-07	4.52E-08	1.28E-08	2.82E-07	4.25E-08
Median	2.83E-08	7.06E-09	1.71E-08	8.63E-09	9.60E-09	5.65E-08	1.62E-08	6.25E-09	4.98E-08	1.82E-08
Maximum	3.83E-06	4.38E-06	1.00E-05	9.05E-06	9.20E-06	1.94E-05	5.06E-06	9.44E-06	1.06E-05	9.86E-06
Minimum	2.03E-09	7.92E-10	7.75E-10	1.22E-09	9.61E-10	1.14E-09	1.42E-09	1.13E-09	1.08E-09	1.22E-09
Std. Dev.	1.02E-07	8.89E-08	3.72E-07	1.75E-07	2.23E-07	9.05E-07	1.47E-07	1.81E-07	6.08E-07	1.99E-07
Skewness	21.91266	43.71632	24.92833	50.18531	33.60671	6.363947	18.80940	51.66522	5.15972	44.40443
Kurtosis	717.35	2124.957	641.7114	2579.741	1244.644	88.22564	548.7843	2686.799	51.81901	2173.847
Jarque-Bera	58,157,928	5.12E+ 08	46,601,803	7.55E+ 08	1.76E+ 08	843,093.3	3.38E+ 07	8.19E+ 08	282,694.5	5.36E+ 08
p-value	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Observations	2725	2725	2725	2725	2725	2725	2725	2725	2725	2725

Note: AT, BE, FI, FR, GE, IE, IT, NL, PT and SP stand for: Austria, Belgium, Finland, France, Germany, Ireland, Italy, The Netherlands, Portugal and Spain.

liquid market both according to the mean and the median (they reach the highest value for this country), while the Netherlands is the more liquid (all indicators show the lowest value for this country).

Tables 1 and 2 show significant differences in credit and liquidity risk in the countries in our sample over the period 2008–2018. This fact alone is an important justification for carrying out a country-by-country analysis. Additionally, there is broad literature providing evidence that the euro area has experienced recurrent fragmentations in its sovereign debt markets since the outbreak of the GFC and the doom-loop between its sovereign debt crisis and the crisis of its banking sector [see, e.g., Fabozzi et al. (2016), Constantini and Sousa (2022), Eijffinger and Pieterse-Bloem (2022) or De Vette and Mosk (2022), among others]. In this respect, Hoffman *et al.* (2020) state that since the euro area is a heterogeneous currency area, both crises had a varied impact, with the southern countries being more strongly affected than the northern ones. In that context, the ECB's UMP measures were in part aimed at offsetting mixed crisis effects, which was reflected in a varied impact of the measures across countries. Indeed, when in July 2022 the ECB raised the official interest rate for the first time in eleven years, President Christine Lagarde maintained that "the ECB was ready to use a wide range of instruments to address fragmentation". Considering that heterogeneity in sovereign debt markets across the euro area is a fact, it is very important to implement a country-by-country analysis, as we do here, to be able to detect disparities across countries.

4.3. Disentangling the key drivers of the spillovers from liquidity risk to credit risk

When analysing the time-varying behaviour of the indicator of net connectedness between sovereign credit and liquidity risks, we observe that for most periods the net pair-wise directional connectedness is from credit risk to liquidity risk, but we also detect some subperiods where the net pair-wise directional connectedness goes from liquidity risk to credit risk. To identify the key drivers of the probability of such events, we adopt an eclectic approach and use an extensive set of variables that include: (1) fundamental macroeconomic variables; (2) variables measuring monetary policy; and (3) variables that gauge uncertainty. Table 3 presents the definitions and sources of the variables used in our analysis.

Regarding the variables that capture the macroeconomic environment (both for each country and for the euro area as a whole), we include inflation rates (INF), gross domestic product (GDP), industrial production (IND), the OECD composite leading indicator (LEAD), and the fiscal position through government debt-to-GDP (DEBT) and government deficit-to-GDP (DEF) ratios. To measure the monetary policy stance, we use M1 and M3 monetary aggregates and the shadow short rate (SSR), which is a proxy for conventional and unconventional monetary shocks.[27] Finally, to gauge overall uncertainty and risk, we make use of indicators that measure global and euro area expectations of future volatility in stocks markets (VIX and Vstoxx, respectively), a measure to account for national stock market volatility (VOL), a proxy for bond volatility (MOVE), the cross-currency basis swap spread at 5-year (CCBSS5y) as a proxy for euro area funding liquidity stress, the euro area and national composite indicators of systemic stress (EACIIS and CIIS, respectively) which aim to measure the state of instability in the financial system as a whole or, equivalently, the level of "systemic stress" (the amount of systemic risk which has already materialized), the euro area and national composite indicators of systemic sovereign stress (EASovCISS and SovCISS, respectively) which quantify tensions in sovereign bond markets, and the European, global and (when available) national economic policy uncertainty index (EUEPU, GEPU and EPU, respectively) which proxy uncertainty primarily related to economic policies and financial decisions.[28]

5. Empirical results

5.1. Dynamic net pairwise directional connectedness

To examine the dynamic dependence between sovereign credit and liquidity risks at the 5-year maturity, we compute the net pairwise directional connectedness. The results are illustrated in Table 4 and Figs. 1 and 2. Following Pelizzon et al. (2016), we conduct our analysis after winsorizing the data at the 1% level to diminish the importance of outliers.[29]

To provide a measure of the intensity of interdependence between them, we calculate the net pairwise directional spillovers across the sovereign risk indicators under study as the difference between shocks transmitted from credit risk to liquidity risk and shocks transmitted from liquidity risk to credit risk in each country. Therefore, the positive (negative) values indicate a source (recipient) of

[27] The shadow short rate is a synthetic summary measure that is derived from yield curve data and essentially reacts to the degree to which intermediate and longer maturity interest rates are lower than would be expected if a zero-policy rate prevailed in the absence of unconventional policy measures (see Krippner, 2014 and Damjanović and Masten, 2016).

[28] These indices are based on monthly searches in the press and represent the volume of newspapers articles that simultaneously contain words related to the notion of "uncertainty", "economy", and "policy" (Baker et al., 2016). They proxy policy-related economic uncertainty that may lead businesses and individuals to delay spending and investments because of uncertainty in the market. See Al-Thaqeb and Algharabali (2019) for a review of the impact of economic policy uncertainty on financial markets and risk management.

[29] All results are based on a VAR model of order 2 and generalised variance decompositions of 10-week-ahead forecast error. The number of lags is selected using the Bayesian information criterion (BIC), which renders more parsimonious models than alternatives, such as the Akaike information criterion (AIC), the Hannan–Quinn information criterion (HQC) and the Akaike's final prediction error criterion (FPE), which in turn leads to better inferences in a TVP-VAR set-up, as the model can get overparameterized very quickly (see, e.g., Korobilis and Yilmaz, 2018). To check for the sensitivity of the results to the choice of the order of VAR, we also calculate the spillover index for orders 2 through 4, as well as for forecast horizons ranging from 4 weeks to 10 weeks. The main results of our paper are not affected by these choices. Detailed results are available from the authors upon request.

Table 3
Potential drivers of the probability of net connectedness from liquidity risk to credit risk.

	Variable	Definition	Source
	INF	Inflation rate based on the Harmonized Index of Consumer Prices	Eurostat
Fundamental Macroeconomic	GDP	Gross Domestic Product	Eurostat
	IND	Total industry excluding construction	Main Economic Indicators, Organization for Economic Co-operation and Development
	LEAD	Leading Indicator	Main Economic Indicators, Organization for Economic Co-operation and Development
	DEBT	General government debt as a percentage of gross domestic product	Eurostat
	DEF	General government deficit/surplus as a percentage of gross domestic product	Eurostat
	M1	Currency in circulation and overnight deposits	International Financial Statistics, International Monetary Fund
Monetary Variables	M3	M1 plus deposits with agreed maturity up to two years, deposits redeemable at notice up to three months, repurchase agreements, money market fund shares and money market paper, and debt securities up to two years.	International Financial Statistics, International Monetary Fund
	SSR	Shadow short rate	https://www.rbnz.govt.nz/research-and-publications/research-programme/additional-research/measures-of-the-stance-of-united-states-monetary-policy/comparison-of-international-monetary-policy-measures
	VIX	CBOE Volatility Index	Chicago Board Options Exchange
	Vstoxx	EURO STOXX 50 Volatility Index	Investing.com
	VOL	Measure of stock market volatility	Own estimations (see footnote 15)
	MOVE	Measure of bond volatility	Bloomberg
	CCBSS5y	Cross-currency basis swap spread at 5 year	Bloomberg
	EACIIS	Euro area Composite Indicator of Systemic Stress	Statistical Data Warehouse, European Central Bank
Uncertainty Variables	CIIS	Composite Indicator of Systemic Stress	Statistical Data Warehouse, European Central Bank
	EASovCISS	Euro area Sovereign Systemic Stress Composite Indicator	Statistical Data Warehouse, European Central Bank
	SovCISS	Sovereign Systemic Stress Composite Indicator	Statistical Data Warehouse, European Central Bank
	EUEPU	European Economic Policy Uncertainty Index	https://www.policyuncertainty.com/
	GEPU	Global Economic Policy Uncertainty Index	https://www.policyuncertainty.com/
	EPU	National Economic Policy Uncertainty Index	https://www.policyuncertainty.com/

Table 4
Net connectedness between liquidity and credit risks in euro area countries: 2008–2018.

PANEL A: PERIPHERAL COUNTRIES						
	IRELAND	ITALY	PORTUGAL	SPAIN		
Total observations	2716	2716	2716	2716		
Positive (credit risk=>liquidity risk)	1889	2162	2047	1839		
Negative (liquidity risk=>credit risk)	827	554	669	877		
Credit risk = >Liquidity risk	70%	80%	75%	68%		
Liquidity risk = >Credit risk	30%	20%	25%	32%		
PANEL B: CENTRAL COUNTRIES						
	AUSTRIA	BELGIUM	FINLAND	FRANCE	GERMANY	NETHERLANDS
Total observations	2716	2716	2716	2716	2716	2716
Positive (credit risk=>liquidity risk)	1788	2111	1871	2057	2058	2231
Negative (liquidity risk=>credit risk)	928	605	845	659	658	485
Credit risk = >Liquidity risk	66%	78%	69%	76%	76%	82%
Liquidity risk = >Credit risk	34%	22%	31%	24%	24%	18%

risk transmission to (from) liquidity risk.

Table 4 shows that in the ten countries in our sample, during most of the sample period (2008–2018), credit risk drives liquidity risk. Overall, results are quite similar for peripheral and central countries. Concretely, Panel A shows that, in the case of peripheral countries, this percentage ranges from 68% (Spain) to 80% (Italy). For central countries, Panel B indicates that the percentage of computed values that are positive is equally high as for peripheral countries and ranges between 66% (Austria) and 82% (The Netherlands). However, differences increase if we compare the different countries individually. While three countries register a percentage close to or above 80% (the Netherlands, Italy and Belgium), the percentage does not reach 70% in the case of Finland, Austria, and Spain. All in all, according to these results, credit risk is identified in most cases as the net transmitter to liquidity risk. When credit risk rises (falls), the bid-ask spread on euro area government bonds tends to widen (tighten) and/or volumes traded tend to fall (rise). In other words, when credit risk rises, investors demand a higher liquidity premium or reduce their risk by transacting less, and when credit risk falls the liquidity premium also falls and investors are comfortable transacting in larger volumes.

