"Dynamic connectedness between credit and liquidity risks in EMU sovereign debt markets"

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Abstract

We examine the dynamic interconnection between sovereign credit and liquidity risks in ten euro area countries at the 5-year maturity with high-frequency data from MTS over the period January 2008-December 2018 using the extension of the TVP-VAR connectedness approach of Antonakakis et al. (2020). Our results indicate that for most periods 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 find that the latter episodes can be related to several unconventional monetary policy measures of the ECB. Then, we examine the drivers of the connectedness indicator by means of a Probit model. Our results suggest that monetary policy shocks and economic policy uncertainty increase the probability of risk transmission from liquidity to credit, while global funding liquidity, tensions in financial markets and surprises in inflation and GDP are factors that reduce such probability.

JEL classification: C22, C53, G12, G14, G15.

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

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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 or safety" 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 has 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 countries. Concretely, the aggregate debt-to-GDP ratio of the euro area, after reaching a peak of almost 100% in 2020, remains very close to it (97%) in 2021. And according to the European Commission's forecasts[1], the European Union (EU) aggregate debt ratio in 2023 is set to remain above the pre-COVID-19 crisis level of 79% of GDP in 2019. Half of the member states are set to 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 annual inflation rate in the euro area to a record high of 8.6% in June of 2022[2]. Intensifying and broadening inflationary pressures are propelling a faster normalisation of monetary policy in the euro area, prompting the ECB's first interest rate hike in eleven years on 21st July 2022 (50 bps.) which has been followed by a second interest rate increase on 8th September 2022 (75 bps.)

[1] See European Commission's spring and summer 2022 forecasts (European Commission, 2022a and 2022b, respectively).
[2] It peaked to 9.1% in August 2022.

The expected 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 risk spreads in the early summer of 2022, especially in economies with the most debt-laden governments. In order to stem fragmentation in the euro zone 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 extend 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 and worries that credit risk dynamics in the euro area sovereign bond market inadvertently triggers a sovereign debt crisis in a highly indebted country, with all the subsequent contagion effects to other peripheral countries[3].

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 high-frequency data from the Mercato Telematico dei Titoli di Stato (MTS), but Pellizzon *et al.* (2016) only focus their analysis on a single country (Italy) and explicitly examine the dynamic relation between credit and liquidity risks in times of crisis, whilst O'Sullivan and Papavassiliou (2020) only explore liquidity dynamics between two groups of

[3] Indeed, despite the TPI announcement, volatility and reduced liquidity has characterized the performance of eurozone sovereign bond markets over the summer following the withdrawal of the ECB's debt purchase programs and expectations of further interest rate hikes.

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

euro area economies (core and periphery) during tranquil and turbulent periods. Furthermore, both studies find different results. Pelizzon *et al.* (2016) find that credit risk leads liquidity risk, and that market stress reinforces this relation, whereas O'Sullivan and Papavassiliou (2020) find a negligible effect of credit risk on liquidity risk, and rather that liquidity risk has a significant impact on perceived creditworthiness in both the pre-crisis and crisis periods.

So, since an empirical analysis of the interaction between credit and liquidity risks has not yet been carried out in the context of each euro area country on a case-by-case basis, our study contributes to infer both euro area generalised and country-specific relations, being the objective of this paper twofold. First, 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 with high-frequency data from MTS that cover the period January 2008-December 2018 using the extension of the time-varying parameter vector autoregressive (TVP-VAR) connectedness approach of Antonakakis *et al.* (2020) to characterize dynamic connectedness. Subsequently, once a time-varying net measure of interdependence between liquidity and credit risks is computed 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 sovereigns' ability to access the bond market and add important insights to it 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. Pelizzon *et al.* (2016) analysis is based on the bid-ask spread while O'Sullivan and Papavassiliou (2020) paper is based on two measures of liquidity that are used independently: a relative spread (i.e., tightness, calculated as the best bid-ask spread divided by the midpoint of the bid and ask quotes) and the quoted volume (i.e., depth, defined as best bid size plus best ask size). Unlike the previous studies, our paper proposes to use a measure of liquidity (the slope measure) that encompasses two of its main dimensions: tightness and depth.

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

Our second contribution is that, in contrast to earlier studies, we do not study a single country (Pelizzon *et al.*, 2016) or two groups of countries (O'Sullivan and Papavassiliou, 2020) in the euro area, but analyse separately 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, unlike Pelizzon *et al.*, (2016) and O'Sullivan and Papavassiliou (2020), our methodology is not based on a Granger-causality test (Granger, 1969). Following Fernández *et al.* (2015 and 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 Yılmaz (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 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 improved methodological framework captures possible changes in the underlying structure of the data more flexibly and robustly than the Granger-causality methodology (see Section 3). The measure of net interdependence directly measures 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 the 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. First, we use quote data from the MTS bond trading platform 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 to construct liquidity measures for the ten euro area sovereigns included in this study at the five-year maturity. Our liquidity measure captures the variation in time for these different sovereign issuers between January 2008 and December 2018 at a daily frequency. Secondly, credit default swap (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 at the same maturity (five years), for the same period and at the same frequency, 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[6]. 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.

