FROM SMP TO PEPP:
A FURTHER LOOK AT THE RISK ENDOGENEITY OF THE CENTRAL BANK

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Abstract

This paper examines the evolution of credit risk arising from monetary policy operations and ELA on the Eurosystem balance sheet over the last decade. This is a key indicator of the macroeconomic and institutional cost of the unconventional measures, as future capital losses may hinder the independence of the central bank and hence its effectiveness in the pursuit of the price stability mandate. We employ a market-driven risk model relying on the expected default frequencies for sovereigns, banks and corporates provided by Moody's Analytics. Dependence between defaults is modelled with a multivariate Student *t* distribution with time-varying parameters. We find that at the end of 2020 risk is slightly above its average value in 2010 and approximately equal to one quarter of the value measured at the peak of the sovereign debt crisis in 2012, notwithstanding the threefold increase in the Eurosystem monetary policy exposure occurred since then. This is due to the launch of the OMT and PEPP, which succeeded in quelling market turmoil, thereby reducing the Eurosystem's own balance sheet risk. The OMT in particular has had a long lasting effect in lowering sovereign risk. Our findings support the view that, in periods of severe financial distress, sovereign risk for a central bank is largely endogenous. Following the launch of the CSPP in 2016, credit risk arising from corporate bond purchases has built up. We show that the corporate segment is where the risk borne by the central bank is likely to grow in the medium term.

JEL Classification: E58, E52, C15.
Keywords: financial risk measurement, unconventional monetary policies, ELA, sovereign risk, corporate risk.

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1. Introduction[1]

Over the last decade the Eurosystem and other major central banks have adopted unprecedented programmes of long-term lending and large-scale asset purchases, which have stemmed the threats to price stability and financial stability.[2] The *'whatever it takes'* statement by President Draghi and the ECB's decision on the Outright Monetary Transactions (OMT) programme in 2012 have clearly shown that the central bank's commitment to act as a potential buyer of last resort is in itself capable of shifting expectations in the economy (Altavilla, Giannone and Lenza, 2016). These unconventional measures, though, have raised some criticism and concerns that their costs and side effects may be sizeable.[3]

While the effectiveness of the unconventional measures in terms of the achievement of the price stability mandate is the subject of a large body of empirical literature, their consequences for the financial risk borne by the Eurosystem are less explored, owing also to the confidential nature of central bank exposures. Nevertheless, this risk is a key indicator of the macroeconomic and institutional cost of the unconventional measures, as future capital losses may hinder the independence of the central bank and hence its effectiveness in the pursuit of the price stability mandate (BIS, 2013).[4]

The credit risk component of the Eurosystem's balance sheet has received increasing attention since the global financial crisis, owing to the absence of an area-wide fiscal authority that can be considered truly risk free (Buiter and Rahbari, 2012; Hall and Reis, 2013; Reis, 2015). The financial risk borne by the Eurosystem following the launch of the Securities Market Programme (SMP) and the OMT is the subject of a recent study by Caballero, Lucas, Schwaab and Zhang (2020).

We draw from the latter study and investigate the evolution of credit risk on the monetary policy and emergency liquidity assistance (ELA) operations of the Eurosystem over the last decade, from the SMP

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1 The views expressed in this paper are those of the authors and do not involve the responsibility of the Bank of Italy. We are grateful for their valuable comments to Michele L. Bianchi, Luigi Cannari, Diego Caballero, Alberto Locarno, Fernando Monar, Franco Panfili, Stefano Siviero, Jonas Willequet, and seminar participants at the Bank of Italy, the ECB, the IFABS 2021 Oxford Conference, and the 2021 CREDIT Conference in Venice.

2 For the Eurosystem, the full list includes the Securities Market Programme (SMP), the Very Long-Term Refinancing Operations (VLTROs; see the glossary at the end of the paper), the Targeted Longer-Term Refinancing Operations (TLTROs), the Asset Purchase Programme (APP), and, most recently, the Pandemic Emergency Longer-Term Refinancing Operations (PELTROs) and the Pandemic Emergency Purchase Programme (PEPP). In addition, the Eurosystem has provided USD swap facilities to euro area banks on a regular basis and euro liquidity to non-euro area central banks (EUREP). In the sample period, the Governing Council of the ECB also introduced 'forward guidance' on monetary policy decisions in the communication to the public. For a cross-country analysis of the unconventional monetary policy tools, see BIS (2019). For a survey of the literature on the effectiveness of the non-standard monetary policy measures of the ECB, see Neri and Siviero (2019) and Rostagno *et al.* (2019).

3 Recurring concerns relate to the following issues: i) unconventional policies (UPs) may reduce bank profitability (Borio, Gambacorta and Hofmann, 2015); ii) they may lead to the build-up of asset-price deviations from their fundamentals and trigger a sharp asset-price correction (Borio, 2014); iii) UPs may induce financial intermediaries to move toward riskier assets (Rajan, 2005; Borio and Zhu, 2012); iv) UPs expose monetary authorities to political interference (Taylor, 2016); v) they have undesirable income and wealth redistribution effects (Lenza and Slacalek, 2018); vi) they may increase wage pressure, inflation and undermine the competitiveness of the industry sector (Sinn, 2019 and 2021); vii) UPs may cause a slowdown of consolidation and structural reforms on the part of sovereign issuers (Bundesbank, 2016). Extreme critics deem the sovereign purchases illegal.

4 Financial results may be important for a central bank even though it can always create money to pay its bills, it cannot be declared bankrupt by a court, and it does not exist to make profits. Losses or negative capital may raise doubts about the central bank's ability to deliver on policy targets, and expose it to political pressure.

to the Pandemic Emergency Purchase Programme (PEPP) of 2020.[5] We thus aim to contribute to the empirical literature on the impact and costs of the unconventional measures. We focus on the notion of risk endogeneity for monetary policy, whereby the central bank itself, with its own monetary policy measures, generates spillover risk elsewhere in its balance sheet. While this notion is not new, and it goes all the way back to the lender-of-last-resort concept discussed by Thornton (1802) and Bagehot (1873), it is admittedly very difficult to appraise with accuracy.

Our methodological approach bears some similarity with Caballero *et al.* (2020). We employ a dynamic, market-driven risk model and use probabilities of default (PDs) over a 1-year horizon inferred from real-time market data, through the Credit Edge platform provided by Moody's Analytics. Such PDs are available for private issuers (as their expected default frequency, or EDF) as well as sovereign issuers (CDS-Implied EDF, or CDS-I-EDF). Moody's EDFs are widely used within the financial sector. Moody's CDS-I-EDFs for sovereign issuers – when compared with PDs inferred from CDS premia, like those employed by Caballero *et al.* (2020) – seem more effective at filtering out the noise inevitably associated with market data. From a statistical viewpoint, we model dependence between issuers/counterparties using a multivariate Student *t* distribution with time-varying parameters. This copula captures the varying degree of fatness in the tails of the joint distribution of asset values. We use the model as an engine to simulate scenarios of possible losses from lending operations and asset holdings at the end of a 1-year period. The risk metric is the expected shortfall at the 99 percent (ES99) confidence level, i.e. the average loss occurring in the worst one percent of the scenarios. We track the risk of the Eurosystem at a weekly frequency. Our results exhibit a high degree of robustness to different specifications.

We extend the work of Caballero *et al.* (2020) along several dimensions. First, the period under analysis is from 2010-2020, encompassing all measures from SMP to PEPP, and we include the ELA operations. Second, we widen the perimeter of the entities and instruments. In addition to banks and to the five sovereigns purchased under the SMP, we simulate all other euro area sovereigns as well as all euro area corporate issuers and structured finance instruments (covered bonds and ABSs). Third, we employ detailed data on exposures with monetary policy counterparties and their collateral in credit operations. Fourth, we use a 'double default' model, whereby losses on refinancing operations are estimated conditionally on the joint default of both the counterparty and the collateral issuers. Last, our approach for the estimation of the Student *t* copula employs a three-year rolling window of weekly data, thus providing fully out-of-sample (instead of in-sample) risk estimates.