Figs. 1 and 2 display the dynamic behaviour of the net connectedness indicator in peripheral and central countries respectively.

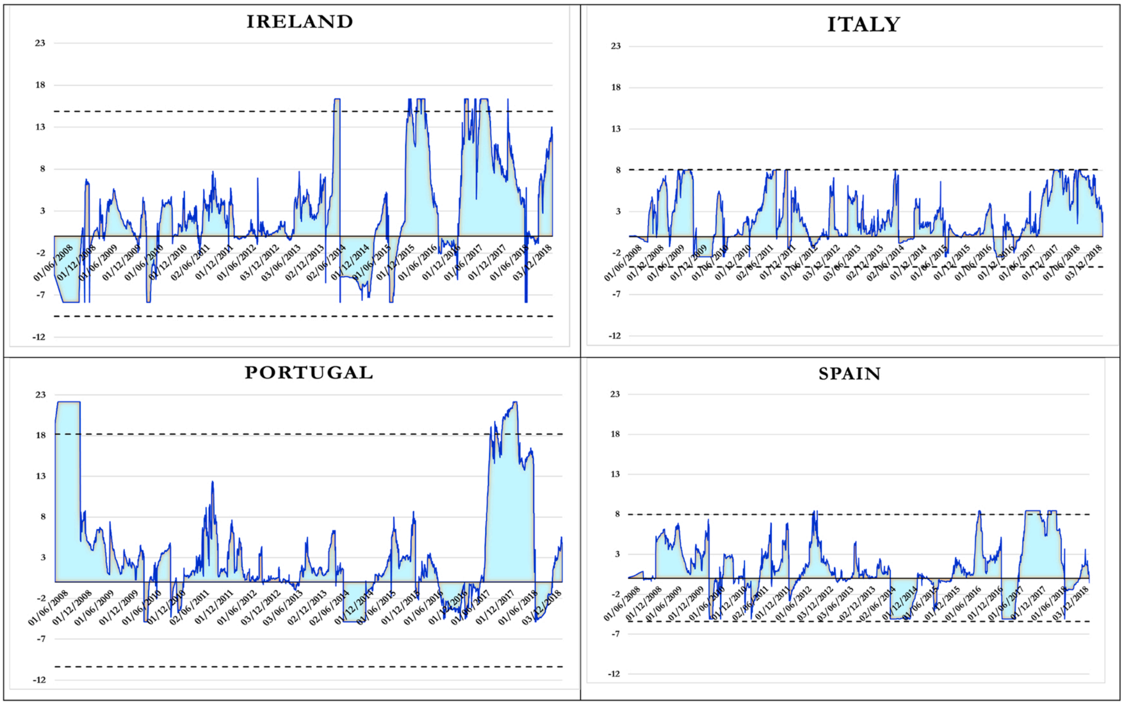

Fig. 1. Dynamic net connectedness from credit to liquidity risk in euro area peripheral countries: 2008–2018.

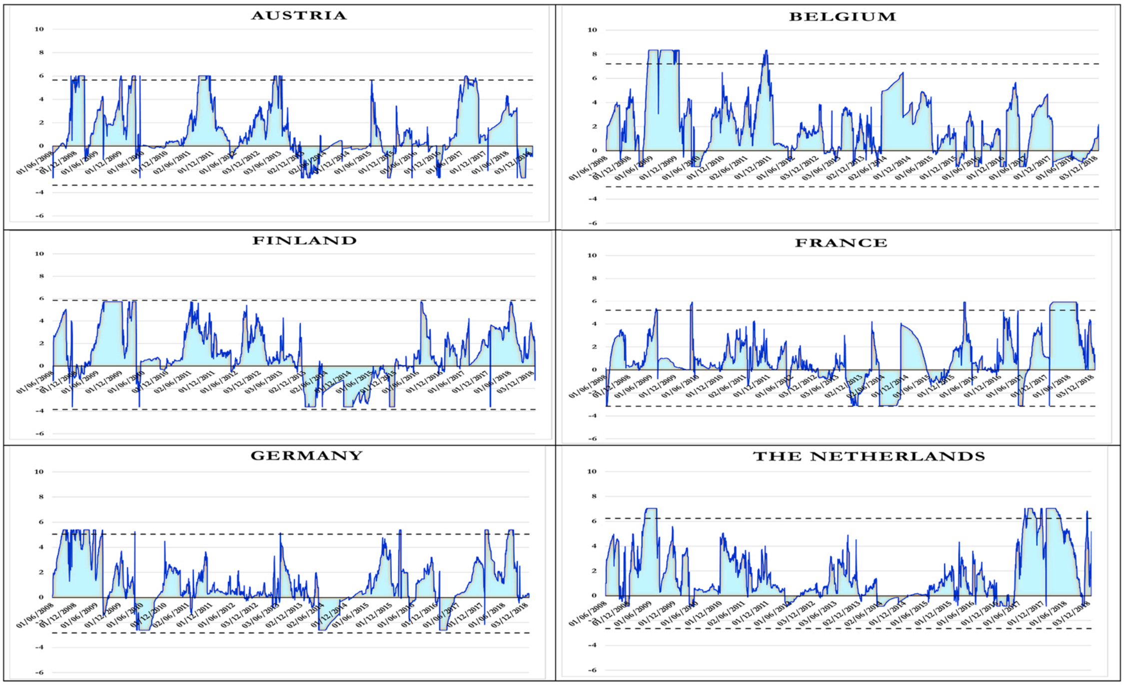

Fig. 2. Dynamic net connectedness from credit to liquidity risk in euro area central countries: 2008–2018.

These figures show that although, on average, credit risk triggers liquidity risk during the period 2008–2018, in around one-third of the sample period the net connectedness indicator becomes negative, meaning that it is liquidity risk that drives credit risk. Our econometric approach allows a two-way relation between variables and the tracking of the evolution of spillovers over time seems to encompass the results in Pelizzon et al. (2016) and O'Sullivan and Papavassiliou (2020). The first find a significant Granger-causality parameter from credit risk to liquidity risk for Italy between July 2010 and January 2013, which we confirm with our result that interconnectedness in that country runs mostly from credit risk to liquidity risk in that period (see Fig. 1), and in 80% of cases for the broader period of 2008–2018. The latter find that liquidity risk can affect credit risk across core and periphery country groups between January 2008 and December 2013. Through our time-varying results, we can confirm that in this period, as well as in the subsequent five years, there are indeed episodes in all individual countries where liquidity is rather a net trigger of risk. Pelizzon et al. (2016) provide a theoretical framework modelled on the trading behaviour of market makers that grounds the credit-to-liquidity relation in theory. We are not aware of any paper that gives equal theoretical grounding to the empirical phenomenon that the relation can run from liquidity to credit risk. Pastor and Stambaugh (2003) investigate whether market-wide liquidity associated with temporary price fluctuations induced by order flow is a state variable important for pricing US stocks. They argue that liquidity risk, namely the possibility that liquidity may be scarce precisely when a market participant wants to exit a position, is the critical aspect of liquidity that is priced. Lin et al. (2011) find that liquidity risk is similarly priced in the cross-section of US corporate bond returns. O'Sullivan and Papavassiliou (2020) establish for the Eurozone government bond market that liquidity is priced both as a characteristic and as a risk factor, even when controlling for credit risk. Clancy et al. (2019) include two trading aspects in their explanation, being hedging behaviours of dealers (referencing Dunne, 2019) and information linkages between dealers across markets (referencing Cespa and Foucault, 2014) as two other potential channels. Buis et al. (2020) highlight the importance of the institutional setting of the Eurozone government bond markets, centred around the special status and role of primary dealers among the various market makers and the new issuance fee awarded to them in the primary market that significantly influences liquidity in the secondary market.

Instead of focusing on the identification of the mechanism through which the liquidity-to-credit relation works in the euro area sovereign context, we direct our attention to empirically ascertaining the possible determinants that can explain the episodes in which this occurs. However, as Ramsey (1973) points out that one of the relevant roles of empirical testing is to identify aspects of the underlying theoretical framework that require re-examination, our findings suggest the need for rigorous theoretical analysis to support the detected causal relation between market liquidity and sovereign credit risk. This is an interesting avenue for future research.

The episodes[30] for which the indicator is negative in more than eight countries[31] in our sample are presented in Appendix 2, where it can be observed that they are concentrated during the months of April-May 2010, April-October 2014, June 2015, June 2016, November-December 2016, April 2017 and October 2018.[32] In those episodes, liquidity triggers credit risk in almost all the countries in the euro area. In the next subsections, we further explore the nature and possible determinants of the occurrence of these episodes.

To verify the robustness of our results to the choice of the liquidity risk indicator, we have recalculated the dynamic net connectedness using separate indicators that offer information on the price (bid-ask spread) and quantity (volume).[33] The results, not shown here to save space but available from the authors upon request, indicate that the time profiles obtained using these alternative liquidity indicators are very similar to those reported in Figs. 1 and 2, lending further support to our results.

Finally, as an additional test to ensure the reliability of the empirical results, we have also examined the relation between sovereign credit and liquidity risks using a dynamic Granger-causality framework.[34] In particular, we apply Hsiao (1981)'s sequential method to test for causality, which combines Akaike (1974)'s final predictive error and the definition of Granger-causality (Canova, 1995, 62–63), carrying out rolling regressions using a window of 200 observations. The results, not shown here but available from the authors upon request, suggest that our procedure for analysing the dynamic linkages between credit and liquidity risks using the TVP-VAR connectedness approach, by accounting for all possible cross-country relations between them, can uncover the propagation of risk shocks that are not captured by the dynamic Granger-causality tests.

5.2. Event study results

In Appendix 1 we present some major ECB UMP decisions and announcements that we use to examine whether they had an impact on the estimated net pairwise directional connectedness using an event-study approach. The appeal of event studies lies in their ability to account for different policies in a unified framework (including the announcements themselves) and to determine the effects as there are no measurable quantitative interventions to evaluate the effectiveness of a given policy.[35]

Following Hofmann et al. (2020), we divide ECB UMP into two phases: (1) the period of the GFC and the subsequent euro area sovereign debt crisis from 2008 to 2012, characterised by long-term large-scale liquidity provision to banks and targeted asset purchase programmes; and (2) the period of persistently low inflation and stagnation from 2013 to 2018, characterised by forward

[30] The episodes presented in Appendix 2 correspond to the months for which the indicator is negative more than one day.

[31] Since results in Table 4 show that peripheral and central countries have similar results, we chose a rule of thumb that is based on the distribution number of countries registering a given event to guide our selection of significant episodes, being that the lower benchmark number is the mean of such distribution plus one standard deviation, resulting in eight.

[32] Some of these episodes are also identified by Motto and Özen (2022) as relevant policy events triggering large and moderate changes in euro area financial markets.

[33] We thank an anonymous referee for suggesting this robustness analysis.

[34] We are grateful to an anonymous referee for suggesting this exploratory analysis.

[35] D'Amico and King (2013) provide evidence that the stock effects of asset purchase programmes (i.e., the impact from their expected reduction in bond supply) are large while the flow effects (i.e., the impact on financial markets of the actual implementation of the measure in later periods) are relatively small.