Our paper provides new insights into the dual interaction between liquidity and credit risks for the European sovereign debt markets and allows us to reconcile the apparently contradictory findings of Pelizzon *et al.* (2016) and O'Sullivan and Papavassiliou (2020). Our results indicate 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 on a temporary basis and detect episodes where liquidity is a net trigger of risk. In our empirical analysis we also find that the ECB's unconventional monetary policy surprises diminish the net risk of propagation from credit to liquidity. Moreover, we uncover global funding liquidity, tensions in financial and sovereign bond markets and surprises in inflation and GDP as factors that reduce the probability of transmission from liquidity risk to credit risk, while monetary policy shocks and economic policy uncertainty are found to increase such 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.

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[6] 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 has 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 1H 2008 to 9.0 in 2H 2018, having peaked at 12.2 in 2H 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 global financial crisis (see: Aldasoro, I. and Ehlers, T., 2018) by the statement that the market has become increasingly standardised, with contract maturities concentrating around the five-year mark, also referencing Abad *et al.* (2016) in this respect. That the 5-year CDS is the most frequently traded is also echoed by major participants in the fixed income market (such PIMCO for example: https://nl.pimco.com/en-nl/resources/education/understanding-credit-default-swaps/).

2. Literature review

In the academic literature, most papers that explicitly study the interaction between liquidity and credit risks are found in the area of corporate bonds, subscribing to the importance of liquidity deemed for corporates' bond returns[7]. 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 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 Milbrandt, 2014). Studies on the determinants of corporate bond yields or spreads itself also assess the role of both liquidity and credit risk[8]. Furthermore, the majority 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 (EMU), 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 (2006, 2008 and 2009) 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

[7] 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).

[8] 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.

bond market, plays a side role. This is presumably because of the hitherto correct observation that countries have access to bond financing at all times 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.

Interest in the determinants of euro area sovereign bond spreads surges after the Global Financial Crisis (GFC), when spreads rise significantly and reach first-time highs in the European sovereign debt crisis. A large number of 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 Misale (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[9], another set is focusing on the financial market linkages[10]. 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 near-defaults of other sovereigns in the periphery of Europe, clearly demonstrates that access to the bond market can be jeopardized for some sovereigns and is available in differing degrees for others.

Liquidity risk in those studies 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 Schwartz, 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

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

[10] See Manganelli and Wolswijk (2009), Afonso *et al.* (2013), D'Agostino *et al.* (2014), Gómez-Puig *et al.* (2014), Eijsing *et al.* (2015) and Schwartz (2019).

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, and 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 explicit include the dual interaction of liquidity and credit risks of the sovereign itself. Doing so from the perspective of the market maker for Italian bonds, Pelizzon *et al.* (2016) establish that the relation between the credit risk of this sovereign and its liquidity is statistically significant. They also find that credit risk leads liquidity and not the other way around and that this relation is stronger in times of market stress and weakened by the monetary policy measures of the ECB. O'Sullivan and Papavassiliou (2020) examine Granger causality between volatility, bond returns across the term structure, liquidity measures –based on relative spreads and quoted depths–, and CDS spreads using GIIPS and non-GIIPS data over the pre-crisis and crisis period[11]. They, however, find that the effect credit risk has on liquidity is negligible. Concretely, their results indicate that liquidity (when measured by relative spreads) Granger cause CDS spreads significantly in both the pre-crisis and crisis periods, but CDS spreads exert no impact on liquidity in the pre-crisis period, whilst they impact minimally on liquidity in the crisis period.

Indeed, although many studies point to the importance of liquidity risk and its potential to create spillover effects –lending 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 between individual countries in the euro area. Baele *et al.* (2020) and Beber *et al.* (2009) both find that during times of market stress, liquidity determines the destination of investment flows. Baele *et al.* (2020) show that flights-to-liquidity takes place in an international bond-stock context and Beber *et al.* (2009) show that in the euro area sovereign

[11] GIIPS refers to the financially distressed economies of Greece, Ireland, Italy, Portugal and Spain during the European debt crisis and the acronym non-GIIPS is used in reference to the more creditworthy economies of Austria, Belgium, Finland, France, Netherlands and Germany. Their dataset spans from January 2008 to December 2013 and they consider the period January 2008 until October 2009 as the pre-crisis sample.

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 *et al.* (2014) show that after controlling for bond-specific liquidity and credit risks, it is rather Germany that is benefitting from those flows. Moreover, both Garcia and Gimeno (2014) and De Santis *et al.* (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.