Our main findings may be summarized as follows. First, while from 2010 to 2020 the Eurosystem exposure from monetary policy operations grew more than threefold (from around €2,000 to over €6,000 billion), at the end of 2020 financial risk estimated with our model is slightly above its average value in 2010 and corresponds to 23 percent of the same measure at the peak of the sovereign debt crisis in 2011-2012 (€43 billion *vs* €185 billion). We attribute this finding mainly to the launch of OMT: with this programme the ECB has made it clear that it considers supporting sovereign issuers that experience financial distress as being, under well-defined conditions, within its mandate.[6] This clarification has filled

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[5] Risk originating from the holding of foreign reserves and own funds is not considered.

[6] Draghi (2012), ECB (2012).

a void that previously existed in the institutional set-up of the euro area and has had a long lasting effect in lowering sovereign risk in the euro area.

Second, while risk arising from credit operations can be managed by appropriately selecting collateral and calibrating valuation haircuts, whereby the central bank can effectively gauge the maximum level of risk that it is prepared to bear, the credit risk arising from securities purchased outright is practically unmitigated and the central bank is directly exposed to financial market distress. Therefore, the Eurosystem financial risk mainly accrues from outright purchase holdings (APP and PEPP), which produce over 90 percent of total risk at the end of 2020. Risk from public sector purchases accounts for 62 percent of total risk.

Third, financial risks in the market and in the Eurosystem's balance sheet reached their peaks before or shortly after the ECB's announcement of OMT and PEPP, after which they receded. Our interpretation of this result is that during highly distressed periods financial risks, especially credit risk arising from sovereign holdings, appear as largely endogenous for the central bank.[7] Recognizing the different nature of uncertainty in a crisis environment, especially when sovereign debt is involved, is essential for central banks. They are not constrained by liquidity or capital motives and, by making their balance sheet promptly available to absorb the risks that the private sector cannot bear, they can act to prevent the sovereign debt market from settling in a bad equilibrium.[8]

Fourth, our high frequency estimates lend themselves to an analysis of the 'risk efficiency' of the monetary policy measures. The notion of risk efficiency implies that a certain expected policy impact should be achieved with the minimum level of balance sheet risk (ECB, 2015). Our proxies for the policy impact of the different measures are the long-term inflation expectations (inferred from the swap market) and financial stability risks (as measured by the Composite Indicator of Systemic Stress, or CISS, developed by the ECB). By comparing these variables with the change in Eurosystem risks around the time of some major policy announcements in the last decade, we find that OMT and PEPP, activated amid severely deteriorating market conditions, have been powerful circuit breakers (the result for OMT being broadly in line with Caballero *et al.*, 2020). The SMP's effectiveness was undermined by a hesitant

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7 Our evidence is consistent with the argument put forward by Danielsson and Shin (2003), that in normal conditions, when expectations are heterogeneous, market agents are price takers and asset prices only depend on the financial and economic fundamentals, treating risk as exogenous is appropriate. In this case, the use of the standard risk measurement tools, based on the probability densities inferred from past data, is a sound practice. However, when there is a prevailing view concerning the direction of market outcomes and such uniformity leads to broadly similar trading strategies, as occurs during a crisis, the standard risk measurement tools may no longer be adequate. In such circumstances, asset prices not only depends on financial and economic fundamentals but, to a large extent, they are also affected by the response of individual agents to the unfolding events: market distress can feed on itself. As a matter of fact, when asset prices fall and traders get closer to their trading limits, they are forced to sell. In turn, the selling pressure sets off further downward pressure on asset prices, which induces a further round of selling, and so on (Brunnermeier and Pedersen, 2009; Danielsson, Shin and Ziegrand, 2010, Danielsson, Shin and Ziegrand, 2012).

8 In particular, with reference to government debt markets, the presence of self-fulfilling defaults is widely studied in the literature. In light of the multiplicity of self-fulfilling equilibria in sovereign debt markets, within a wide range of fiscal fundamentals, the fiscal position of a sovereign may support both equilibria without default and equilibria with default. Calvo (1988) addresses the issue on a theoretical level. De Grauwe and Yuemei (2012 and 2013), Corsetti and Dedola (2016) and Orphanides (2017) apply this notion to the euro area. Reis (2017) shows that quantitative easing can be an effective tool for the central bank during a fiscal crisis, by reducing the sensitivity of inflation to fiscal shocks and preventing a credit crunch.

and uncertain commitment to act. The APP, finally, was launched in a relatively calm market environment to counter the de-anchoring of inflation expectations, so its risk efficiency is relatively smaller and mainly connected to the price stability objective.

Fifth, we find that following the launch of the CSPP in 2016, credit risk arising from corporate bond purchases has built up. We note that EDFs and CDS-I-EDFs provide an early warning signal about sudden changes in default risk. However, a full assessment of the riskiness of an issuer may involve both point-in-time (PIT) and through-the-cycle (TTC) default probabilities. We find that at the end of 2020 EDFs for corporates are lower than their TTC levels. This suggests that the corporate segment is where the credit risk borne by the central bank might concentrate in the medium term.

Finally, a consideration of the financial strength of the Eurosystem is in order. The notion of solvency for a central bank is not appropriate, in the sense that the central bank is not liquidity constrained in the currency of issue (unless this endangers the price stability objective), and it may even operate with negative capital. Still the question arises as to whether the Eurosystem capital buffers are capable of withstanding the materialization of an extreme ES99-sized credit loss. We find that the Eurosystem as a whole has relatively large capital buffers, defined as the sum of capital and reserves (i.e., paid-up capital, legal reserves and other reserves), revaluation accounts (i.e., unrealized gains on certain assets like gold), and risk provisions. These buffers increased from €430 billion in 2010 to €737 billion in 2020.[9] At individual NCB level, comparing the buffers with our risk estimates, for the major NCBs the buffers were a multiple of the ES99-sized credit loss arising from monetary policy and ELA operations in all years, including at the peak of the sovereign debt crisis and of the pandemic crisis. We note however that the buffers should cater for all risks in the central bank balance sheet, not simply for those related to monetary policy implementation, i.e. including risks on foreign exchange reserves, investments, etc.

The remainder of the paper is organized as follows. Section 2 describes the methodology underlying our estimates. Sections 3 and 4 describe the data used for the estimation of the exposures and the probabilities of default, respectively. Section 5 presents our results. Section 6 is devoted to robustness analysis. Section 7 examines the evolution of Eurosystem risks, the long-term inflation expectations and the conditions of financial stress around some key ECB announcements. Section 8 shows how the risk of the PEPP portfolio would change if the current exposures were replaced by the total envelope announced by the ECB. Section 9 provides a focus on the risk of the corporate sector purchase programme portfolio. Section 10 concludes. The Appendix provides further methodology details.

2. Methodology

We estimate the financial risks[10] of the Eurosystem over a 1-year horizon by means of a Monte Carlo simulation in which more than 100,000 scenarios are drawn at any date, with the exact number (which

[10] Financial risk refers to potential losses due to financial events, such as issuers' defaults. It does not consider, for example, potential losses due to operational or legal reasons.

may be as high as 200,000) depending on the fulfilment of a convergence criterion.[11] In any scenario, losses arising from purchase programmes and monetary policy and ELA refinancing operations are computed and aggregated. Risks are computed as the expected shortfall at the 99 percent confidence level (ES99), i.e. taking the average of the 1 percent most adverse losses realized in the simulated scenarios at any particular date.

We focus on default risk, which is the most relevant risk component in the Eurosystem's balance sheet, since the holdings of purchase programmes are held to maturity with very few exceptions, and market risk in refinancing operations can materialize only subordinately to the default of the counterparty. This implies that we calculate losses only conditionally on the default of one or more debtors to whom the Eurosystem is exposed.[12]

With reference to purchase programme portfolios, loss is zero for those assets whose issuers do not default, while in case of default the loss is computed as the difference between the book value[13] and a fixed percentage of the nominal value, as follows:

$$L = \sum_{a} \delta_{issuer(a)} \cdot (BV_a - RR_a \cdot FV_a)$$

where L is loss, a is the asset index, δ is a binary default indicator (1 if issuer defaults, 0 otherwise), BV and FV are, respectively, the book and the face value of the asset, RR is the recovery rate.

Our recovery rate assumptions are 60 percent for structured finance instruments (covered bonds and ABSs) and 30 percent for all the other assets.