Table 5
Event study parameter estimates.

	AT	BE	FI	FR	GE	IE	IT	NL	PT	SP
08 October 2008		-4.02 *	-2.41 **	-2.45 **	-2.37 *	-9.12 *	-2.23 *		-3.13 *	-2.37 *
		(1.34)	(1.29)	(1.18)	(0.66)	(2.63)	(0.65)		(0.92)	(0.75)
13 October 2008		-3.62 *		-2.62 *		-7.98 *	-3.48 *		-2.63 *	-3.15 *
		(1.50)		(0.84)		(2.14)	(1.02)		(0.82)	(0.98)
07 May 2009		-5.31 *		-3.58 *	-3.21 *	-6.79 *	-4.99 *	-2.23 *	-1.25 *	-4.61 *
		(1.38)		(1.12)	(1.04)	(1.97)	(0.97)	(0.71)	(0.35)	(1.52)
10 May 2010		-3.52 *	-2.78 *		-4.44 *	-6.24 *	-4.29 *		-2.21 *	-4.15 *
		(1.27)	(1.18)		(1,23)	(1.85)	(1.65)		(0.68)	(1.30)
07 August 2011	-2.40 **	-4.75 *		-4.56 *						
	(0.68)	(1.31)		(1.48)						
06 October 2011	-3.26 *	-2.96 *					-4.51 *			
	(1.10)	(1.24)					(1.50)			
05 July 2012										-5.97 *
										(1.82)
26 July 2012		-2.48	-2.17 *			-4.76 *	-2.50 *	-1.93 *	-2.92 *	-4.45 *
		(1.34)	(1.62)			(1.36)	(0.74)	(1.26	(0.85)	(1.43)
02 August 2012			-4.20 *				-2.68 *		-2.90 *	-4.57 **
			(1.31)				(0.86)		(0.93)	(1.50)
04 July 2013	-2.69 **				-3.191 *					
	(1.23)				(1.03)					
09 January 2014	-3.09 *	-3.16 *	-4.21 *	-4.17 *		-5.88 *		-2.70 *		
	(1.12)	(1.21)	(1.31)	(1.18)		(1.72)		(0.87)		
05 June 2014		-4.05 *	-3.78 *	-4.21 *	-3.71 *	-8.76 *	-3.75 *	-2.61 *	-8.74 *	-5.85 *
		(1.29)	(1.18)	(1.24)	(1.03)	(2.50)	(1.15)	(0.31)	(2.42)	(1.72)
22 August 2014		-3.96 *	-1.97 *	-3.78 *	-2.82 *	-7.87 *	-3.57 *	-1.93 *	-8.34 **	-6.44 *
		(1.28)	(0.56)	(1.18)	(0.76)	(2.18)	(1.02)	((0.60)	(3.97)	(1.89)
04 September 2014		-4.66 *		-4.22 *	-2.65 **	-7.22 *	-2.96 *	-1.75 *	-8.81 **	-6.36 *
		(1.27)		(1.22)	(1.22)	(2.12)	(0.95)	(0.51)	(4.02)	(1.79)
02 October 2014		-2.30 *		-3.22 *	-2.83 **	-8.47 *	-2.66 *	-2.16 *	-7.96 *	-6.41 *
		(1.13)		(1.01)	(1.23)	(2.54)	(0.76)	((0.72)	(2.57)	(1.82)
22 January 2015			-2.43 **							-3.01 *
			(1.18)							(0.94)
05 March 2015			-3.42 **							-3.91 *
			(1. 61)							(1.22)
09 March 2015		-3.01 **	-3.43 **			-6.23 *	-3.86 *		-4.60 *	-3.00 *
		(0.45)	(1.08)			(1–54)	(1.20)		(1.35)	(1.05)
22 October 2015	-3.57 *		-4.23 *		-3.15 *	-10.72 *			-4.36 *	
	(1.21)		(1.41)		(0,89)	(3.28)			(1.20)	
03 December 2015						-10.21 *				
						(2.83)				
21 January 2016						-12.11 *				
						(3.55)				
10 March 2016				-3.63 *		-12.18 *				
				(1.17)		(3.38)				
08 December 2016	-3.42 *	-3.39 **			-1.60 **		-2.04 **	-2.66 * *	-8.05 **	-6.37 *
	(1.10)	(1.44)			(0.73)		(0.97)	(1.14)	(2.50)	(1.88)
27 June 2017	3.65 *					12.14 *		3.58 *	14.14 *	7.57 *
	(1.15)					(3.37)		(1.17)	(4.04)	(2.16)
26 October 2017		2.78 **		2.43 **	2,88 *		4.74 *	3.59 *	17.01 *	7.33 *
		(1.38)		(1.18)	(0.96)		(1.66)	(1.26)	(5.15)	(2.22)
08 March 2018				4.63 *		6.97 **	4.15 *	5.05 *	12.94 *	7.18 *
				(1.45)		(3.29)	(1.19)	(1.41)	(3.71)	(2.25)
ΔMRO	2.63 *	1.71 *	2.79 *	2.75 *	2.11 *	2.86 *	3.75 *	2.41 *	3.61 *	2.73 *
	(1.03)	(0.55)	(0.87)	(0.83)	(0.66)	(0.73)	(1.25)	(0.73)	(1.03)	(0.78)
TED	-0.65 *	-2.63 *	-0.87 *	-0.66 *	-0.93 *	-2.89 *	-1.89 *	-0.27 *	-2.32 *	-1.29 *
	(0.14)	(0.69)	(0.15)	(0.13)	(0.27)	(0.78)	(0.46)	(0.09)	(0.66)	(0.36)
MOVE	0.30 *	0.34 *	0.77 *	0.80 *	0.55 *	0.88 *	0.91 *	0.83 *	0.85 *	0.75 *
	(0.07)	(0.02)	(0.24)	(0.23)	(0.17)	(0.24)	(0.29)	(0.26)	(0.25)	(0.23)
VOL	0.11 *	0.41 *	-0.42 *	0.42 *	0.66 *	0.55 *	0.95 *	0.40 *	0.57 *	0.45 *
	(0.03)	(0.12)	(0.12)	(0.11)	(0.21)	(0.12)	(0.31)	(0.13)	(0.17)	(0.14)

Notes: Impact estimates of the parameter K_1^C in the event study regression (6). The event dates are given in Appendix 1. AT, BE, FI, FR, GE, IE, IT, NL, PT and SP stand for: Austria, Belgium, Finland, France, Germany, Ireland, Italy, The Netherlands, Portugal and Spain. We consider two-day event windows. In the ordinary brackets below the parameter estimates are the corresponding Efron (1982)'s heteroscedastic consistent standard errors. * and * * denote significance at the 1% and 5% level respectively.

guidance, negative deposit rates and eventually large-scale public asset purchases.

Our event study regression results are shown in Table 5, where we report the estimates that are statistically significant at least at the 5% confidence level.[36]

Before discussing the results, we note that a caveat of working with daily data instead of intra-day data seems to be that it is not able to fully capture the effect of asset purchases that the ECB made under interventionist programs aimed to improve monetary transmission by addressing tensions in bond markets of individual member states. The Securities Markets Programme (SMP) is an interventionist program, where market participants only knew which countries were in the program but very little about the timing and amounts bought by the ECB. Ghysels et al. (2017) indeed show that the impact of the SMP is biased downwards when using daily data. This caveat is limited to the SMP program though. As the focus of asset purchases shifts from 2014 onwards to monetary easing, the ECB significantly widens the scope of its asset purchases, and unlike the SMP, pre-announced amounts for the total program for a set of months going forward are provided to market participants, as well as much more detail on the types of securities involved. While Altavilla et al. (2019) show with Thomson Reuters tick data that there are significant yield effects from ECB official monetary policy announcements, in the small time-window around the press release and press conference moments, the vast majority of studies are able to otherwise record significant effects from the announcement and actual asset purchases of the ECB's UMPs using daily data.[37]

Particularly, in the case of our event study, Table 5 indicates that the introduction of the new SMP and reactivation of fixed-rate full allotment for longer-term refinancing operations (LTROs) on 10 May 2010 are negatively significant, meaning that they reduce the net risk propagation from credit to liquidity risk, in almost all the countries and, in particular, in peripheral countries (Ireland, Italy, Portugal and Spain). We recall that between 2008 and 2010, banks outside the large euro area countries were the main borrowers in the Euro-system's liquidity operations, in particular Greek and Irish banks, reflecting the banking strains in these countries. Then, since 2011, Spanish and Italian banks become the main takers of Euro-system liquidity, reflecting the spreading of the euro area sovereign debt crisis to these economies (see Hofmann et al., 2020). Therefore, our results suggest that ECB interventions (by means of SMP and LTROs) lead to a reduction of credit risk (especially, in the most stressed countries) and, consequently, the transmission of risk from credit to liquidity also decreases.

These results are in concordance with previous empirical studies.[38] Krishnamurthy et al. (2017) and Jäger and Grigoriadis (2017), for example, document that the SMP had a significant announcement effect and indicate that this effect was largest for bond yields and spreads of those jurisdictions for which purchases were expected to take place. Eser and Schwaab (2016) find, besides large announcement effects of the SMP, a measurable direct impact in reducing spreads in sovereign bonds at the 5-year maturity, which is also documented by De Pooter et al. (2018) at this maturity for countries that were in the program (Ireland, Italy, Portugal and Spain). These results might explain the important concentration of episodes where the net connectedness indicator from credit to liquidity risk is negative in April and May 2010 (see Appendix 2) when also the SMP program was active. Krishnamurthy et al. (2017) and Jäger and Grigoriadis (2017) show that LTROs had, additionally, an indirect positive effect on sovereign bond spreads via the bank credit channel, meaning that the increase in funding liquidity of banks via this expanded program increased liquidity in the euro area sovereign debt markets. There may have also been an important default risk signalling effect from both the LTROs and the SMP, as investors recognise that the direct purchases of crisis-hit bonds makes the ECB the backstop for this credit risk, both leading to a softening of credit risk in that period.

It is relevant to highlight that, as expected, the famous "whatever it takes" speech by ECB President Mario Draghi on 26 July 2012 (Draghi, 2012) also led to a significant reduction in the net pairwise directional connectedness from credit to liquidity risks (see Table 5), again mainly in euro Southern countries more hit by the sovereign debt crisis (Ireland, Italy, Portugal and Spain). This result suggests that Draghi's words had a strong impact on the most stressed sovereign markets and as their perceived credit risk declines (narrowing sovereign spreads again the German benchmark), the transmission of that risk to liquidity risk also declines.

Likewise, on 2 August 2012, the announcement of the possibility of Outright Monetary Transactions (OMT) led to a reduction in the net connectedness from credit to liquidity risk mainly in peripheral countries (Italy, Portugal and Spain). The OMT program would allow the ECB to intervene in unlimited ways in case of need, but it was never activated, although it effectively put an end to the strains in euro area sovereign bond markets (again, the perception of credit risk decreased, and with it, its transmission to liquidity risk).[39]

Table 5 also shows that the announcement in June 2014 of a reduction of the ECB's deposit facility rate (DFR) to negative values

[36] Given that the dependent variable in equation (6) is "generated", following a referee's suggestion, we compute Efron (1982)'s heteroskedastic consistent standard errors that are found to produce satisfactory results for small samples in this context (Lewis and Linzer, 2005).