In this context, the analysis in our paper tries to shed further light on this scarcely explored and still open debate in the literature by using a methodology that allows for time-dependency in the interconnection between sovereign credit and liquidity risks and 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 a given 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) pointed 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 Yılmaz (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 (2012, 2014)'s 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:

$$Y_t = \beta_t Y_{t-1} + \varepsilon_t \qquad \varepsilon_t \sim N(0, \Sigma) \tag{1}$$

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

where β_t is an NxN_p dimensional time-varying coefficient matrix and ε_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 *j*th 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 *j*th 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 $\tilde{D}_t^{g^H} = \left[\tilde{d}_{i,j,t}^{g^H} \right]$, the following normalization is necessary: $\tilde{d}_{i,j,t}^{g^H} = \frac{d_{i,j,t}^{g^H}}{\sum_{j=1}^{N} d_{i,j,t}^{g^H}}$, where by construction $\sum_{j=1}^{N} \tilde{d}_{i,j,t}^{g^H} = 1$ and $\sum_{i,j=1}^{N} \tilde{d}_{ij}^{g^H} = N$

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

The off-diagonal entries of $\tilde{D}_t^{g^H}$ 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:

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

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 taking into account 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 assess 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*, D_t is a dummy variable associated with major ECB UMP news associated with new measures and announcements (taking the value of 1 on the one day around each news, and zero elsewhere)[13], κ_0^c and κ_1^c are a constant and a slope parameters to be estimated, and ζ_t^c is the error term. In particular, κ_1^c measures the impact of each monetary policy decision. We use the change in the main refinancing operations (MRO) rate as a control variable to ensure that the announcement dummies do not pick up the effects of conventional monetary policy measures[14].

[13] We also considered a two-day window around the UMP events. The results are qualitatively similar but quantitatively smaller, suggesting the impact is better captured through the one-day window.

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

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 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:

$$\Pr(y = 1 \mid X, \beta) = 1 - \Phi(-X'\beta) = \Phi(X'\beta) \tag{7}$$

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 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 liquidity measure which we construct from the MTS bond data jointly with the credit measures based on the CDS premia from IHS Markit. For each, we provide a summary of descriptive statistics.

4.1. Measuring liquidity

We take our bond price information from the MTS dealing platform. 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[15].

Our sample period includes the nadir of the global financial crisis (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 way the LSM measure is formulated is 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 liquidity slope measure (LSM) as:

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

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. Similar to 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,

[15] 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).

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. 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:

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

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, …, 10 for maturity m, being m = 5-years in our study, in three different ways. First, we string together the respective liquidity measure belonging to the bonds 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 five-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 1 presents the descriptive statistics of this liquidity measure organized by country[16].

[Insert Table 1 here]

Table 1 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 and market liquidity present the highest volatility, while central countries' markets are the most liquid with lower volatility. Concretely, Ireland appears as the least liquid market both according to the mean and the median (they reach the highest value in this country), while the Netherlands is the more liquid (all indicators show the lowest value in this country).

4.2. Measuring credit risk

For our credit risk measures, we use the information in credit default swaps (CDS) to obtain a direct real-time market measure of the size of the default component. With a CDS, the

[16] 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.

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 premia 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 (CCP) as a 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[17]. 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][18] as well as in several contagion studies of these bonds in stress periods[19]. Furthermore, several empirical studies show that the liquidity premia in CDS spreads is lower than in bond spreads[20]. This holds in particular for fixed maturity CDS, especially the five-year CDS. Coudert and Gex (2013) document that in the price discovery process the CDS market leads the bond market in the case of peripheral euro area sovereigns and vice versa in the case of core euro area sovereigns, but with only a slight lead of the bond market. These differences in the lead are attributed, amongst others, to differences in liquidity between these two groups of bond markets. This study also shows that the role of the CDS market increases in times of crisis. Agiakloglou and Deligiannakis (2020) find that the relation between EU

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

[18] 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.

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

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

government bond yields and their associated CDS spread is time-varying and that a significant credit event can alter it. These results provide a strong hint to the 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 are the single-name reference entity in the swap contract. There is ample liquidity in single-name euro area sovereign CDS, particularly at the five-year maturity.[21] We take the series that string together the premia for the five-year for our sample period on a daily basis. We obtain this data from IHS Markit, which is the market's most extensive source of CDS data. Table 2 presents the descriptive statistics of our credit measure based on this CDS data, organized by country.

[Insert Table 2 here]

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 2 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 is decidedly–expressed in the near term (five-year maturity) for the lower credit-rated countries with a weaker fiscal stance.

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

As we will see, 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

[21] The BIS Quarterly Review of June 2018 on the CDS market (see: Aldasoro, I. and Ehlers, T., 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 $1.6 trillion (3.4% of the market) in mid-2007 to around $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.

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 that reflect sentiments; (3) variables measuring monetary policy; and (4) variables that gauge uncertainty. Table 3 presents the definitions and sources of the variables used in our analysis.