In the previous formula, book and face values, proxies of the exposure-at-default (EAD), are those observed at the reference date, not the net purchases which were already set and announced to take place within the 1-year horizon. Risk estimates under the former approach ignore the fact that the EAD over a 1-year horizon would be larger than that implied by current exposure. For most programmes the empirical difference between the two approaches is absorbed over time, since our analysis spans a long period (eleven years): programmes eventually reach their maximum amount, which is reflected in the corresponding risk estimates. For the PEPP, however, which had not been fully implemented at the end of 2020, the difference between the two approaches might be significant. In Section 8, risks are estimated under the alternative assumption.

The calculation of losses arising from monetary policy credit operations takes into account the double layer of protection offered by the counterparty and the collateral pledged. First, the counterparty risk is simulated: if the counterparty does not default, then the loss is zero. Otherwise, each asset in its collateral pool is simulated as well, and the loss is computed as the difference, if positive, between the EAD and the sum of all collateral asset values. The value of each collateral asset is set equal either to a fixed

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11 After the first 50,000 simulations, we estimate risk by adding 10,000 scenarios at a time and we stop the simulation when the change in the estimated risk is below 1 percent for five consecutive times (i.e., in the last additional 50,000 scenarios estimated risk changes by less than 1 percent).

12 Potential losses arising from market prices movements are therefore not considered.

13 This takes into account the fact that purchase programme holdings are not marked-to-market.

percentage of its nominal value, if the issuer defaults, or to its value before the haircut, if the issuer does not default,[14] as follows:

$$L = \sum_{c} \delta_c \cdot max\left(0, EAD_c - \sum_{a\ in\ collateral(c)} (\delta_a \cdot FV_a \cdot RR_a + (1-\delta_a) \cdot BH_a)\right)$$

where *c* is the counterparty index, *a* is the collateral asset index, *EAD* is the assumed exposure-at-default, δ are the binary default indicators for the counterparties and the collateral asset issuers, *BH* are the values before haircut, *FV* are the face values and *RR* are the recovery rates.

The estimation of EAD is not straightforward since banks, under the regime of full allotment that has been in place throughout the sample period, might increase their monetary policy exposure during a crisis. Current exposure thus generally is an underestimate of the potential EAD. We make a conservative assumption and set EAD equal to the current collateral value after haircuts,[15] assuming that banks under stressful conditions would increase their monetary policy exposure up to the maximum allowed amount, given by the value of collateral they have pledged (net of the haircuts).[16] Therefore, our assumed EAD may be significantly higher than the amount of money actually lent to each counterparty at any date. As an example, on the reference date of 25 December 2020 the total refinancing exposure was €1,800 billion, while the total net collateral value – which we use as EAD - was €2,600 billion (+46 percent).

With this assumption, losses arising from monetary policy credit operations are computed as:

$$L = \sum_{c} \delta_c \cdot max\left(0, \sum_{a\ in\ collateral(c)} (AH_a - \delta_a \cdot FV_a \cdot RR_a - (1-\delta_a) \cdot BH_a)\right)$$

where *AH* are the values after haircut.

Since collateral value before haircuts is always larger than collateral value after haircut (*BH* > *AH*), collateral assets that do not default add a negative contribution to losses, which offsets the positive contribution originated by collateral assets that do default. Thus, we take into account both the diversification effect in the collateral pool and the protection offered by the haircuts.

Regarding ELA operations, losses could be calculated with the same formula reported above for the monetary policy credit operations, since ELA has the same financial structure (it is a collateralized loan). However, in the case of ELA, exposures are likely to be of worse quality than exposure through regular OMOs, due to the lower credit quality of the counterparties accessing ELA and the wider collateral set typically eligible for ELA operations. In addition, data regarding the exact amount and composition of collateral are generally not available. Finally, the potential role of the government, as the ultimate effective guarantor, should be taken into account in case of a systemic banking crisis. In practice, risk

14 Since our analysis focuses on default risk, the market risk of collateral (i.e., the possibility that its price goes down during the liquidation process) is not considered.

15 Excluding cash collateral (if any), since it does not carry risk.

16 In principle, this approach could lead to an underestimation of EAD as well, since banks could also decide to increase their collateral pool (i.e., to pledge more assets). However, such a hypothesis would require an estimation of eligible unencumbered assets for each counterparty, which is difficult to obtain.

from ELA exposures should be modelled with some suitable assumptions, depending on the type of the operations conducted in the sample period (see the Appendix, Section B for more details).

In the above formula exposures (book values, face values, values before haircuts, values after haircuts) are static data, and do not change from one scenario to another. Default events (δ), on the contrary, must be simulated. In particular, we simulate three sets of debtors for each scenario:

i. issuers of assets held in the purchase programme portfolios;

ii. counterparties in monetary policy and ELA operations;

iii. issuers of assets pledged as collateral by counterparties.

These debtors are jointly simulated according to a multivariate Student *t* distribution, whose parameters, namely the correlation matrix and the degrees of freedom, are estimated as described in the Appendix, Section A.[17]

In practice, for each debtor *i* we define a Student *t* random variable X_i as:

$$X_i = \sqrt{\frac{\nu}{u}} \cdot Z_i$$

where *u* and Z_i are independent with *u* distributed as a chi-square (with ν degrees of freedom) and Z_i as a standard normal. In turn, Z_i are calculated as:

$$Z_i = \sum\nolimits_{k=1}^{m} \beta_{i,k} \cdot F_k + \sqrt{1 - \sum\nolimits_{k=1}^{m} \beta_{i,k}^2} \cdot \varepsilon_i$$

where F_i and ε_i are independent and distributed as a standard normal. Since the factors F_i are common to all debtors, the correlations are given by:

$$\rho(X_i, X_j) = \rho(Z_i, Z_j) = \sum\nolimits_{k=1}^{m} \beta_{i,k} \cdot \beta_{j,k}$$

Once the random deviates (X_i) are drawn from the multivariate Student *t* distribution, they are compared with a given threshold (T_i) in order to determine if a default occurs:

$$\delta_i = \begin{cases} 1, & if\ X_i < T_i \\ 0, & otherwise \end{cases}$$

The thresholds are set equal to the (univariate) Student *t* quantile of the probability of default (PD):

$$T_i = Q(PD_i)$$

This yields a simulated default rate equal to the PD, up to the Monte Carlo error.

The PDs used in our exercise are described in Section 4.

[17] Our distribution is symmetric. Caballero *et al.* (2020), which use a similar dataset to calibrate a skewed *t* copula, argue that the introduction of an asymmetric term has a small effect on the expected shortfall estimates.

We note that, while issuers in the purchase programme portfolios and counterparties are simulated over a 1-year horizon (namely, the risk horizon),[18] collateral is simulated over a much shorter horizon (typically a few weeks), since it is assumed to be swiftly liquidated by the Eurosystem in the event of a counterparty default. In practice, this means that PDs must be scaled down for collateral assets. For more details see the Appendix, Section B.

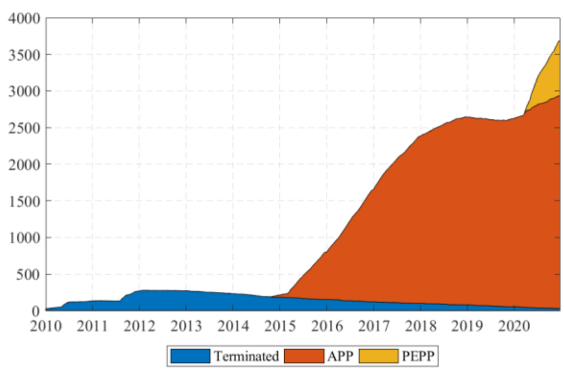
Notwithstanding the large number of input parameters and methodological assumptions, our results exhibit a high degree of robustness, as shown in Section 6.