[37] Papers that focus on the announcement (news) effects and/or actual asset purchases of ECB UMP on euro area sovereign bond yields or spreads, typically through event studies, panel regressions or VAR models with time-varying coefficients, use for the majority of them daily data (see, e.g., Belke and Gros, 2021; Falagiarda and Reitz, 2015; Farinha and Vidrago, 2021; Saka et al., 2015; De Pooter et al., 2018; Eser and Schwaab, 2016) or work with two-day changes when the impact is measured on Eurozone government bond yields, benchmark spreads or CDS spreads (see, e.g., Krishnamurthy *et al.*, 2018; Jäger and Grigoriadis, 2017). Occasionally for such studies, a monthly frequency of data is used (see, e.g., Lemke and Werner, 2020). Monthly data frequencies are more common when among the impact of the ECB UMP also the impact on macroeconomic variables is incorporated (see, e.g., Afonso et al., 2020; De Santis, 2020; Afonso et al., 2018; Afonso and Jalles, 2019; Blot et al., 2020; Kinateder Wagner, 2017; Lewis and Roth, 2019). Among all of those, studies that include different UMP actions and programs (such as the LTROs, SPM, OMT, APP, PEPP) do not vary their data frequency or their methodology to cater for their differences in objectives or use by the ECB.

[38] In this vein, the analysis of Pelizzon et al. (2016) also indicates that, following the LTROs of the ECB, the improvement in funding liquidity available to the banks strongly attenuated the dynamic relation between credit risk and market liquidity in Italy.

[39] However, neither Mario Draghi's words in July 2012 nor the OMTs announcement in August 2012 were enough to reverse the sign of the net connectedness between credit and liquidity risk as can be seen in Appendix 2.

jointly with the introduction of new targeted LTROs and preparations of a new asset-backed securities purchase programme (ABSPP) and the announcement in October 2014 of the details of both corporate bonds purchase programme (CBPP3) and ABSSP is negatively significant in most of the countries (Austria is the exception), meaning that the net transmission of risk from credit to liquidity decreases. These events might be behind the fact that liquidity triggered credit risk (see Appendix 2) at the 5-year maturity in June 2014 and in October 2014 in almost all the countries in our sample (Belgium and Austria are the exceptions).

Moreover, Table 5 also shows further reductions in the connectedness from credit to liquidity risk associated with ECB monetary policy decisions taking place during the 9 January 2014–22 October 2015 period, which includes the monetary policy measures launched in mid-2014 and shortly thereafter (negative interest rates, targeted long-term refinancing operations, quantitative easing –expanded APP and public sector purchase programme (PSPP)– programmes and forward guidance) aimed to stabilize markets, address market segmentation and illiquidity and safeguard the monetary policy transmission. These results corroborate the findings of Afonso and Jalles (2019), Blot et al. (2020) and Farinha and Vidrago (2021) that the asset purchase programmes that were introduced after the SMP decreased both credit and liquidity risk premia of all euro area countries (not only peripheral ones). These results might explain the concentration of episodes where liquidity is a transmitter of risk during the 2014–2016 period (as shown in Appendix 2).[40]

All in all, our findings are consistent with earlier research showing that CDS spreads help to predict government bond prices in normal circumstances, but that the relation may weaken or even revert when the ECB provides ample liquidity through its UMPs, especially in the periphery [see, e.g., Coudert and Gex (2013), Gyntelberg et al. (2018), Anelli et al. (2021), or Anelli and Patanè (2022)].

Finally, against the background of improving macroeconomic conditions, the ECB started to taper asset purchases in December 2016, ending its net purchases at the end of 2018. This is reflected in Table 5 since, during that period, UMP announcements are positively significant in most of the countries, meaning an increase in the net risk propagation from credit to liquidity at the end of the sample period. This finding is consistent with how American investors responded to the Federal Reserve's announcements of surprise asset purchases and the possibility that it would taper its asset purchases (see, e.g., Neely, 2014). Interestingly, the only exception is the initial announcement on 8 December 2016 of the tapering of purchases under the APP from April 2017. Market participants interpret this announcement as an indication that the ECB would continue injecting money in support of the euro area economy.[41] This can be taken as an example of communication that is prone to subjective interpretation and when investors interpret market movements as an indication of the interpretation of others (see, e.g., Caballo, 2017).

Regarding the control variables, our results indicate that, as suggested by the standard view of the monetary transmission, a rise in MRO has a strong, positive effect on long-term rates (Roley and Sellon, 1995), and therefore increases the relative dominance of credit risk over liquidity risk. We find that higher stock market volatility (VOL) and bond market volatility (MOVE) are also associated with an intensification of the relative influence of credit risk on liquidity risk. The opposite occurs with a rising TED, which indicates that liquidity is being withdrawn, and therefore might explain that the net propagation from liquidity to credit risk increases.

Summing up, the event study illustrates how different ECB measures, including unconventional policy actions, influence net pairwise directional connectedness of credit and liquidity risk in government bond yields of all euro area countries. These findings may offer fresh insight into the efficacy of conventional and unconventional measures intended to mitigate the negative effects of financial market disruptions on the real economy. In the following subsection, we use the SSR as a measure of conventional and unconventional monetary policy shocks[42] along with other potential variables to examine the determinants of the detected episodes when the propagation of risk goes from liquidity to credit.[43]

5.3. *Probit analysis*

For the subperiods where net pair-wise directional connectedness goes from liquidity risk to credit risk, we estimate a Probit model to comprehensively examine which variables might explain the probability that this occurs.

Core and periphery countries in the euro area underwent extremely diverse economic paths during the GFC and the European sovereign debt crisis after the adoption of the euro and a single monetary policy framework (see, e.g., Krugman and Obstfeld, 2009; or Coudert et al., 2020). Additionally, the fiscal orientation is not uniform in the euro area (Schmidt and Sigwalt, 2022) and there is a distinct break in monetary policy around 2012–2013 (Eijffinger and Pieterse-Bloem, 2022). To account for this potential heterogeneity, we systematically explore differences across the countries in our sample by estimating a specific Probit model for each of them.

[40] Only one episode, the one in June 2016, cannot be related to UMP news from the ECB. In that month the unexpected outcome of a referendum in the United Kingdom to leave the European Union, which subsequently became known as Brexit, shocked bond markets (e.g., Kadiric and Korus, 2019). In Appendix 3 we present the main economic and policy events (some of them coincide with some ECB monetary decisions and have already been presented in Appendix 1) that took place during the detected episodes of net risk transmission from liquidity to credit (see Appendix 2) to examine whether they had an impact on the change of the direction of net connectedness using an event-study approach.

[41] https://www.politico.eu/article/ecb-to-scale-back-monetary-stimulus-from-april-2017-european-central-bank-mario-draghi/

[42] Francis et al. (2020) show that Krippner's SSR offers a better proxy for the policy instrument when compared to the Wu and Xia (2013) shadow rates or a naive VAR. Claus *et al.* (2014) offer further evidence of its usefulness to quantify the effect of monetary policy shock on asset markets.

[43] Notice that some of the episodes shown in Appendix 2 where liquidity risk triggered credit risk (April 2017 and May 2018, for example) do not appear to be related to any ECB monetary policy decision.

Given that most of the instruments used as independent variables are constructed on a monthly frequency, we also need to compute the dependent variable in the Probit models on a monthly basis.[44] To do so, we first assign a value of one to the daily observation if the net pairwise directional connectedness from credit to liquidity risk is negative. In the second step, we compute the monthly data by averaging the daily observation and assigning a value of one if the resulting monthly average is greater than 0.5 (i.e., if at least for half of the month there is evidence of risk transmission from liquidity to credit).

We argue that if our selected set of potential determinants of the computed probability can adequately explain the occurrence of the net risk spillovers from liquidity to credit, these can be interpreted as the drivers of such net pairwise directional connectedness. To that end, we follow the general-to-specific approach based on the theory of reduction (Hendry, 1995).

Therefore, our empirical analysis starts with a general unrestricted statistical model including all explanatory variables presented in Table 3 and their lagged values to capture the essential characteristics of the underlying dataset. We then move in steps with our testing procedures to eliminate statistically insignificant variables. We carefully check the validity of the reductions versus old and new variable combinations at each stage to ensure congruence of the finally selected model. We thus find a parsimonious version of the initial model containing the combination of variables that best explain the occurrence of net risk transmission from liquidity risk to credit risk.[45] In Table 6 we report the final results of the Probit models estimated by maximum likelihood.[46] Given that some of the explanatory variables are generated regressors that could bias estimates (Pagan, 1984), the z-statistics in that table are based on robust standard errors computed using the cluster bootstrap method (Chen et al., 2022).[47]

The results of Table 6 show that the variables that are found to be statistically significant in reducing the probability of net transmission from liquidity risk to credit risk are either related to financial markets stress, fiscal sustainability or fluctuation of economic activity around its long-term potential level. That is (1) the composite indicator of systemic stress (CIIS); (2) the composite indicator of systemic sovereign stress (SovCISS); (3) the public deficit/GDP ratio (DEF); (4) the public debt/GDP ratio (DEBT); and (5) the OECD composite leading indicator (LEAD). Notice that, although CISS is found to be statistically significant for all the countries under study, LEAD is only significant for Austria and Germany and SovCiSS is not significant for the latter two countries. While debt dynamics matter in all countries, the relevant fiscal variable for Belgium, Ireland, Italy, and Portugal is DEBT (the countries with the highest average public debt-to-GDP ratios during the period analysed), but is DEF for the rest of the countries. All in all, according to these results when those variables are heightened, investor funds are flowing into bonds discriminately, so into safe-haven bonds more than into risky bonds, thereby reducing the dominance of liquidity risk over credit risk.

On the other hand, the variables that lead to an increase in the probability of net risk transmission from liquidity to credit are related to funding liquidity, monetary policy shocks and economic policy uncertainty. That is (1) the cross-currency basis swap spread at five years (CCBSS5y); (2) the shadow short rate (SSR); (3) the stock market volatility (VOL) index; and (4) the policy uncertainty index (EPU). Observe that while CBSS5y and SSR are significant for all countries and VOL is significant for all except Germany, EPU is only relevant for highly indebted countries. A rise in CCBSS5y indicates a reduction in funding liquidity, whilst an increase in the rest of these variables (monetary policy shocks or economic policy uncertainty) indicate that funds are flowing into bonds indiscriminately (either from the ECB through its conventional but more likely through its unconventional measures, or from risk-off flows out of equity markets, because of heightened political uncertainty), therefore liquidity risk increases, and it dominates credit risk. These results are in concordance with those presented by Damjanović and Masten (2016) regarding the near direct translation of monetary policy shocks to financing conditions of euro area countries proxied by SSR, as well as with Nagar et al. (2019), who contend that the risks of low market liquidity and reduced market efficiency always accompany periods of high uncertainty, and Będowska-Sójka and Echaust (2020), who document that investors' perception on liquidity increases when the financial market becomes more volatile.

It is interesting to notice that, except for EAEPU (that is used as a proxy when there is not a specific national EPU available for a given country), none of the variables for the euro area as a whole is found to be significant, suggesting the latent existence of market segmentation, a key feature of financial fragmentation. This finding is consistent with the results of De Vette and Mosk (2022) who find that a factor reflecting diverging dynamics across countries is a major driver of euro area sovereign credit risk and that this factor is correlated with larger differences in market liquidity conditions.