[Insert Table 3 here]

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), unemployment rates (UR), gross domestic product (GDP), industrial production (IND), retail trade (TRT), leading indicators (LEAD), exports (EXP), imports (IMP), and the fiscal position: government debt-to-GDP (DEBT) and government deficit-to-GDP (DEF). As for the variables reflecting sentiments, the role of both consumer and business opinion surveys are considered (COS and BOS, respectively). To measure the monetary policy stance, we use M1 and M3 monetary aggregates, the real broad effective exchange rate (REER) and the shadow short rate (SSR) which is a proxy for conventional and unconventional monetary shocks[22]. Finally to gauge overall uncertainty and risk, we make use of the VIX and Vstoxx indicators as measures of global and euro area expectations of future volatility in stocks market, MOVE as a proxy for bond volatility, TED spread (the difference between the three-month Treasury bill and the three-month LIBOR based in U.S. dollars, TED) as a measure of global funding liquidity risk, cross-currency basis swap spread at five-year (CCBSS5y) as a proxy for euro area funding liquidity risk, the euro area composite indicator of systemic stress (CIIS) which aims to measure the current 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 composite indicator of systemic sovereign stress (Sov CISS) which quantifies tensions in sovereign bond markets, the European and global economic policy uncertainty index (EUEPU and GEPU, respectively) which proxies uncertainty primarily related to economic policies and financial decisions[23], a short-, medium- and long-term excess bond premium (EBPST, EBPMT and EBPLT) to gauge strains in the financial sector at different

[22] 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).

[23] 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.

horizons (Gilchrist, *et al*., 2021)[24] and surprises in inflation and GDP in the euro area as a whole (EAINFSUR and EAACTSUR)[25].

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 Figures 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[26].

[Insert Table 4 here]

[Insert Figures 1 and 2 here]

In order 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 a given country. Therefore, the positive (negative) values indicate a source (recipient) of 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 drove liquidity risk, for all countries at the five-year maturity. 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). Therefore, 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

[24] The excess bond premium is a measure of investor sentiment or risk appetite in the corporate bond market introduced by Gilchrist and Zakrajšek (2012).

[25] The surprises are constructed as the standardised difference between the released data and their expected values according to the ifo World Economic Survey (see Andrada-Félix *et al.,* 2022).

[26] 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.

premium or reduce their risk by transacting less, and when credit risk falls the liquidity premium also falls and investors are comfortable to transact in larger volumes.

Figures 1 and 2 display the dynamic behaviour of the net connectedness indicator in peripheral and central countries respectively. 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 allowing a two-way relation between variables and the tracking of the evolution of spillovers over time seems to encompass the previous contradictory results in Pelizzon *et al.* (2016) and O'Sullivan and Papavassiliou (2020), where the first find unidirectional Granger-causality from credit risk to liquidity risk and the latter the opposite. We show that the interconnection between credit and liquidity risk is time dependent: the transmission of risk mostly runs from credit risk to liquidity risk, but we are also able to identify the changing transmitters of risk shocks on a temporary basis and to detect episodes where liquidity is rather a net trigger of risk in our sample. The episodes[27] for which the indicator is negative in more than eight countries 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[28]. In those episodes, liquidity triggered 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.

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[29].

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

[27] The episodes presented in Appendix 2 correspond to the months for which the indicator is negative more than one day.
[28] 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.
[29] 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.

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 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.

[Insert Table 5 here]

Table 5 indicates that the introduction of the new Securities Market Program (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, in almost all the countries. This is in concordance with other empirical studies[30]. 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 (Portugal, Ireland, Italy and Spain). These studies explain those lower spreads to reduced liquidity risk premia in bonds and local supply effects in segmented bond markets. Such a risk succession 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) studies 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[31]. There will have also been an important default risk signalling effect from both the LTROs and the SPM, as investors recognised that the direct purchases of crisis hit bonds made the ECB the back-stop for this credit risk, both leading to a softening of credit risk in that period.

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[30] In this vein, Pelizzon *et al.* (2016) analysis also indicate 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.

[31] Both studies also show that LTROs had an effect mostly on Spain (Krishnamurthy et al., 2017) and on the non-crisis countries (Jäger and Grigoriadis, 2017).

On the other hand, it is relevant to highlight that 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, but not enough to change its sign that still went from credit to liquidity risk as it is shown in Appendix 2. A similar effect is detected on 5 July 2012, when the ECB reduced the deposit rate to zero but did not announce any measure to support stressed bond markets. The three dates are identified by Motto and Özen (2022) as large ECB monetary-policy surprises.

Besides, Table 5 also shows that the announcement in June 2014 of a reduction of the ECB's deposit facility rate (DFR) to negative values jointly with the introduction of new targeted LTROs and preparations of a new backed securities purchase programme (ABSPP) and the announcement in October 2014 of the details of both corporate bonds purchase programme (CBPP3) and ABSSP are negatively significant in most of the countries. These events might be behind the fact that liquidity triggered credit risk (see Appendix 2) at the five-year maturity in June 2014 and in October 2014 in almost all the countries in our sample.