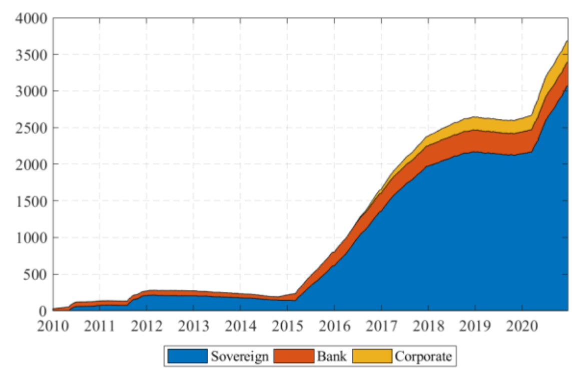
3. Exposure

For purchase programme portfolios, exposures (book and face values) are retrieved from our internal database. The first available date is 5 July 2013. For the period September 2010 – June 2013, we estimate exposures of the Covered Bond Purchase Programmes 1&2 (CBPP1 and 2) and of the Securities Market Programme (SMP) from the total (publicly available) outstanding portfolio. We assume the same composition by issuer as that observed on 5 July 2013 for CBPP1 and 2. For the SMP we take into account the different country composition during the two waves of the programme.[19]

Figure 1 plots the evolution of the monetary policy securities holdings between September 2010 and December 2020, which significantly increased after the launch of the APP at the end of 2014, and especially during its first three years of operations (with monthly net purchases of €60-80 billion).

Figure 1. Monetary policy securities holdings (book value, € billion)





Source: ECB and own calculations.

The left panel shows the composition by category: the terminated programmes (CBPP1&2, SMP), the Asset Purchase Programme (APP, which includes the Covered Bond, ABS, Public Sector and Corporate Sector Purchase Programmes), and the Pandemic Emergency Purchase Programme (PEPP). As of

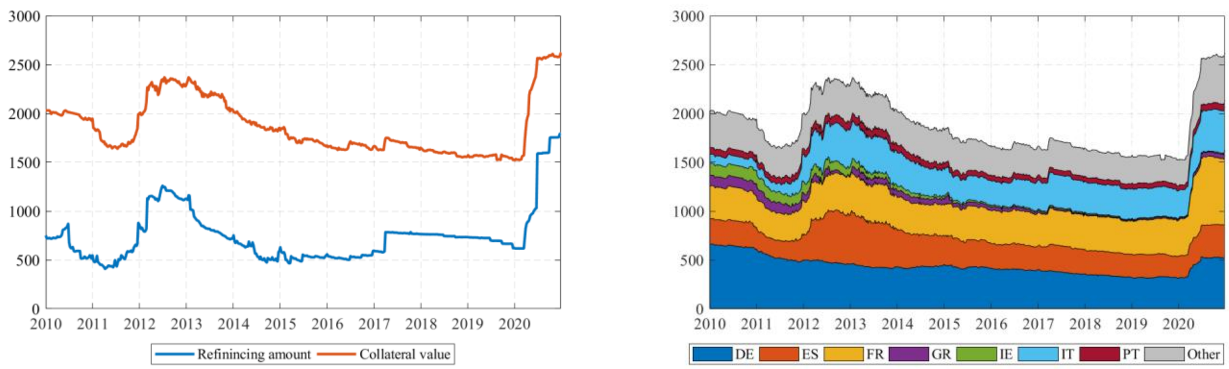
[18] In principle, purchase programme holdings with maturity below one year should be simulated over a horizon equal to their maturity. We do not take this into account, which seems acceptable if one considers the practice of reinvestment which has taken place until the end of the sample period.

[19] SMP purchases were conducted by Eurosystem central banks in two main waves. The first one (May 2010 - March 2011) dealt with government bonds from the secondary markets of Greece, Ireland, and Portugal. The second one (which started on 7 August 2011 and ended in February 2012) also dealt with government bonds from Italy and Spain.

December 2020, the APP represents 78 percent of total exposure. The right panel shows the breakdown by sector: public, corporate and bank (covered bonds and ABSs). As of December 2020, the exposure towards the public sector amounts to 84 percent of the total.

For credit operations, exposures (collateral face value, collateral value before and after haircuts) are retrieved from our internal database.[20] Figure 2 plots the evolution of credit operations between September 2010 and December 2020. The left panel compares the value of collateral (after haircut), which is our assumed EAD (see Section 2), with the actual refinancing amount.[21] Both quantities significantly increased after the outbreak of the pandemic and the related collateral easing measures approved by the ECB in the second quarter of 2020. While the over-collateralization[22] is 46 percent as of December 2020, on some dates in the first half of 2011 it was close to 300 percent. The right panel shows the distribution of collateral by jurisdiction.

Figure 2. Credit operations (refinancing amount and collateral value, € billion)



Source: ECB and own calculations.

For ELA operations, exposures are derived from confidential data.[23]

[20] The first available date is 17 September 2010. For the period 1 January 2010 – 17 September 2010, data have been estimated from the total collateral value per asset class, as reported in several internal sources. Within each asset class, we assume the same composition by issuer as that observed on 17 September 2010.

[21] For simplicity, the blue line ('refinancing amount') only includes the monetary policy refinancing operations denominated in euro. The estimation of risks, however, also takes into account the monetary policy operations in other currencies (US dollar liquidity providing operations), since it is based on the total collateral pledged by monetary policy counterparties (see Section 2), which covers all the outstanding operations.

[22] Computed as: (collateral value)/(refinancing amount) - 1.

[23] Some public information regarding ELA may be found on the website of the relevant NCB. More detailed evidence regarding ELA exposures of the Eurosystem is reported in Mourmouras (2017). As of May 2017, qualitative information has been provided by the ECB with the publication of the *'Agreement on emergency liquidity assistance'*, a document that describes the allocation of responsibilities, costs, and risks for ELA operations within the Eurosystem (ECB, 2017). A thorough discussion of the lender of last resort role of the Eurosystem and other central banks is provided by Calomiris, Flandreau and Laeven (2016).

4. Probability of default

We use the 1-year probabilities of default (PDs) computed by Moody's as expected default frequencies (EDFs). They are widely employed in the financial sector as input in counterparty assessment, early warning systems and portfolio monitoring, internal risk rating systems, and loss provisioning. These market-driven EDFs, which are independent from agency ratings, enable us to investigate the behaviour of financial risks around some major monetary policy announcements of the last decade.

For financial and non-financial corporates, EDFs are produced with a proprietary model (known as KMV), which uses equity prices and balance sheet indicators as input data. For sovereign issuers, in the absence of the latter input, EDFs are derived from CDS premia (CDS-I-EDF), with a methodology that relies on two equations: a spread valuation equation, which converts CDS premia into risk-neutral PDs, and a translation equation, which converts risk-neutral PDs into physical PDs. The parameters of the translation equation are calibrated so that CDS-I-EDFs are – on average – consistent with 'standard' EDFs.[24]

Both EDFs, for corporates and sovereigns, can be considered as 'physical' PDs (as opposed to 'risk neutral' PDs), and thus require no adjustment to disentangle the quantity of risk from the market price of risk for use in credit risk estimation.[25] Our sample comprises 364 debtors, distributed by sector as reported in Table 1.

Table 1. EDFs sample: number of debtors

Sovereign & Supra	19
Bank	126
Corporate - Invest. Grade	151
Corporate – High Yield	68

We use high yield EDFs for credit claims pledged as collateral with non-investment grade credit quality.[26] Table 2 reports some EDF statistics by sector and time period.

[24] Moody's Analytics (2010). The approach is used to derive the 5-year CDS-I-EDFs. The EDFs for different horizons, such as the 1-year horizon that is used in this paper, are derived from the 5-year ones employing a model of the relationship between credit risk and time horizons that relies on three components: an asymptotic default tendency, a systemic factor and a firm-specific factor (see Moody's Analytics, 2017 for further details).

[25] When deriving default probabilities from market prices (equity prices, bond yield spreads, CDS premia), it is important to distinguish between physical and risk-neutral default probabilities. While risk-neutral default probabilities adjust for investors' risk aversion, physical default probabilities, which can be thought of as 'real world' default probabilities, do not. Market prices, including CDS premia, reflect the expected loss – equal to the product of the probability of default (PD) times the loss given default (LGD) – and the risk premium, but frequently PDs extracted from market prices fail to remove the risk premium, thus largely overstating actual default rates, especially among higher rated entities. Moody's EDF measures are physical PDs; since they filter out the premium demanded by investors to compensate for risk inherent in the CDS contract, they reflect only the risk of the underlying credit. See Hull, Predescu and White (2005).