Table 6 also presents the conditional marginal effects showing the impact of a unit change in the mean value of the explanatory variables on the probability of net transmission from liquidity risk to credit risk. Focusing on our proxy for conventional and unconventional monetary shocks (SSR), the results suggest that if it increases, the probability of net risk transmission from liquidity to credit increases from 0.0044 in the case of Germany to 0.0535 in the case of Ireland, while our proxy for euro area funding liquidity stress (CCBSS5y) has a moderate positive effect (ranging from 0.0028 for France to 0.0090 for Belgium). The most intense negative effects arise from the indicators of overall (CISS) and sovereign (SovCISS:) systemic stress, varying from − 0.1401 for Belgium to − 0.8244 for Austria and from − 0.2311 for the Netherlands to − 0.4914 for Italy, respectively. Of special interest are the marginal effects of the two indicators of fiscal sustainability, with the results suggesting that if DEF increases by one percent, it will decrease the probability of net risk transmission from liquidity to credit in a range between − 0.0024 for the Netherlands to − 0.0901 for Austria, while a rise in DEBT will have a reduction in that probability fluctuating from − 0.0125 in the case of Portugal to − 0.0179 in the case

[44] For GDP, DEBT, DEF, EAINFSUR and EAACTSUR, monthly data are linearly interpolated from quarterly data. Regarding VIX, Vstoxx, VOL, MOVE and SSR, daily data are converted into monthly data by taking the mean value during the month.

[45] See Hendry and Krolzig (2005) for a detailed description of the general-to-specific approach to model selection.

[46] The results are very similar for Logit models run on the same data.

[47] Using simulation analysis, Chen et al. (2022) demonstrate that bootstrapping is effective at eliminating the generated regressor bias and offers several significant benefits that indicate that bootstrapping should be preferred in most empirical research.

Table 6
Estimated Probit regressions.

	Austria	Belgium	Finland	France	Germany	Ireland	Italy	Netherlands	Portugal	Spain
CCBSS5y	0.0232 *	0.0038 *	0.0163 * *	0.0125 *	0.0155 *	0.0214 *	0.0096 *	0.0083 *	0.0253 *	0.0195 *
	(2.85)	(2.92)	(2.37)	(2.71)	(2.95)	(2.91)	(2.91)	(2.85)	(2.93)	(2.90)
	[0.0082]	[0.0090]	[0.0053]	[0.0028]	[0.0050]	[0.0075]	[0.0028]	[0.0023]	[0.0071]	[0.0068]
VOL	0.0534 *	0.0422 *	0.0523 *	0.0281 *		0.0533 *	0.0571 *	0.0525 *	0.1228 *	0.0272 *
	(2.92)	(2.85)	(3.19)	(3.01)		(2.97)	(2.85)	(2.94)	(2.83)	(2.94)
	[0.0189]	[0.0100]	[0.0171]	[0.0060]		[0.0187]	[0.0163]	[0.0131]	{0.0344}	[0.0095]
SSR	0.0586 *	0.1785 *	0.0633 *	0.0941 *	0.0135 *	0.1592 *	0.1907 *	0.0231 *	0.0728 *	0.0382 *
	(3.03)	(2.94)	(2.93)	(3.17)	(2.93)	(2.97)	(2.93)	(2.88)	(2.91)	(2.87)
	[0.0207]	[0.0422]	[0.0207]	[0.0156]	[0.0044]	[0.0535]	[0.0692]	[0.0058]	[0.0204]	[0.0133]
EUEPU									0.0101 *	
									(2.97)	
									[0.0028]	
EPU		0.0016 *				0.0014 *	0.0052 *			
		(2.87)				(2.92)	(2.84)			
		[0.0039]				[0.0005]	[0.0015]			
CISS	-4.5573 *	-0.9635 *	-3.8528 *	-2.3862 *	-2.1561 *	-1.2590 * *	-1.4268 * *	-2.7443 *	-0.8584 *	-3.6837 *
	(−2.78)	(−2.90)	(−3.11)	(−3.09)	(2.99)	(−2.49)	(−2.37)	(−2.91)	(−2.85)	(2.97)
	[− 0.8244]	[− 0.1401]	[− 0.3749]	[− 0.3806]	[− 0.4456]	[− 0.2154]	[− 0.2670]	[− 0.4277]	[− 0.2420]	[− 0.6526]
LEAD	-0.2552 *				-0.0012 *					
	(−2.87)				(−2.87)					
	[− 0.0901]				[− 0.0034]					
SovCISS		-0.1428 * *	-- 1.7260 *	-1.8284 * *		-1.3965 * *	-1.4268 *	-1.3368 *	-0.9240 *	-1.2754 *
		(−2.40)	(−3.26)	(−2.37)		(−2.34)	(−2.95)	(2.96)	(−2.92)	(−2.81)
		[− 0.3318]	[− 0.2618]	[− 0.2900]		[− 0.4392]	[− 0.4914]	[− 0.2311]	[− 0.3773]	[− 0.4468]
DEF	-0.0884 * *		-0.0425 *	-0.0586 *	-0.1411 *			-0.0087		-0.0390 *
	(−1.99)		(−2.98)	(2.78)	(2.89)			(−2.87)		(−2.88)
	[− 0.0901]		[0.0139]	[0.0131]	[− 0.0455]			[− 0.0024]		[− 0.0136]
DEBT		-0.0758 *				-0.0140 *	-0.0160 *		0.0126 *	
		(−2.51)				(−2.87)	(−2.88)		(−2.87)	
		[− 0.0179]				[− 0.0128]	[− 0.0146]		[− 0.0125]	
Constant						0.5054 * *	1.5886 * *	1.7790 *	0.6819 *	0.2052 * *
						(2.49)	(2.38)	(2.85)	(2.84)	(2.34)
McFadden's pseudo-R^2	0.7249	0.7317	0.7071	0.7622	0.7452	0.7014	0.7224	0.7678	0.7351	0.7369
AIC	1.2669	0.9921	0.9335	0.9294	1.1715	1.2239	1.0920	0.9846	1.0137	1.2519
BIC	1.2651	1.1450	1.0864	1.0892	1.3025	1.4131	1.4231	1.1561	1.2112	1.3231
Log-likelihood	-43.96	-57.52	-54.61	-54.34	-71.32	-66.52	-66.24	-59.38	-59.92	1.2519
Wald statistic	44.11 *	48.31 *	28.21 *	31.37 *	31.10 *	49.37 *	44.86 *	54.52 * *	46.44 *	47.90 *
	{0.0000}	{0.0000}	{0.0002}	{0.0001}	{0.0000}	{0.0000}	{0.0000}	{0.0272}	{0.0000}	{0.0000}
Hosmer-Lemeshow statistic	4.74	3.58	4.78	4.67	4.15	4.88	4.51	4.43	5.40	4.62
	{0.7804}	{0.8930}	{0.7575}	{0.7383}	{0.8412}	{0.7700}	{0.8081}	{0.7951}	{0.7139}	{0.7850}

Notes: In parenthesis below the parameter estimates are the corresponding z-statistics, based on robust standard errors computed using the cluster bootstrap method. Conditional marginal effects are given in square brackets. *p*-values are given in curly brackets. * and * * denote significance at the 1% and 5% level respectively.

of Belgium.

Finally, the lower part of Table 6 reports several statistics to assess the predictive performance of our models. The Wald statistics are high in all cases, indicating that the models are statistically significant (i.e., they fit significantly better than a model with no predictors). The Hosmer-Lemeshow goodness-of-fit tests also indicate that the models fit quite well since the null hypothesis that the observed and expected or predicted probabilities are the same across different levels of predicted values cannot be rejected. The McFadden pseudo-R^2, which is the likelihood ratio index, and is an analogy to the R^2 reported in linear regression models, is estimated between 70.74% (for Ireland) and 76.78% (for the Netherlands) suggesting that in this high range, the probability of transmission from liquidity to credit risk can be explained by the identified explanatory variables. Moreover, as a further measure of the goodness-of-fit of the estimated Probit models, we compute the overall correct prediction percentage using the standard positive outcome threshold of 50%, obtaining values ranging from 70.93% to 75.92%, again for the same countries.

6. Concluding remarks

In our study of the dual interaction between credit risk and liquidity risk in the euro area sovereign bond market, we use the extension of the time-varying parameter VAR (or TVP-VAR) connectedness approach of Antonakakis et al. (2020), which not only allows us to examine the interconnection between these two sources of risk but also to characterize their dynamic connectedness. For ten euro area countries, we use trading data from IHS Markit on single-name CDS as our measure of credit risk and high-frequency data from the MTS limit order book to construct a slope from price and volume sovereign bond quotes as our measure for liquidity risk, both at a daily frequency and at the 5-year maturity for the period January 2008 to December 2018.

Using the TVP-VAR framework with these two risk measures, we estimate the net pairwise directional connectedness as the difference between shocks transmitted from credit risk to liquidity risk and shocks transmitted from liquidity risk to credit risk in each country. The net pairwise directional connectedness allows us to measure the difference in the strength of the dynamic linkages between credit and liquidity risks, and to detect their time-varying direction. From the ten indicators for the euro area countries and their behaviour over our sample period, we find our two main results. The first is that for most periods and all countries the net pair-wise directional connectedness is from credit risk to liquidity risk. The second is that the direction is time-dependent, because we also detect some subperiods where the net pair-wise directional connectedness goes in the other direction, namely from liquidity risk to credit risk.

Defining episodes as a month in which the direction runs from liquidity risk to credit risk on more than one day in at least eight countries, we establish that these pertain to the months of April-May 2010, April-October 2014, June 2015, June 2016, November-December 2016, April 2017 and October 2018. Through an event study we determine that these episodes can be related to several unconventional monetary policy (UMP) measures and announcements of the ECB, including the introduction of the SMP and reactivation of fixed-rate full allotment for LTROs (on 10 May 2010), the reduction of the deposit facility rate (DFR) to negative values jointly with the introduction of new targeted LTROs and preparations of a new asset-backed securities purchase programme (ABSPP) (in June 2014), and the announcement of the details of both corporate bonds purchase programme (CBPP3) and ABSSP (in October 2014).

For the subperiods where net pair-wise directional connectedness goes from liquidity risk to credit risk, we estimate a Probit model to determine which variables explain the probability that this occurs. We find that variables that reduce the probability of transmission from liquidity risk to credit risk are either variables associated with stress in financial markets or deterioration of fiscal sustainability in euro area countries. The ECB's UMP measures increase this probability, along with variables associated with a decline in global funding liquidity and policy uncertainty in the euro area.

This paper contributes to the sparse literature on the interaction of credit and liquidity risks in the euro area government bond market and adds to the literature on the determinants of their yields and the contagion in times of stress through the identification of the main source of risk under different circumstances. Our study confirms that the ECB's unconventional monetary policy measures have mitigated credit risk and helps identify which UMP actions and announcements have been most effective. It helps policymakers with governments in realising that typically, out of the two domestic risk factors that they can influence, that credit risk is the one to focus on (implementing measures to improve debt sustainability) as it remains the main driver of their sovereign's bond yields. However, our findings also suggest that policymakers should not disregard liquidity risk. The identification of the theoretical mechanism modelled on market participants' behaviour through which the liquidity-to-credit relation works in the euro area sovereign bond context is an interesting avenue for future research.