Moreover, Table 5 also show 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 effect of asset purchase programmes that were introduced subsequent to the SMP is on the credit and liquidity risk premia of all euro area countries. Our results, specifically, explain the concentration of episodes where liquidity is a transmitter of risk during the 2014-2016 period (as shown in Appendix 2). 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 to the European Union, which subsequently became known as Brexit, shocked bond markets (e.g., Kadiric and Korus, 2019)[32]. This indicates that this event is the likely trigger for the change in the direction of net connectedness to run from liquidity

[32] 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.

to credit risk in that month. In all other cases our results indicate that the ECB's UMP measures had the effect of reversing flight-to-safety dynamics.

In this regard, although there has been some debate and concerns regarding the potential adverse impacts of ECB asset purchases on bond market liquidity or on the crowding out of other investors, our results are in line with those of Jurksas *et al.* (2018) who analyse a range of euro area sovereign bond market liquidity metrics for the period between the start of the PSPP and early 2018 and suggest that the liquidity situation in euro area sovereign bond market did not deteriorate over this horizon despite the build-up of PSPP holdings. Indeed, Altavilla et *al.* (2021) state that, on balance, the available empirical evidence does not point to a deterioration in sovereign bond market liquidity since the start of the asset purchase programme (APP) in 2015; and Buis *et al.* (2020) show that liquidity dynamics in the euro area sovereign bond market do change over this period, where the ECB becomes an important liquidity provider when it commences its UMP, alongside the sovereign. Afonso *et al.* (2018) argue from the results of their study that following the announcement of OMT in August 2012, a new bond-pricing regime commenced, characterised by a weakened link between spreads and fundamentals, especially in the periphery countries. The policy interventions by the ECB in the Eurozone bond affect this relationship not only directly, but also indirectly, working through the bank credit risk channel. The expansion of the ECB's balance sheet through purchases of sovereign bonds expressed the commitment of the ECB to preserve the single currency and enabled markets to exit the crisis regime.

All in all, 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. In the following subsection, we use the SSR as a measure of conventional and unconventional monetary policy shocks [33] along with other potential variables to examine the determinants of the detected episodes when the propagation of risk goes from liquidity to credit.

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.

[33] Francis *et al.* (2014) 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 on its usefulness to quantify the effect of monetary policy shock on asset markets.

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[34]. To do so, we first assign a value of 1 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 1 if the resulting monthly average is greater than 0.5 (i.e., if at least for half of the month there is evidence of negative 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 the 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 statistical model that captures the essential characteristics of the underlying dataset, reducing the complexity of this general model by eliminating statistically insignificant variables while checking the validity of the reductions at every stage to ensure congruence of the finally selected model. In Table 6 we report the final results of the Probit models estimated by maximum likelihood[35]. The *z*-statistics in that table are based on robust standard errors computed using the Huber-White quasi-maximum likelihood method.

[Insert Table 6 here]

The results of Table 6 show that the variables that reduce the probability of transmission from liquidity risk to credit risk are either variables associated with liquidity funding or stress indicators related to the financial system or the sovereign bond market. That is (1) the cross-currency basis swap spread at five years (CCBSS5y); (2) the Euro Area Composite Indicator of Systemic Stress (EACIIS); (3) the euro area composite indicator of systemic sovereign stress (EASov CISS) and (4) inflation surprises in the euro area (EAINFSUR). Therefore, 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 increase the probability of risk transmission from liquidity to credit are: (1) the shadow short rate (SSR); (2) the Vstoxx index; and (3) the policy

[34] For GDP, DEBT, DEF, EAINFSUR and EAACTSUR, monthly data are linearly interpolated from quarterly data.
[35] The results are very similar for Logit models run on the same data.

uncertainty index pertaining to the euro area as whole (EAEPU). When the latter variables are heightened, these 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 or because of heightened political uncertainty in the euro area), liquidity risk dominates credit risk. Finally, note that the McFadden R^2, which is the likelihood ratio index, and it is an analogy to the R^2 reported in linear regression models, is estimated to be 0.7750, suggesting that 77.50% of the probability of transmission from liquidity to credit risk can be explained by the right-hand-side variables. Moreover, as a further measure of the goodness-of-fit of the Probit model, we compute the overall correct prediction percentage, obtaining a value of 76.62%.

Our results are in line with those presented in Damjanović and Masten (2016) regarding the almost direct translation to financing conditions of both the core and the periphery euro area countries of monetary policy shocks 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 Bekiros *et al.* (2020) who uncover a significant role of surprise and uncertainty in the spillovers across European sovereign credit markets. Moreover, our results extend not only the findings of Mody (2009) and Rho and Saenz (2021) who document a strong association between financial stress and sovereign credit risk, but also the findings of those other researchers analysing the role of financial distress in the nexus between sovereign and bank credit risk and how sovereign risk affects bank funding conditions (see, e. g., Brunnermeier *et al*, 2016, Böhm and Eichler, 2020 and Benetton and Fantino, 2021).

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 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, and trading data from IHS Markit on single-name CDS as our measure of credit risk, both at a daily frequency and at the five-year maturity for the period January 2008 to December 2018.