[26] The credit claims accepted as collateral under the Additional Credit Claims (ACC) regime belong to this category.

Table 2. EDF statistics (percentage values)

		Avg.	Percentiles				
			5th	25th	50th	75th	95th
2010-2012	**Sovereign & Supra**	0.80	0.01	0.01	0.07	0.30	3.07
	Bank	2.60	0.15	0.38	0.58	1.41	14.73
	Corporate - Invest. Grade	0.46	0.02	0.04	0.12	0.38	1.32
	Corporate - High Yield	1.11	0.03	0.11	0.34	1.18	5.14
2013-2017	**Sovereign & Supra**	0.17	0.01	0.01	0.01	0.03	0.62
	Bank	1.46	0.09	0.31	0.60	1.30	5.58
	Corporate - Invest. Grade	0.14	0.01	0.02	0.04	0.14	0.50
	Corporate - High Yield	0.70	0.02	0.05	0.14	0.52	3.30
2018-2020	**Sovereign & Supra**	0.02	0.01	0.01	0.01	0.01	0.06
	Bank	0.76	0.01	0.15	0.35	0.67	3.11
	Corporate - Invest. Grade	0.12	0.01	0.01	0.02	0.07	0.41
	Corporate - High Yield	0.69	0.02	0.06	0.13	0.49	2.97

Such sample does not cover all the entities for our risk estimation, which amount to around 7,000 distinct debtors (including counterparties, purchase programme issuers and collateral issuers). In order to make this large number tractable, we create country-sector EDF indices, which are assigned to debtors without an EDF in our sample. More specifically, we cluster debtors by country and sector, and for each cluster we compute the median of all available EDFs, which is then assigned to all the entities in the cluster without an EDF. We chose the median rather than the average EDF since the former is less sensitive to outliers, in line with Caballero *et al.* (2020). Since there is a single sovereign for each country,[27] sovereign indices correspond to the individual EDFs (and not to a median of several EDFs).

In all, we calculate 36 indices, as reported in Table 3. These EDF indices are also used for the estimation of the parameters of the multivariate Student *t* distribution (see the Appendix, Section A).

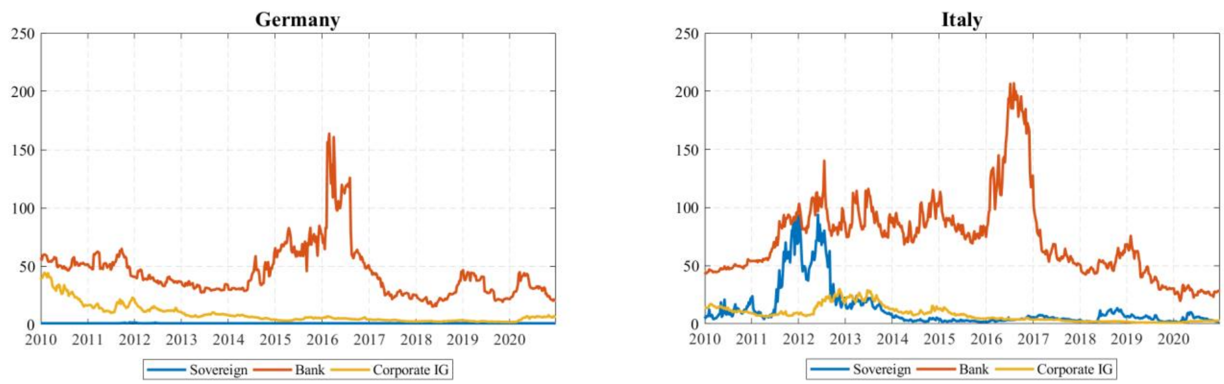
[27] While distinct EDFs are available for central governments and local governments, we only consider central government EDFs, which we apply to local government issues as well.

Table 3. Country-sector EDF indices

Sovereign & Supra (19)	Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Malta, Portugal, Slovakia, Slovenia, Spain, Netherlands,[28] Others
Bank (8)	Austria, Germany, Spain, France, Greece, Ireland, Italy, Others
Corporate - Invest. Grade (7)	Belgium, Germany, Spain, France, Italy, Netherlands, Others
Corporate – High Yield (2)	Euro Core, Euro Peripheral

Figure 3 shows the EDF indices for Germany and Italy.

Figure 3. Country-sector EDF indices (basis points)

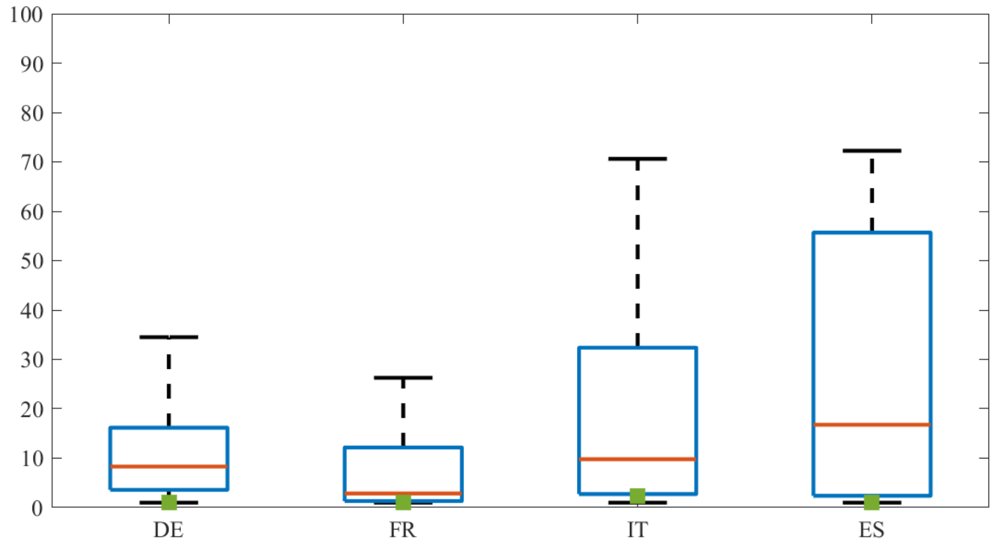


Source: Moody’s Credit Edge and own calculations.

A robustness check of CDS-I-EDFs is challenging, because very few sovereign defaults are available. A possible course of action is verifying that the sovereign CDS-I-EDF in each country is consistent with domestic corporate (financial and non-financial) EDFs, under the assumption that the former should be lower, since the sovereign is normally perceived as less risky than the safest firms in its jurisdiction. Figure 4 shows that this is indeed the case for the largest countries of the euro area.

[28] We proxy the (unavailable) EDF of Luxembourg with the one of the Netherlands.

Figure 4. Sovereign (green squares) and corporate (boxplots) EDFs for the major jurisdictions in the euro area (average in Q4 2020; basis points)



Source: Moody's Credit Edge and own calculations.

We note that EDFs and CDS-I-EDFs can be used to produce point-in-time, market based risk estimates as those reported in this paper. EDFs incorporate not only information about an issuer's own credit risk profile, but also sectoral, geographic, and macro-credit cycle factors. EDF measures may thus provide an early warning signal of sudden changes in default risk. However, a full assessment of the riskiness of an issuer may require both point-in-time and through-the-cycle default probabilities. In certain circumstances, for example concerning long-term decision-making or building capital buffers, the use of through-the-cycle (TTC) PDs might be more appropriate, as they isolate the issuer's underlying credit trend from the macro-credit cycle, thus providing less volatile default probability estimates over the credit cycle. In Section 9 we compute risk using Moody's TTC EDFs, which are available for corporate issuers.

5. Results

Figure 5 plots risk (left y-axis) and exposure (right y-axis) at weekly frequency from 1 January 2010 to 25 December 2020. Risk is estimated for the entire Eurosystem as the expected shortfall at the 99 percent confidence level (ES99) with the methodology described in Section 2. Risk reaches local highs on the following occasions: a) the sovereign debt crisis in the first half of 2012; b) the ELA provision to Greek banks in 2015; c) the political tensions in Italy surrounding the formation of the new government in May 2018; d) the outbreak of the pandemic in March 2020, followed by a split among EU members on the extraordinary relief package and the German constitutional court pronunciation on the illegality of the PSPP, in April-May 2020.