Declaration of interest

The authors have no declaration of interest to make.

Data Availability

Data will be made available on request.

Acknowledgements

The authors wish to thank three anonymous referees and the editor for their helpful comments and suggestions on a previous draft of this article, which have enabled them to introduce substantial improvements. This paper is based on work supported by the Spanish

Ministry of Science and Innovation [grant PID2019-105986GB-C21] and the Erasmus Trust Fund [grant 97000.2019.818/071/RB].

Appendix 1. Major ECB UMP measures and announcements

PANEL A: Phase 1: 2008–2012		
2008	Oct 8	Fixed-rate full allotment (FRFA) for main refinancing operations and corridor of the standing facilities reduced to 100 basis points
2008	Oct 13	FRFA for U.S. Dollar funding
2008	Oct 15	1) Expansion of collateral that can be used for refinancing operations and 2) FRFA for longer-term refinancing operations (LTROs)
2009	May 7	1) Introduction of new longer-term refinancing operations (LTRO) with a maturity of one year with FRFA and 2) a new covered bond purchase Programme (CBPP!)
2010	May 10	1) New Securities Market Programme (SMP) and 2) reactivation of FRFA for LTROs and U.S. Dollar funding
2011	Aug 7	Reactivation of SMP
2011	Oct 6	1) New covered bond purchase Programme (CBPP2) and 2) introduction of two new one-year LTROs
2011	Dec 1	ECB President Mario Draghi's speech at the European Parliament mentioning the importance of the European Union and hinting at potential additional aid
2011	Dec 8	1) Introduction of two new LTROs with a maturity of three years and 2) other measures to support lending and money market activity
2011	Dec 21	First three-year LTRO operation
2012	Feb 29	Second three-year LTRO operation
2012	Jul 5	Deposit facility rate (DFR) cut to zero
2012	Jul 26	ECB President Mario Draghi's speech in London stating that the ECB was ready to do "whatever it takes to preserve the euro
2012	Aug 2	Possibility of Outright Monetary Transactions (OMT) mentioned
2012	Sep 6	1) Details of technical features of the OMT Programme and 2) changes in the collateral used in the monetary operations
PANEL B: Phase 2: 2013–2018		
2013	Jul 4	Forward guidance on policy rates
2014	Jan 9	Reinforcement of forward guidance on policy rates
2014	Jun 5	1) DFR cut to − 0.1% (negative rates), 2) introduction of new targeted LTROs (TLTROs) and 3) preparations of a new asset-backed securities purchase Programme (ABSPP)
2014	Aug 22	ECB President Mario Draghi's speech in Jackson Hole stressing the decline in EMU inflation expectations and the resolve of the Governing Council to use available instruments needed to preserve price stability.
2014	Oct 2	Details of the CBPP3 and the ABSPP
2015	Jan 22	Expanded asset purchase Programme (APP) including public sector securities purchase Programme (PSPP)
2015	Mar 5	Details of the PSPP
2015	Mar 9	The first implementation of the PSPP
2015	Sep 3	Increase in the issue share limit for the PSPP
2015	Oct 22	Hint at more asset purchases
2015	Dec 3	1) DFR cut to − 0.3% and 2) extension of the APP
2016	Jan 21	Hint at more monetary easing
2016	Mar 10	1) DFR cut to − 0.4%, 2) expansion of the APP, 3) introduction of a new corporate sector purchase Programme (CSPP) and 4) announcement of new TLROs (TLTRO-II)
2016	Apr 21	Details of the CSPP
2016	Oct 20	Hint at an extension of the APP
2016	Dec 8	Tapering of purchases under the APP
2017	Jun 27	ECB President Mario Draghi's speech in Sintra mentioning strengthening and broadening of the recovery
2017	Oct 26	Further tapering purchases under the APP
2018	Mar 8	Drop of reference of readiness to increase asset purchases if needed
2018	Jun 14	Further tapering purchases of the APP, forward guidance on policy rates
2018	Dec 13	Forward guidance on reinvestment of principal payments from maturing securities

Source: Hofmann et al. (2020)

Appendix 2. Episodes where liquidity risk triggered credit risk in at least 8 out of 10 countries in our sample

	IE	IT	PT	SP	AT	BE	FI	FR	GE	NL
April 2010	X	X	X	X	X	X	X	X	X	X
May 2010	X	X	X	X	X	X	X	X	X	X
April 2014	X	X	X	X	X	X	X	X	X	X
May 2014	X	X	X	X	X		X	X	X	X
June 2014	X	X	X	X	X		X	X	X	X
July 2014	X	X	X	X	X		X	X	X	X
August 2014	X	X	X	X			X	X	X	X
September 2014	X	X	X	X			X	X	X	X
October 2014	X		X	X	X		X	X	X	X
June 2015	X	X	X	X	X	X	X	X		X
June 2016	X	X	X		X	X		X	X	X
November 2016	X		X	X	X	X	X	X	X	X
December 2016	X	X	X	X	X	X	X		X	X
April 2017	X		X	X		X	X	X	X	X
October 2018	X		X	X	X	X		X	X	X

Note: These episodes correspond to months in which there is more than one day where liquidity triggers credit risk. IE, IT, PT, SP, AT, BE, FI, FR, GE, and NL stand for: Ireland, Italy, Portugal, Spain, Austria, Belgium, Finland, France, Germany and The Netherlands.

Appendix 3. Economic and political news occurred in the episodes where liquidity risk triggered credit risk in most of the countries

2010	February	Greek crisis: Rating agencies cut Greece's sovereign rating several notches, raising concerns that the country will not be able to finance its budget deficit. EU urges Greece to take measures to cut its deficit.
2010	April	Greek crisis: Rating agencies cut Greece, Spain and Portugal sovereign ratings. ECB warns of contagion in the European sovereign crisis. Greece receives EU-IMF bailout of E30bln but bail-out faces backlash in Germany
2010	May	Greek crisis: Bank of Spain nationalizes some local banks. EU-IMF announce €750 billion rescue package for Greece. ECB opens the program to buy crisis-hit Eurozone bonds on the condition of economic reforms.
2010	June	Greek crisis: Moody's cuts Greece to junk status. Fears grow of Eurozone banks. The report shows that ECB lending to banks in Greece, Spain, Portugal, Italy and Ireland rose very strong
2010	November	Ireland receives an E85bln EU-IMF bail-out package.
2013	May	Ben Bernanke 22 May 2013 Congress appearance: taper tantrum speech
2014	April	FED decision to continue to taper
2014	May	ECB Draghi hints on UMP measures
2014	**June**	**ECB sets a negative rate (−0.1%) for the first time, in June**
2014	July	European stock market losses (4–5%) when Portuguese Banco Spirito Santo gets into trouble
2014	August	Recession fear is rising in the euro area. Draghi is hinting at ECB QE in Jackson Hole
2014	**September**	**ECB reduces the negative rate to − 0.2% in September**
2014	**October**	**ECB announced Details of the CBPP3 and the ABSPP. (European) stock markets correct > 10% in October**
2014	November	ECB announces expansion of its balance sheet by E1000 billion and does not exclude QE operation for Eurozone government bonds.
2014	December	ECB announces to consider QE program early 2015, backed by low European inflation numbers
2015	**January**	**ECB decision (on 23 Jan) to start (extend) QE program for Eurozone government bonds with announced monthly purchases of E60bln from March onwards**
2015	February	Fed minutes reveal that FOMC is worried that hiking rates too fast will damage the economic recovery. Oil price drop and weak euro support a switch to risk-on sentiment in Europe. Russia - Ukraine peace, Minsk II
2015	**March**	**ECB revises its growth forecast for the Eurozone up from 1% to 1.5% but maintains the QE program. It announces details of the PSPP begins to implement it on Mar 9**
2015	June	Peak of Grexit crisis. Grexit is eventually avoided as the Greek government agrees on reforms for European financial assistance as ECB threatened to no longer support Greek banks
2015	December	Fed raises rates for the first time in 10 years, from 0,25% to 0,50%
2016	**April**	**ECB raises monthly purchases of Eurozone government bonds to E80bln (this was announced in the March ECB MPC meeting) and announces details of the CSPP**
2016	June	UK votes for Brexit in a referendum
2016	November	The US elects Donald Trump as President
2016	**December**	**ECB begins tapering of purchases under the APP. Fed raises interest rates, from 0,25% to 0,50%, partially also because of Trump's spending plans.**
2017	January	President Trump gives America First speech at his inauguration
2017	March	Fed raises rates from 0.75% to 1%. Trump bans foreign immigration from Mexico and several countries in the Middle East. North Korea launches rockets over Asia. UK invokes art 50 of the EU Treaty to officially confirm Brexit
2017	April	ECB announces not to want to change its UMP policy (of negative rates and QE). Trump sends American warships to North Korea
2017	December	Fed raises rates by 0.25%. ECB announces not to change its (UMP) policy. UK and EU reach a deal over the Irish border for Brexit
2018	May	Trump takes US out of the nuclear treaty with Iran, thereby imposing the strongest sanctions on Iran. Russia reacts by imposing sanctions on the US. China steps up anti-China rhetoric. The oil price (Brent) goes over $80.
2018	October	The European Commission and the Italian government are twisting over EU budget rules. Khashoggi's murder puts pressure on US-Saudi relations when oil prices are already high. Trump signs new North American trade deal allows him to impose measures on China

Note: In bold letters, ECB's monetary announcements (see Appendix 1) are highlighted.

References

Abad, J., Aldasoro, I., Aymanns, C., D'Errico, M., Fache-Rousová, L., Hoffmann, P., Langfield, S., Neychev, M., Roukny, T., 2016. Shedding light on dark markets: first insights from the new EU-wide OTC derivatives dataset. Occasional Paper 11. European Systemic Risk Board, Frankfurt am Main.

Acharya, V., Drechsler, I., Schnabl, P., 2014. A pyrrhic victory? bank bailouts and sovereign credit risk. J. Financ. 69, 2689–2739.

Afonso, A., Jalles, J.T., 2019. Quantitative easing and sovereign yield spreads: euro-area time-varying evidence. J. Int. Financ. Mark., Inst. Money 58, 208–224.

Afonso, A., Arghyrou, M.G., Kontonikas, A., 2014. Pricing sovereign bond risk in the European Monetary Union area: an empirical investigation. Int. J. Financ. Econ. 19, 49–56.

Afonso, A., Jalles, J.T., Kazemi, M., 2020. The effects of macroeconomic, fiscal and monetary policy announcements on sovereign bond spreads. Int. Rev. Law Econ. 63, 105924.

Afonso, A., Arghyrou, M.G., Gadea, M.D., Kontonikas, A., 2018. "Whatever it takes" to resolve the European sovereign debt crisis? bond pricing regime switches and monetary policy effects. J. Int. Money Financ. 86, 1–30.

Agiakloglou, C., Deligiannakis, E., 2020. Sovereign risk elevation for European Union countries. J. Int. Money Financ. 103, 102117.

Aizenman, J., Binici, M., Hutchison, M.M., 2013. Credit ratings and the pricing of sovereign debt during the euro crisis. Oxf. Rev. Econ. Policy 29, 582–609.

Akaike, H., 1974. A new look at the statistical model identification. IEEE Trans. Autom. Control 19, 716–723.