From 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 a given country. The net pairwise directional connectedness allows us to measure the difference in 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 being that for most periods and for all countries the net pair-wise directional connectedness is from credit risk to liquidity risk. The second being that 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. We then set up an event study and 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 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 liquidity funding or stress indicators related to the financial system or the sovereign bond market, along with euro area inflation surprises in the five-year maturity. The ECB's UMP measures increase this probability, along with variables associated with stress in the euro area stock market and with 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 policy makers 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.

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Table 1: 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	58157928	5.12E+08	46601803	7.55E+08	1.76E+08	843093.3	3.38E+07	8.19E+08	282694.5	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.

Table 2: 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.

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

	Variable	Definition	Source
Fundamental Macroeconomic Variables	INF	Inflation rate based on the Harmonized Index of Consumer Prices	Eurostat
	UR	Harmonized Unemployment Rate: Total: All Persons	Main Economic Indicators, Organization for Economic Co-operation and Development
	GDP	Gross Domestic Product	Eurostat
	IND	Total industry excluding construction	Main Economic Indicators, Organization for Economic Co-operation and Development
	TRT	Total retail trade: Value for the Euro Area, Index 2015=100	Federal Reserve Economic Data, Federal Reserve Bank of St. Louis
	LEAD	Leading Indicator	Main Economic Indicators, Organization for Economic Co-operation and Development
	EXP	Exports: Value (goods): Total for the Euro Area	Federal Reserve Economic Data, Federal Reserve Bank of St. Louis
	IMP	Imports: Value (goods): Total for the Euro Area	Federal Reserve Economic Data, Federal Reserve Bank of St. Louis
	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
Sentiment's Variables	COS	Consumer Opinion Survey, Euro Area (Normal=100)	Main Economic Indicators, Organization for Economic Co-operation and Development
	BOS	Business Tendency Surveys for Manufacturing (Normal=100)	Main Economic Indicators, Organization for Economic Co-operation and Development
Monetary Policy's Variables	M1	Currency in circulation and overnight deposits	International Financial Statistics, International Monetary Fund
	M1	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
	REER	Real Broad Effective Exchange Rate for Euro Area, Index 2010=100	Federal Reserve Economic Data, Federal Reserve Bank of St. Louis
	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
Uncertainty Variables	VIX	CBOE Volatility Index	Chicago Board Options Exchange
	Vstoxx	EURO STOXX 50 Volatility Index	Investing.com
	MOVE	Measure of bond volatility	Bloomberg
	TED	TED spread (	Bloomberg
	CCBSS5y	Cross-currency basis swap spread at 5 year	Bloomberg
	CIIS	Composite Indicator of Systemic Stress	Statistical Data Warehouse, European Central Bank
	Sov CISS	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/
	EBPST	Short-term excess bond premium	Gilchrist *et al.* (2021), The Federal Reserve Bank of Atlanta
	EBPMT	Medium-term excess bond premium	Gilchrist *et al.* (2021), The Federal Reserve Bank of Atlanta
	EBPLT	Long-term excess bond premium	Gilchrist *et al.* (2021), The Federal Reserve Bank of Atlanta
	EAINFSUR	Inflation surprises in the euro area	The ifo World Economic Survey and Andrada-Felix *et al.* (2022)
	EAACTSUR	GDP surprises in the euro area	The ifo World Economic Survey and Andrada-Felix *et al.* (2022)

Table 4: Net connectedness between liquidity and credit risks in EMU 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%

Table 5: Event study parameter estimates

	AT	BE	FI	FR	GE	IE	IT	NL	PT	SP
8-oct-08				2.26*						
13-oct-08				2.14*						
15-oct-09										
7-may-09		6.20*			4.30*		3.48**	5.22*		5.28*
10-may-10		-3.43**	-3.76*		-3.71*		-3.74**			-3.89**
7-ago-11	3.12**			2.46*						
6-oct-11	4.89*	4.97*					5.80*			
1-dic-11										
8-dic-11										
21-dic-11										
5-jul-12										-6.04*
26-jul-12			-2.85*							-5.36*
2-ago-12			3.71*							4.64**
4-jul-13					3.00*					
9-ene-14	-3.60*		-4.44*							
5-jun-14		-2.92**	-3.10*	-4.12*	-3.71*	-7.45**		-2.66**	-8.85**	-6.38*
22-ago-14		-3.66**		-4.12*	-2.89*	-7.59**			-8.85**	-6.13*
4-sep-14		-3.77*		-4.12*	-2.77**	-7.83**			-8.85**	-6.22*
2-oct-14		-4.25*		-3.61*	-2.47**	-8.89**			-8.85**	-6.35*
22-ene-15			-3.90*							
5-mar-15			-3.10**							
9-mar-15			-3.01**							
3-sep-15										
22-oct-15	-3.89*		-4.62*		-3.11*	-11.40*				
3-dic-15						10.65*				
21-ene-16						13.74*				
10-mar-16				3.43*		10.90*				
21-abr-16										
20-oct-16										
8-dic-16	-3.45*	-3.41**						-2.66**	-8.05**	-6.38*
27-jun-17	4.72*					13.74*		3.51*	13.07*	7.09*
26-oct-17				2.35**			4.64*	3.52*	16.92*	6.77*
8-mar-18				4.90*			4.76*	5.22*	10.93*	7.18*