Risk reached an overall maximum around €185 billion in June 2012, even though monetary policy exposure widely increased since then, following the APP in 2014 and PEPP in 2020.

Figure 5. Risk and Exposure (€ billion)

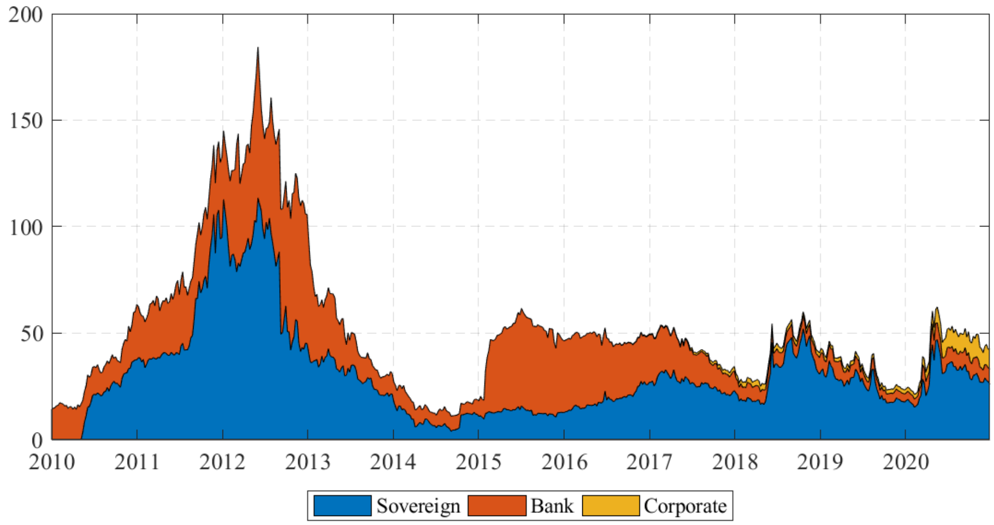
Source: own calculations.

The contribution to risk of monetary policy credit operations is rather small and less sensitive to financial market developments, due to the collateralized nature of refinancing to commercial banks. The risk profile of the Eurosystem has changed since the launch of the purchase programmes, becoming similar to the risk profile of institutional investors that hold diversified portfolios of marketable assets and are directly exposed to financial market volatility. Finally, the risk contribution of ELA operations is quite significant.[29]

Figure 6 plots the risk contribution by sector. The sovereign sector and the corporate sector take into account the risk of the corresponding purchase programmes. In addition to risks arising from purchase programmes (covered bonds and ABSs), the bank sector also includes the risk of monetary policy refinancing and ELA operations. As of December 2020 the public sector accounts for 62 percent of total risk, while the corporate sector and the bank sector account for 21 and 17 percent, respectively.

[29] The breakdown is not shown in Fig. 5 for confidentiality reasons.

Figure 6. Risk breakdown by sector (€ billion)



Source: own calculations.

While sovereign risk is decreasing, especially in the second half of 2020, corporate risk is building up. Section 9 provides a focus on the corporate sector.

Next we examine what would happen if an ES99-sized credit loss materialized: would capital buffers withstand this event? For this purpose we compare the maximum risk borne by the individual NCBs with the financial buffers in each year. Financial buffers include capital and reserves (paid-up capital, legal reserves and other reserves), revaluation accounts (i.e., unrealized gains on certain assets like gold), and risk provisions.

We find that for all major NCBs the buffers were a multiple of the ES99 loss arising from monetary policy and ELA operations, even at the peak of the sovereign debt crisis in 2011-2012 and during the pandemic crisis in 2020.[30]

The picture at the aggregate Eurosystem level is also reassuring as the buffers increased from a minimum of 430 billion in 2010 to a maximum of 737 billion in 2020.[31] We recall however that the buffers should cater for all risks in the central bank balance sheet, not simply for those related to monetary policy implementation.

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30 The individual NCB figures are not provided for confidentiality reasons.

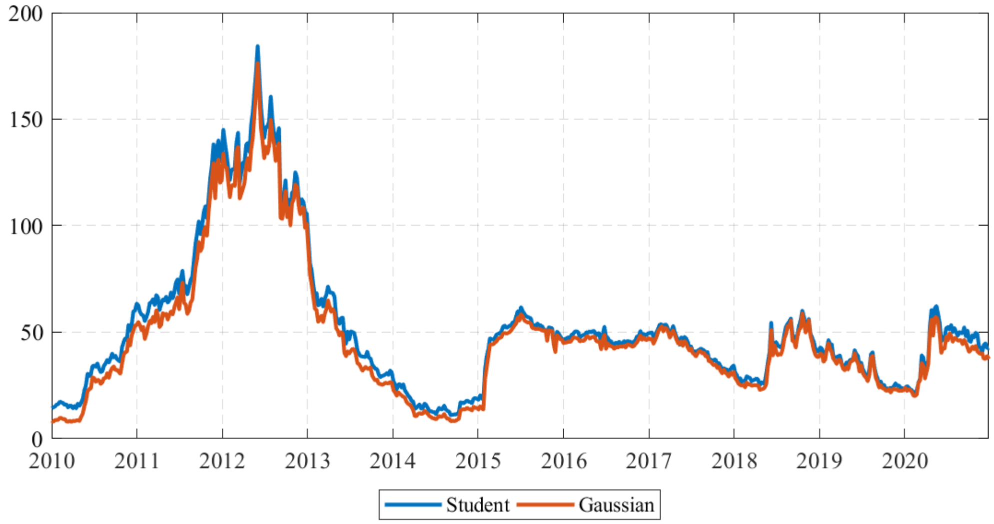
31 The financial buffers in 2010 (430 billion) do not include the NCBs of Lithuania and Latvia, which joined the euro in 2014.

6. Robustness analysis

This Section provides some analysis in order to check the robustness of the results to some of the modelling assumptions.

First, we focus on the default co-dependency model. Figure 7 shows the impact on risk of different copula specifications, comparing the proposed fat-tail approach (Student *t*) with the Gaussian approach.

Figure 7. Risk; Student *vs* Gaussian copula (€ billion)

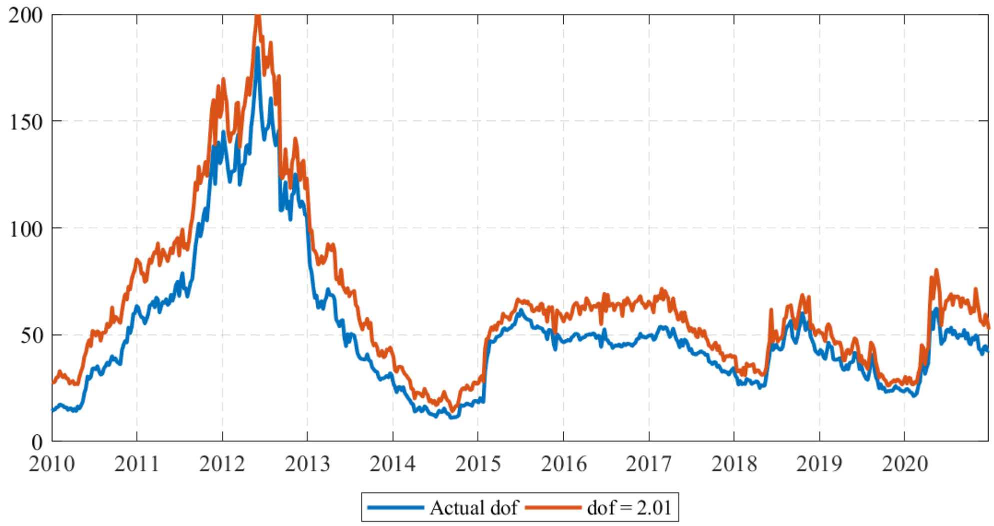


Source: own calculations.

While accounting for fat tails leads to higher estimated risk (the Student *t* copula implies an average increase of risk by 14 per cent with respect to the Gaussian copula), the dynamics of credit risk is quite similar under the two approaches. This is partially due to the fact that our estimates for the degrees of freedom of the Student *t* are moderately high (see Appendix, Section A).