Aldasoro, I., Ehlers, T., 2018. The credit default swap market: what a difference a decade makes. BIS Q. Rev. June 1–14.

Allen, F., Beck, T., Carletti, E., Lane, P.L., Schoenmaker, D., Wagner, W., 2011. Cross-border banking in Europe: implications for financial stability and macroeconomic policies. Centre for Economic Policy Research, London.
Altavilla, C., Giannone, D., Lenza, M., 2016. The financial and macroeconomic effects of the OMT announcements. Int. J. Cent. Bank. 12, 29–57.
Altavilla, C., Brugnolini, L., Gurkaynak, R., Motto, R., Ragusa, G., 2019. Measuring Euro area monetary policy. J. Monet. Econ. 108, 162–179.
Al-Thaqeb, S.A., Algharabali, B.G., 2019. Economic policy uncertainty: a literature review. J. Econ. Asymmetries 20, e00133.
Anelli, M., Patanè, M., 2022. The role of CDS market in the price discovery process of the "PIIGS" countries sovereign credit risk during the recent decade of monetary easing. J. Financ. Invest. Anal. 11 (1), 1–29.
Anelli, M., Patanè, M., Toscano, M., Gioia, A., 2021. The evolution of the lead-lag markets in the price discovery process of the sovereign credit risk: the case of Italy. J. Appl. Financ. Bank. 151–175.
Antonakakis, N., Chatziantoniou, I., Gabauer, D., 2020. Refined measures of dynamic connectedness based on time-varying parameter vector autoregressions. J. Risk Financ. Manag. 13 84 (Art).
Arsov, I., Canetti, E., Kodres, L.E., Mitra, S., 2013. Near-coincident indicators of systemic stress. Working Paper 13/115. International Monetary Fund, Washington, DC.
Baele, L., Bekaert, G., Inghelbrecht, K., Wei, M., 2020. Flights to safety. Rev. Financ. Stud. 33, 689–746.
Baele, L., Ferrando, A., Hördahl, P., Krylova, E., Monnet, C., 2004. Measuring European financial integration. Oxf. Rev. Econ. Policy 20, 509–530.
Baker, S.R., Bloom, N., Davis, S.J., 2016. Measuring economic policy uncertainty. Q. J. Econ. 131, 1593–1636.
Barrios, S., Iversen, P., Lewandowska, M., Setze, R., 2009. Determinants of intra-euro area government bond spreads during the financial crisis. Economic Paper 388. European Commission,, Brussels.
Beber, A., Brandt, M.W., Kavajecz, K.A., 2009. Flight-to-quality or flight-to-liquidity? evidence from the euro-area bond market. Rev. Financ. Stud. 22, 925–957.
Będowska-Sójka, B., Echaust, K., 2020. What is the best proxy for liquidity in the presence of extreme illiquidity? Emerg. Mark. Rev. 43, 100695.
Beirne, J., Fratzscher, M., 2013. The pricing of sovereign risk and contagion during the European sovereign debt crisis. J. Int. Money Financ. 34, 60–82.
Belke, A., Gros, D., 2021. QE in the euro area: Has the PSPP benefited peripheral bonds? J. Int. Financ. Mark., Inst. Money 73, 101350.
Bianchi, R., Drew, M., Wijeratne, T., 2010. Systemic Risk, the TED Spread and Hedge Fund Returns. Discussion Paper 2010–04. Griffith Business School, Brisbane, QLD.
Blot, C., Creel, J., Hubert, P., Labondance, F., 2020. The role of ECB monetary policy and financial stress on Eurozone sovereign yields. Empir. Econ. 59, 1189–1211.
Bolton, P., Jeanne, O., 2011. Sovereign default risk and bank fragility in financially integrated economies. IMF Econ. Rev. 59, 162–194.
Bongaerts, D., De Jong, F., Driessen, J., 2017. An asset pricing approach to liquidity effects in corporate bond markets. Rev. Financ. Stud. 30, 1229–1269.
Brunnermeier, M.K., 2009. Deciphering the liquidity and credit crunch 2007-2008. J. Econ. Perspect. 23, 77–100.
Buis, B., Pieterse-Bloem, M., Verschoor, W.F.C., Zwinkels, R.C.J., 2020. Expected issuance fees and market liquidity. J. Financ. Mark. 48, 100514.
Caballo, G., 2017. The hazards of vague communication. ECB Res. Bull. 34, 1–3.
Canova, F., 1995. VAR: specification, estimation, testing and forecasting. In: Pesaran, H., Wickens, M. (Eds.), Handbook of Applied Econometrics. Blackwell, London, pp. 31–65.
Caporale, G.M., Girardi, A., 2013. Price discovery and trade fragmentation in a multi-market environment: evidence from the MTS system. J. Bank. Financ. 37, 227–240.
Caporin, M., Pelizzon, L., Ravazzolo, F., Rigobon, R., 2018. Measuring sovereign contagion in Europe. J. Financ. Stab. 34, 150–181.
Cespa, G., Foucault, T., 2014. Illiquidity contagion and liquidity crashes. Rev. Financ. Stud. 27, 1615–1660.
Chen, H., Cui, R., He, Z., Milbradt, K., 2018. Quantifying liquidity and default risks of corporate bonds over the business cycle. Rev. Financ. Stud. 31, 852–897.
Chen, N.F., 1991. Financial investment opportunities and the macro economy. J. Financ. 46, 529–554.
Chen, W., Hribar, P., Melessa, S., 2022. Standard error biases when using generated regressors in accounting research. J. Account. Res. https://doi.org/10.1111/1475-679X.12470.
Cheung, Y.C., de Jong, F., Rindi, B., 2005. Trading European Sovereign Bonds: The Microstructure of the MTS Trading Platforms. Working Paper 432. European Central Bank,, Frankfurt am Main.
Cheung, Y.W., Ng, L.K., 1998. International evidence on the stock exchange and aggregate economic activity. J. Empir. Financ. 5, 281–296.
Clancy, D., Dunne, P.G., Filiani, P., 2019. Liquidity and Tail-RIsk Interdependencies in the Euro Area Sovereign Bond Market. Working Paper 10. European Capital Markets Institute, Brussels.
Codogno, L., Favero, C., Missale, A., 2003. Yield spreads on EMU government bonds. Econ. Policy 18, 503–532.
Coluzzi, C., Ginebri, S., Turco, M., 2008. Measuring and Analyzing The Liquidity of the Italian Treasury Security Wholesale Secondary Market. Economics and Statistics Discussion Paper 44/08. Università degli Studi del Molise, Campobasso.
Constantini, M., Sousa, R.M., 2022. What uncertainty does to euro area sovereign bond markets: flight to safety and flight to quality. J. Int. Money Financ. 122, 102574.
Coppola, A., Girardi, A., Piga, G., 2013. Overcrowding versus liquidity in the Euro sovereign bond markets. Int. J. Financ. Econ. 18, 307–318.
Cossin, D., Lu, H., 2005. Are European Corporate Bonds and Default Swap Markets Segmented? Research Paper 133 International Center for Financial Asset Management and Engineering,, Geneva.
Coudert, V., Gex, M., 2013. The interactions between the credit default swap and the bond markets in financial turmoil. Rev. Int. Econ. 21, 492–505.
Coudert, V., Couharde, C., Grekou, C., Mignon, V., 2020. Heterogeneity within the euro area: New insights into an old story. Econ. Model. 90, 428–444.
Covitz, D., Downing, C., 2007. Liquidity or credit risk? The determinants of very short-term corporate yield spreads. The. J. Financ. 62, 2303–2328.
Crouch, P., Marsh, I.W., 2005. Arbitrage relationships and price discovery in the autos sector of the credit market (Working Paper). Cass Business School,, London.
Cutler, D.M., Poterba, J.M., Summers, L.H., 1989. What moves stock prices. J. Portf. Manag. 15, 4–12.
D'Agostino, A., Ehrmann, M., 2014. The pricing of G7 sovereign bond spreads–the times, they are a-changing. J. Bank. Financ. 47, 155–176.
D'Amico, S., King, T., 2013. Flow and stock effects of large-scale treasury purchases: evidence on the importance of local supply. J. Financ. Econ. 108, 425–448.
Damjanović, M., Masten, I., 2016. Shadow short rate and monetary policy in the Euro area. Empirica 43, 279–298.
Darbha, M., Dufour, A., 2013. Microstructure of the Euro-Area government bond market. In: Baker, H.K., Kiymaz, H. (Eds.), Market Microstructure in Emerging and Developed Markets: Price Discovery, Information Flows, and Transaction Costs. John Wiley & Sons, Hoboken, NJ, pp. 39–58.
De Pooter, M., Martin, R.F., Pruitt, S., 2018. The liquidity effects of official bond market intervention. J. Financ. Quant. Anal. 53, 243–268.
De Santis, R.A., 2014. The euro area sovereign debt crisis: identifying flight-to-liquidity and the spillover mechanisms. J. Empir. Financ. 26, 150–170.
De Santis, R.A., 2020. Impact of the asset purchase programme on euro area government bond yields using market news. Econ. Model. 86, 192–209.
De Vette, N. and Mosk, B., 2022. Euro area spread divergence, risk premia and financial stability. European Central Bank Financial Stability Review November.
Dick-Nielsen, J., Feldhütter, P., Lando, D., 2012. Corporate bond liquidity before and after the onset of the subprime crisis. J. Financ. Econ. 103, 471–492.
Diebold, F.X., Yilmaz, K., 2012. Better to give than to receive: predictive measurement of volatility spillovers. Int. J. Forecast. 28, 57–66.
Diebold, F.X., Yilmaz, K., 2014. On the network topology of variance decompositions: measuring the connectedness of financial firms. J. Econ. 182, 119–134.
Draghi, M., 2012. Verbatim of the remarks made by Mario Draghi. Speech by Mario Draghi at the Global Investment Conference in London, 26 July. Frankfurt am Main: European Central Bank.
Dufour, A., Skinner, F., 2004. MTS time series: Market and data description for the European bond and repo database. Discussion Paper in Finance 2004-07. ISMA Centre, University of Reading, Reading.
Dufour, A., Stanca, A., Varotto, S., 2017. The equity-like behaviour of sovereign bonds. J. Int. Financ. Mark., Inst. Money 48, 25–46.
Dunne, P., Moore, M., Portes, R., 2006. European Government Bond Markets: transparency, Liquidity, Efficiency. Center for Economic and Policy Research,, London.
Dunne, P.G., 2019. Positive liquidity spillovers from sovereign bond-backed securities. J. Risk Financ. Manag. 12, 58.
Efron, B., 1982. The Jackknife, the Bootstrap and Other Resampling Plans. Society for Industrial and Applied Mathematics,, Philadelphia, PA.