Notes: Impact estimates of the parameter κ_1^c in the event study regression (5). 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 one-day event windows. * and ** indicate significance at 1% and 5%, respectively

Table 6. Estimated Probit regression

Variable	Coefficient
CCBSS5y	-0.0149 (-3.6839) [0.0000]
Vstoxx	0.0204 (2.2977) [0.2204]
SSR	0.0644 (3.2544) [0.0011]
EUEPU	0.0032 (3.9491) [0.0000]
EASov CISS	-1.4025 (-3.0076) [0.0031]
EACISS	-1.0648 (-2.4080) [0.0162]
EAINFSUR	-0.17863 (-3.8349) [0.0000]
Constant	-0.7525 (-3.3523) [0.0014]
McFadden R-squared	0.7750
AIC	1470.571

Notes: In the ordinary brackets below the parameter estimates are the corresponding *z*-statistics. In the square brackets, the associated marginal effects are given.

Figure 1: Net connectedness between liquidity and credit risks in EMU peripheral countries: 2008-2018

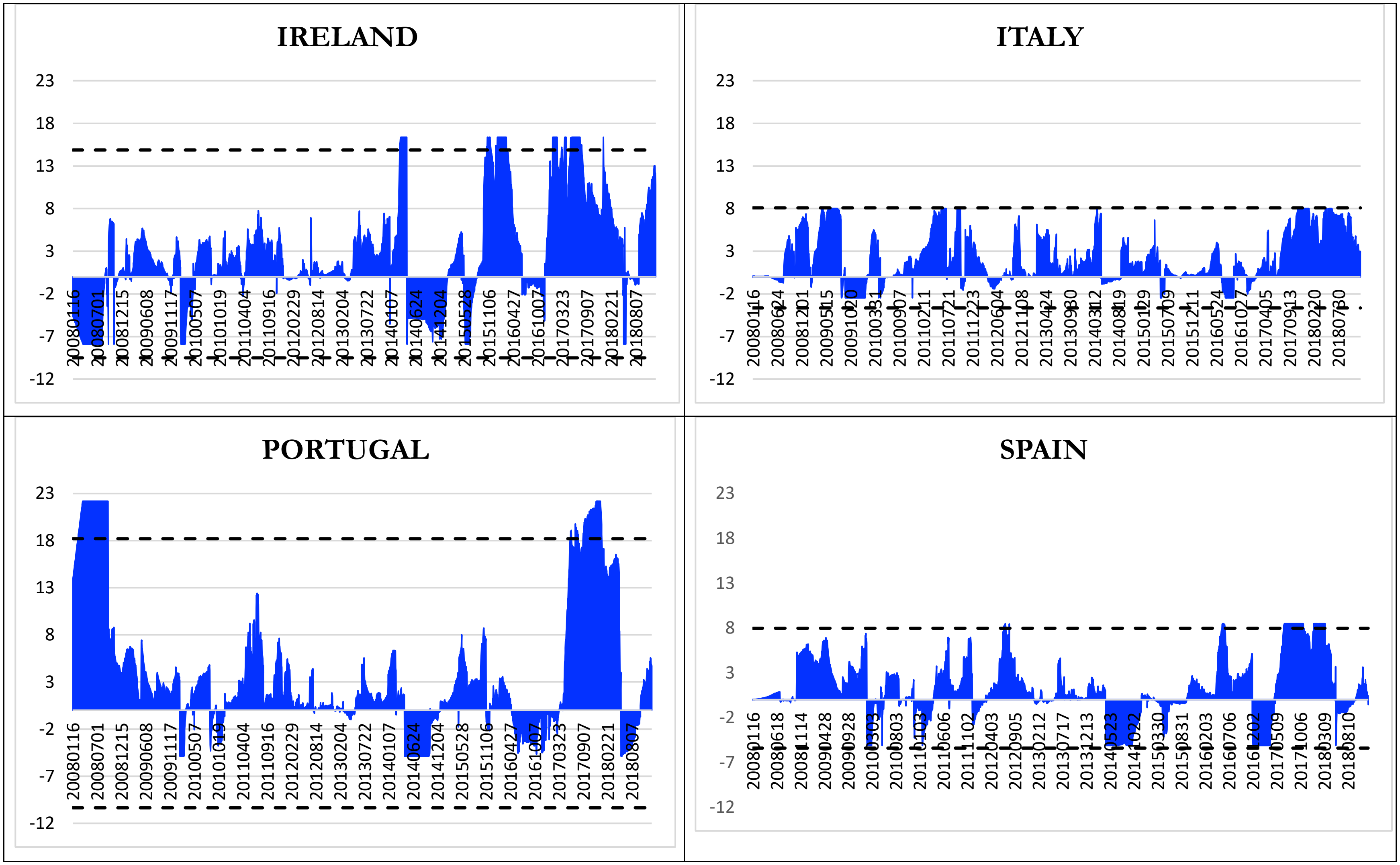
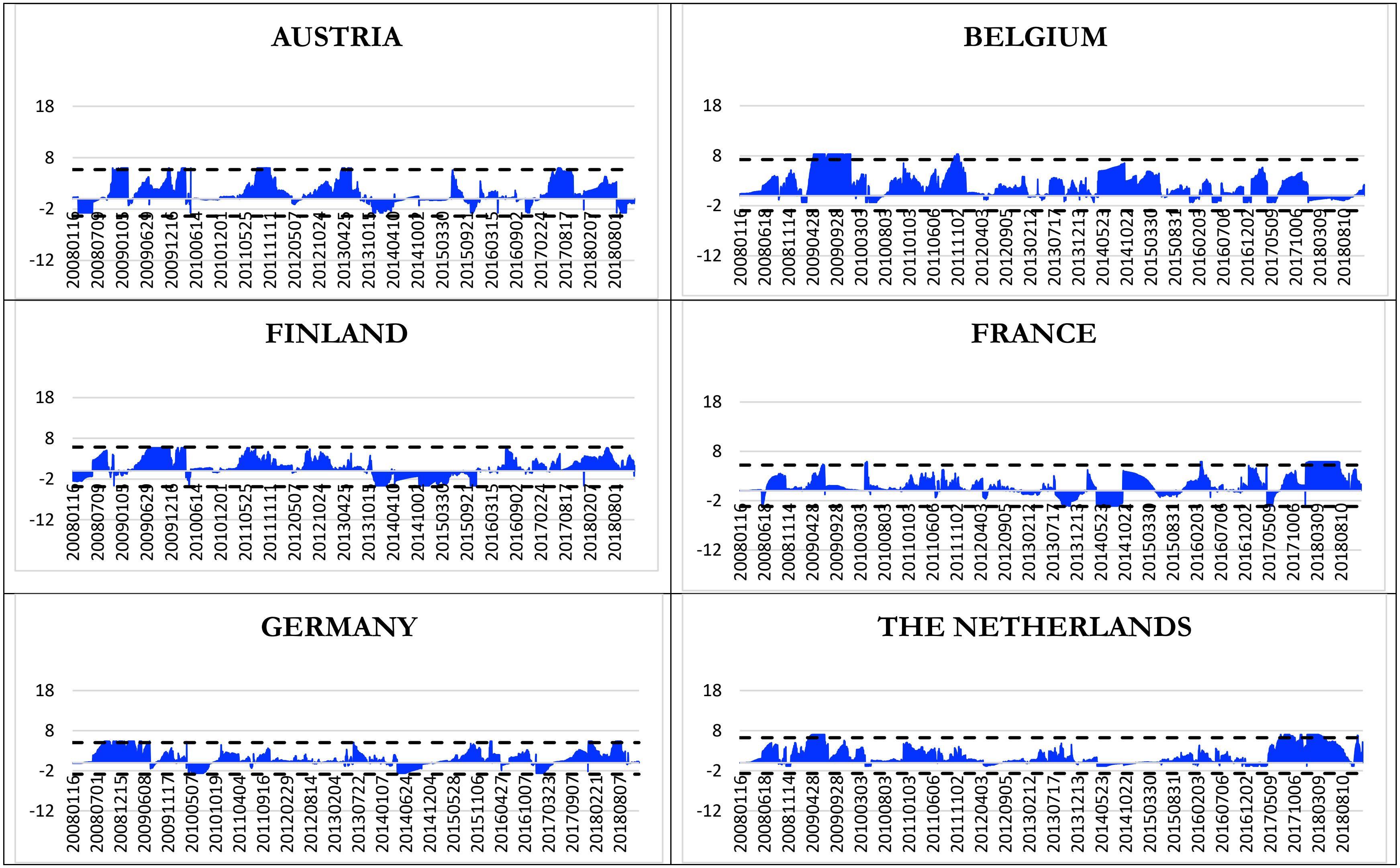


Figure 2: Net connectedness between liquidity and credit risks in EMU central countries: 2008-2018



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 euro area inflation expectations and the resolve of the Governing Council to use available instruments needed to preserve price stability
2014	Sep 4	1) DFR cut to -0.2% (negative rates), 2) changes to the use of collateral for monetary operations and 3) introduction of a new covered bond purchase Programme (CBPP3) and the new ABSPP
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
February 2010										
April 2010	X	X	X	X	X	X	X	X	X	X
May 2010	X	X	X	X	X	X	X	X	X	X
June 2010										
November 2010										
May 2013										
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
November 2014										
December 2014										
January 2015										
February 2015										
March 2015										
June 2015	X	X	X	X	X	X	X	X		X
December 2015										
April 2016										
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
January 2017										
April 2017	X		X	X		X	X	X	X	X
December 2017										
May 2018										
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 a number of 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.