Second, Figure 8 compares our risk estimates with those obtained under the assumption of very fat tails. The latter are obtained with a value of the degrees of freedom artificially lowered to 2.01 at all dates (rather than the values estimated as described in Appendix, Section A). Since a Student *t* distribution with 2 degrees of freedom has infinite variance, 2.01 degrees of freedom imply very fat tails.

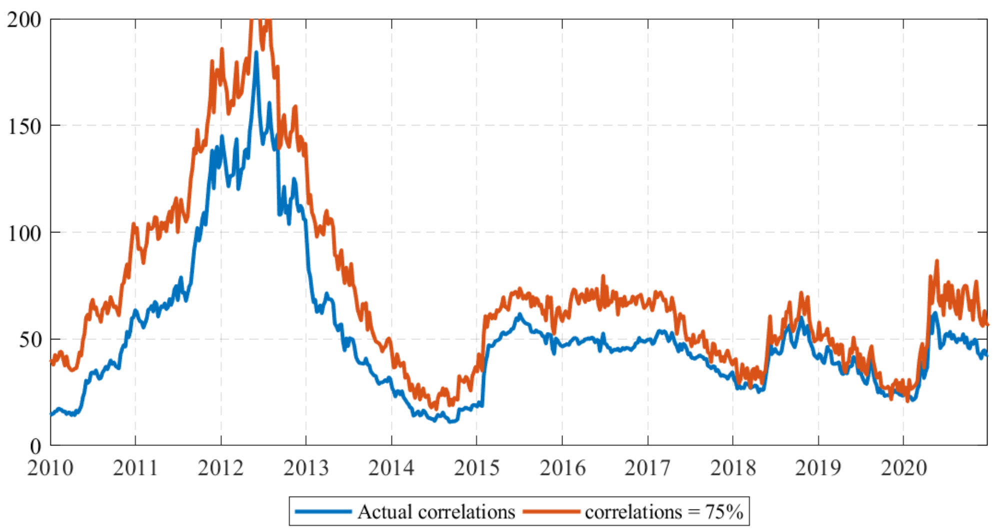
Figure 8. Risk; actual degrees of freedom vs very low degrees of freedom (€ billion)



Source: own calculations

Third, Figure 9 compares our risk estimates with those obtained under the hypothesis that correlations are artificially increased to 75 per cent for all debtors and all dates, i.e. a much higher degree of correlation compared to our estimates. The results are similar to those obtained under a reduction in the degrees of freedom, and the risk profile remains broadly unchanged.

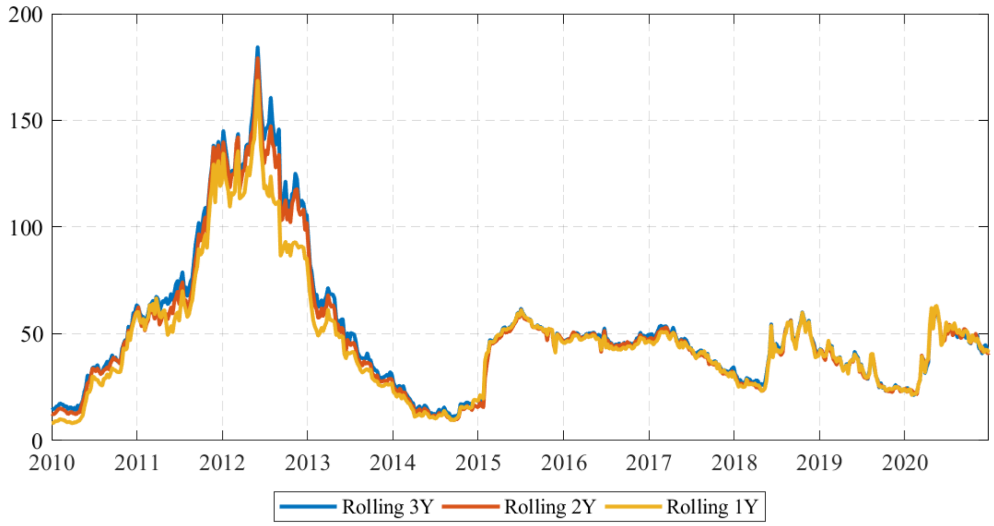
Figure 9. Risk; actual correlations vs very high correlations (€ billion)



Source: own calculations

Next, Figure 10 shows that the choice of different rolling window lengths, namely the 3-year window compared with the alternative 2-year and 1-year windows, does not affect our results in a significant way.

Figure 10. Risk; different rolling window lengths (€ billion)

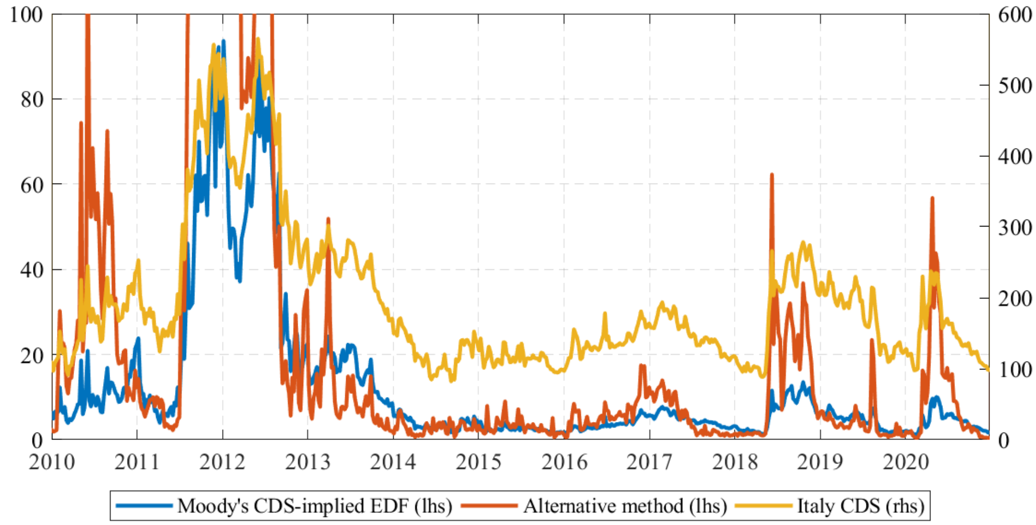


Source: own calculations.

We then examine more closely the PDs. Since sovereigns PDs are by far the most important input of our model, we have also considered as an alternative the methodology proposed by Heynderickx *et al.* (2016), which is also employed by Caballero *et al.* (2020). This alternative method computes physical PDs from CDS quotes, like our model.

For illustration purpose, Figure 11 compares the 1-year CDS-I-EDF for Italy with the PD computed with the Heynderickx method. We note that the latter yields a much larger volatility for the estimated PDs compared with Moody's EDFs. We attribute this to the fact that Moody's CDS-I-EDF benefit from daily updates of the Sharpe ratio, which allows adjustments (from risk-neutral to physical PD) of different magnitude depending on market conditions, possibly filtering out some of the volatility in the underlying CDS quotes. The parameters proposed by Heynderickx *et al.* for converting risk-neutral PDs into physical PDs are constant over time, hence market noise incorporated in risk-neutral PDs is filtered out to a lesser extent.

Figure 11. 1-year probability of default of Italy and Italy's CDS (basis points)



Source: Moody's Credit Edge, CMA, own calculations.

Figure 12 shows the impact on risk of these two different PD specifications for the sovereign: a) Moody's EDF, which we used (the blue line corresponds to the risk reported in Section 5); b) the alternative specification based on Heynderickx *et al.* (2016). The volatility of the PD with the latter method affects the volatility of the corresponding risk estimate, which shows a larger peak-to-trough difference.