Eijffinger, S.C.W., Pieterse-Bloem, M., 2022. Eurozone Government Bond Spreads: A Tale of Different ECB Policy Regimes. Discussion Paper 17533. Centre for Economic Policy Research,, London.
Ejsing, J., Sihvonen, J., 2009. Liquidity premia in German government bonds. Working Paper 1081. European Central Bank, Frankfurt am Main.
Ejsing, J., Grothe, M., Grothe, O., 2015. Liquidity and credit premia in the yields of highly-rated sovereign bonds. J. Empir. Financ. 33, 160–173.
Ericsson, J., Renault, O., 2006. Liquidity and credit risk. J. Financ. 61, 2219–2250.
Eser, F., Schwaab, B., 2016. Evaluating the impact of unconventional monetary policy measures: empirical evidence from the ECB′ s securities markets programme. J. Financ. Econ. 119 (1), 147–167.
European Commission, 2022a. European Economic Forecast. Summer 2022. European Economy Institutional Paper 183. Luxembourg: Publications Office of the European Union.
European Commission, 2022b. European Economic Forecast. Spring 2022. European Economy Institutional Paper 187. Luxembourg: Publications Office of the European Union.
Fabozzi, F.J., Giacommetti, R., Tschida, N., 2016. Factor decomposition of the Eurozone sovereign CDS spreads. J. Int. Money Financ. 65, 1–23.
Falagiarda, M., Reitz, S., 2015. Announcements of ECB unconventional programs: implications for the sovereign spreads of stressed euro area countries. J. Int. Money Financ. 53, 276–295.
Fama, E.F., French, L., 1989. Business conditions and expected on stocks and bonds. J. Financ. Econ. 25, 23–49.
Farinha, J.B., Vidrago, J., 2021. The impact of the ECB's asset purchase programme on core and peripheral sovereign yields and its transmission channels. J. Econ. Asymmetries 24, e00213.
Favero, C., Missale, A., 2012. Sovereign spreads in the Euro area: which prospects for a Eurobond? Econ. Policy 27, 231–270.
Favero, C., Pagano, M., von Thadden, E.-L., 2010. How does liquidity affect government bond yields? J. Financ. Quant. Anal. 45, 107–134.
Fernández-Rodríguez, F., Gómez-Puig, M., Sosvilla-Rivero, S., 2015. Volatility spilllovers in EMU sovereign debt markets. Int. Rev. Econ. Financ. 39, 337–352.
Fernández-Rodríguez, F., Gómez-Puig, M., Sosvilla-Rivero, S., 2016. Using connectedness analysis to assess financial stress transmission in EMU sovereign bond market volatility. J. Int. Financ. Mark., Inst. Money 43, 126–145.
Francis, N.R., Jackson, L.E., Owyang, M.T., 2020. How has empirical monetary policy analysis in the U.S. changed after the financial crisis? Econ. Model. 84, 309–321.
Garcia, J.A., Gimeno, R., 2014. Flight-to-Liquidity Flows In The Euro Area Sovereign Debt Crisis. Working Paper 1249. Bank of Spain, Madrid.
Georgoutsos, D.A., Migiakis, P.M., 2013. Heterogeneity of the determinants of Euro-area sovereign bond spreads: what does it tell us about financial stability? J. Bank. Financ. 37, 4650–4664.
Geyer, A., Kossmeier, S., Pichler, S., 2004. Measuring systematic risk in EMU government yield spreads. Rev. Financ. 8, 171–197.
Ghysels, E., J., Idier, S., Manganelli, Vergote, O., 2017. A high-frequency assessment of the ECB securities markets programme. J. Eur. Econ. Assoc. 15, 218–243.
Giglio, S., 2016. Credit default swap spreads and systemic financial risk. Working Paper 15. European Systemic Risk Board, Frankfurt am Main.
Gómez-Puig, M., 2006. Size matters for liquidity: Evidence from EMU sovereign yield spreads. Econ. Lett. 90, 156–162.
Gómez-Puig, M., 2008. Monetary integration and the cost of borrowing. J. Int. Money Financ. 27, 455–479.
Gómez-Puig, M., Sosvilla-Rivero, S., Ramos-Herrera, M.C., 2014. An update on EMU sovereign yield spread drives in times of crisis: a panel data analysis. North Am. J. Econ. Financ. 30, 133–153.
Granger, C.W.J., 1969. Investigating causal relations by econometric models and cross-spectral methods. Econometrica 37, 24–36.
Gyntelberg, J., Hordahl, P., Ters, K., Urban, J., 2018. Price discovery in euro area sovereign credit markets and the ban on naked CDS. J. Bank. Financ. 96, 106–125.
He, Z., Xiong, W., 2012. Rollover risk and credit risk, The. J. Financ. 67, 391–429.
He, Z., Milbradt, K., 2014. Endogenous liquidity and defaultable bonds. Econometrica 82, 1443–1508.
Helwege, J., Huang, J.Z., Wang, Y., 2014. Liquidity effects in corporate bond spreads. J. Bank. Financ. 45, 105–116.
Hendry, D.F., 1995. Dynamic Econometrics. Oxford University Press, Oxford.
Hendry, D.F., Krolzig, H.M., 2005. The properties of automatic GETS modelling. Econ. J. 115, C32–C61.
Hofmann, B., Illes, A., Lomabardi, M., Mizen, P., 2020. The impact of unconventional monetary policies on retail lending and deposit rates in the euro area. Working Paper 850. Bank for International Settlements, Basel.
Hsiao, C., 1981. Autoregressive modeling and money-income causality detection. J. Monet. Econ. 7, 85–106.
Jäger, J., Grigoriadis, T., 2017. The effectiveness of the ECB's unconventional monetary policy: comparative evidence from crisis and non-crisis Euro-area countries. J. Int. Money Financ. 78, 21–43.
Jarrow, R., Protter, P., 2020. Credit risk, liquidity, and bubbles. Int. Rev. Financ. 20, 737–746.
Kadiric, S., Korus, A., 2019. The effects of Brexit on credit spreads: evidence from UK and Eurozone corporate bond markets. International economics and economic policy, 16, 65–102.
Kinateder, H., Wagner, N., 2017. Quantitative easing and the pricing of EMU sovereign debt. Q. Rev. Econ. Financ. 66, 1–12.
Klingler, S., Lando, D., 2018. Safe haven CDS Premiums. Rev. Financ. Stud. 31, 1856–1895.
Koop, G., Korobilis, D., 2014. A new index of financial conditions. Eur. Econ. Rev. 71, 101–116.
Koop, G., Pesaran, M.H., Potter, S.M., 1996. Impulse response analysis in non-linear multivariate models. J. Econ. 74, 119–147.
Korobilis, D., Yilmaz, K., 2018. Measuring dynamic connectedness with large Bayesian VAR models. Working Paper 20937. Essex Finance Centre, University of Essex,, Essex.
Krippner, L., 2014. Measuring the stance of monetary policy in conventional and unconventional environments. Working Paper 6/2014. Canberra: Centre for Applied Macroeconomic Analysis, Australian National University.
Krishnamurthy, A., Nagel, S., Vissing-Jorgensen, A., 2017. ECB policies involving government bond purchases: impact and channels. Rev. Financ. 22, 1–44.
Krugman, P., Obstfeld, M., 2009. International Economics: Theory and Policy, eighth ed. Pearson Addison-Wesley, Boston.
Lemke, W., Werner, T., 2020. Dissecting long-term Bund yields in the run-up to the ECB's public sector purchase programme. J. Bank. Financ. 111, 105682.
Lewis, J.B., Linzer, D.A., 2005. Estimating regression models in which the dependent variable is based on estimates. Political Anal. 13, 345–364.
Lewis, V., Roth, M., 2019. The financial market effects of the ECB's asset purchase programs. J. Financ. Stab. 43, 40–52.
Lin, H., Wang, J., Wu, C., 2011. Liquidity risk and expected corporate bond returns. J. Financ. Econ. 99, 628–650.
Longstaff, F.A., Mithal, S., Neis, E., 2005. Corporate yield spreads: default risk or liquidity? New evidence from the credit default swap market. J. Financ. 60, 2213–2253.
Manganelli, S., Wolswijk, G., 2009. Euro bond spreads. Econ. Policy 24, 191–240.
Motto, R., Özen, K., 2022. Market-Stabilization QE. Working Paper 2640. European Central Bank, Frankfurt am Main.
Nagar, V., Schoenfeld, J., Wellman, L., 2019. The effect of economic policy uncertainty on investor information asymmetry and management disclosures. J. Account. Econ. 6, 36–57.
Nashikkar, A., Subrahmanyam, M.G., Mahanti, S., 2011. Liquidity and arbitrage in the market for credit risk. J. Financ. Quant. Anal. 46, 627–656.
Neely, C.J., 2014. Lessons from the Taper Tantrum. Economic Synopses. Federal Reserve Bank of St. Louis, St. Louis, MO.
O'Sullivan, C., Papavassiliou, V.G., 2020. On the term structure of liquidity in the European sovereign bond market. J. Bank. Financ. 114, 105777.
Pagan, A., 1984. Econometric issues in the analysis of regressions with generated regressors. Int. Econ. Rev. 25, 221–247.
Pagano, M., von Thadden, E.-L., 2004. The European bond markets under EMU. Oxf. Rev. Econ. Policy 20, 531–554.
Palladini, G., Portes, R., 2011. Sovereign CDS and Bond Pricing in the Euro Area. Working Paper 17586. National Bureau of Economic Research,, Washington, DC.
Parkinson, M., 1980. The extreme value method for estimating the variance of the rate of return. J. Bus. 53, 61–65.
Pastor, L., Stambaugh, R.F., 2003. Liquidity risk and expected stock returns. J. Political Econ. 111, 642–685.
Pelizzon, L., Subrahmanyam, M.G., Tomio, D., Uno, J., 2016. Sovereign credit risk, liquidity, and ECB intervention: Deus ex machina? J. Financ. Econ. 122, 86–115.
Pesaran, M.H., Shin, Y., 1998. Generalized impulse response analysis in linear multivariate models. Econ. Lett. 58, 17–29.
Ramsey, J.B., 1973. Why Econometrics? University of Birmingham, Birmingham.

Rogers, J.H., Scotti, C., Wright, J.H., 2014. Evaluating asset-market effects of unconventional monetary policy: a multi-country review. Econ. Policy 29, 749–799.
Roley, V.V., Sellon, G.H., 1995. Monetary policy actions and long-term interest rates. Fed. Reserve Bank Kans. City Econ. Q. 80, 77–89.
Rostango, M., Altavilla, C., Carboni, G., Lemke, W., Motto, R., Saint Guilhem, A., Yingou, J., 2019. A tale of two decades: the ECB's monetary policy at 20. Working Paper 2346. European Central Bank, Frankfurt am Main.
Saka, O., Fuertes, A.M., Kalotychou, E., 2015. ECB policy and Eurozone fragility: was De Grauwe right? J. Int. Money Financ. 54, 168–185.
Schmidt, K., Sigwalt, A., 2022. Fiscal policy orientation in the euro area in real-time. Working Paper 896. Banque de France, Paris.
Schwarz, K., 2019. Mind the gap: Disentangling credit and liquidity in risk spreads. Rev. Financ. 23, 557–597.
Wang, J., Wu, C., 2015. Liquidity, credit quality, and the relation between volatility and trading activity: evidence from the corporate bond market. J. Bank. Financ. 50, 183–203.
Wu, J.C., Xia, F.D., 2013. Measuring the macroeconomic impact of monetary policy at the zero lower bound. J. Money, Credit Bank. 48, 253–291.
Wuyts, G., 2008. The impact of liquidity shocks through the limit order book. Working Paper 2008/53. Center for Financial Studies,, Frankfurt am Main.
Zhu, H., 2006. An empirical comparison of credit spreads between the bond market and the credit default swap market. J. Financ. Serv. Res. 23, 211–235.