Figure 12. Risk; Moody's EDFs vs Alternative PDs (€ billion)

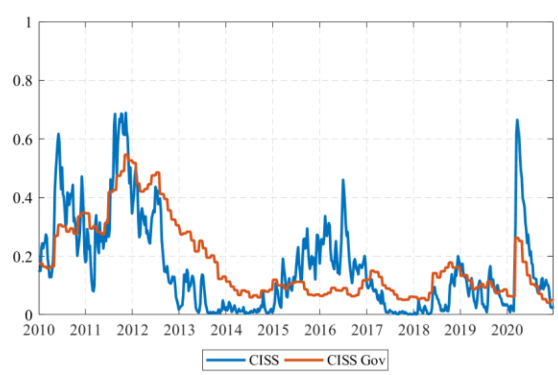
Source: own calculations

Since the risk profile is broadly similar in all cases, with a peak in June 2012 and a value which is several times smaller at the end of 2020, our conclusions hold true also under these conservative and/or alternatives assumptions, confirming the robustness of our results.

7. Risk endogeneity and risk efficiency

In this Section we look more closely at the evolution of risk during four time periods encompassing the launch of the major purchase programmes for sovereign bonds: SMP, OMT, PSPP and PEPP. In order to assess these monetary policy measures under a comprehensive cost-benefit perspective, we also report two indicators related to the central bank price stability mandate and financial stability: a) the 5-year, 5-year forward euro inflation swap rate, which is commonly used as a proxy for the market's long-term inflation expectations in the euro area; b) the Composite Indicator of Systemic Stress (CISS), which is computed by the ECB as the equally weighted average of 15 market-based financial stress measures from the financial intermediaries sector, money market, equity market, bond market and foreign exchange market (this indicator ranges between 0 and 1).[32] The left panel of Figure 13 plots the 5-year, 5-year forward euro inflation swap rate (left y-axis) and, for comparison, the long-term inflation expectations from the Survey of Professional Forecasters. The right panel of the same figure plots the CISS index and its sovereign component.

Figure 13. Inflation expectations and Systemic stress indicator



Source: ECB.

We cannot perform a proper event study analysis. Such an approach rests on the assumption that markets are informationally efficient. In our context, this would require that the impact of the ECB's unconventional policies materializes on the exact date of announcement, while in the cases under consideration expectations are more likely to have been shaped over a period of time, during which views and actions of financial market participants, including the central bank, have interacted with each other

[32] Garcia-de-Andoain and Kremer (2018), Holló, Kremer and Lo Duca (2012).

in a continuous process. A case in point is the APP, which had been fine-tuned according to financial and economic developments and communicated to the market on different occasions during the second half of 2014.

Therefore, we focus on the main events and narratives that have accompanied the four monetary policy announcements, including some major statements by policy makers.

SMP

The first time window of interest is related to the Securities Market Programme, launched on 10 May 2010 and involving the purchase of sovereign bonds in secondary markets as a monetary policy tool for the first time since the introduction of the euro in 1999. To many commentators, the decision seemed behind the curve and taken without much conviction, coming only a few days after the conclusion of a scheduled meeting of the Governing Council, during which the possibility of purchasing sovereign bonds was not even discussed.[33] Yet the market tensions that led to the launch of the SMP had been going on since the end of 2009, when difficulties with public finances in Greece had come into the focus of financial market participants.

In launching the SMP, as well as in subsequent official speeches by the President of the ECB, the communication was very cautious.[34] On 10 May the ECB did not announce any key features of the SMP, such as which securities it would target, the amount that would be purchased, and how long the programme would last.[35] Furthermore, it became evident that the ECB was not acting decisively also on account of diverging views within the Governing Council.

At the German-French summit of 19 October 2010 in Deauville, Chancellor Merkel and President Sarkozy called for a permanent crisis resolution mechanism in Europe *'comprising the necessary arrangements for an adequate participation of the private sector'*. Private investors interpreted the announcement as an official signal that sovereign debt restructuring would henceforth be considered acceptable in EU countries. Bond yields of vulnerable sovereign issuers steeply increased on the news.

During the summer of the following year the financial contagion spread to Spain and Italy. On 7 August 2011 the ECB stated that it would have actively implemented the SMP on the assessment that the governments of Italy and Spain were committed to reforms in the areas of fiscal and structural policies,

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33 ECB (2010a).

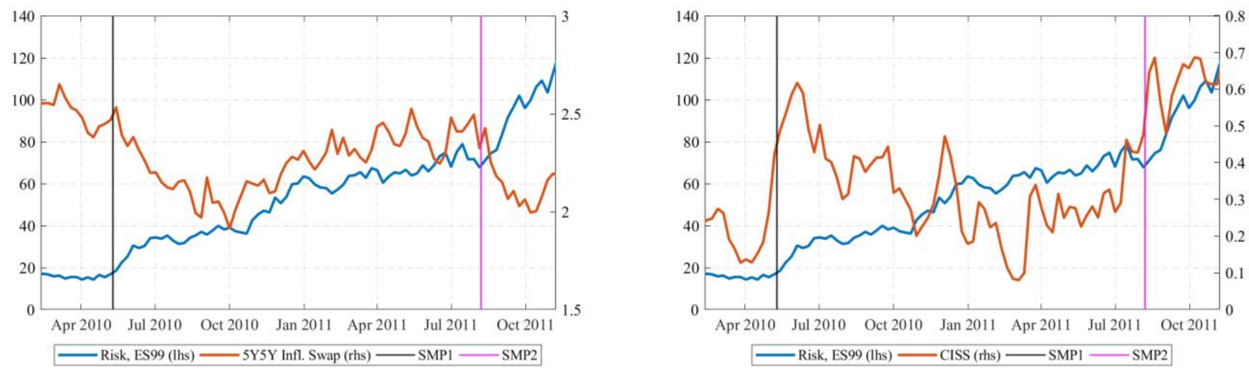
34 It was made very clear that *'the ECB was not printing money'*, the purchases made on the secondary market were *'not meant to help Governments to circumvent the fundamental principle of budgetary discipline'* and, even more importantly, purchases would be decided by the Governing Council at its discretion (ECB, 2010b).

35 Fairly soon, bond traders learned about the ECB's actual presence in the market under SMP. As evidence accumulated about the likely size and time profile of the official interventions in the distressed jurisdictions, investors grew concerned that the programme might fall short of the minimum scale that, in their assessment, would be necessary to decisively eradicate the fear that was gripping the sovereign bond market (Rostagno *et al.*, 2019). At the press conference following the Governing Council meeting of 10 June 2010, in response to a question about the size and jurisdictions of purchases, President Trichet replied: *'You could see that the first week we withdrew approximately 16.5 billion euros, the second week 10 billion more, the third week an additional 8.5 billion, in the fourth week 5.5 billion. So you have this information. We withdraw exactly the level of liquidity that we inject. No other indication.'*

aimed at enhancing the competitiveness and flexibility of their economies and at rapidly reducing public deficits.[36]

The sovereign crisis did not abate after the launch of the second wave of the SMP, as shown in Figure 14, which plots the evolution of risk for the Eurosystem (left and right panels) plus the inflation expectations (left panel) and the systemic stress indicator (right panel) around the two relevant SMP dates, 10 May 2010 and 7 August 2011.[37]

Figure 14. Risk (€ billion), Inflation expectations (percentage values) and Systemic stress indicator around the two SMP announcements (10 May 2010 and 7 August 2011)



Source: ECB and own calculations.

OMT

The two three-year Very Long-Term Refinancing Operations (VLTRO) launched by the ECB in December 2011 and February 2012, respectively, had limited and short-lived effects on the sovereign market conditions. In mid-2012 the tensions in the euro area government bond markets reached new peaks and spread to the banking sector.

At their summits in the first half of 2012 the European leaders took several decisions to break the circle between banks and sovereigns, the most relevant being the set-up of the European Stability Mechanism (January) and of the Single Supervisory Mechanism (June).

As a further intervention to avoid impairment in monetary policy transmission, in the period from July to September 2012 the Governing Council announced that the ECB might have engaged in Outright Monetary Transactions (OMTs) in the secondary markets for government bonds. In particular, on 26 July 2012, during a conference in London, President Draghi said that the ECB was ready to do *'whatever it takes'* to preserve the euro within the limits of its mandate.[38] On 2 August 2012, at the press conference

36 ECB (2011).

37 After the August 2011 decision, the spread between 10 year Italian and German government bond yields decreased from around 400 basis points to 270 basis points. This positive market reaction was short lived and the spread climbed to 500 basis points at the beginning of November 2011 and again in January 2012.

38 Draghi (2012). The irreversibility of the euro made the premia on sovereign bonds (owing to the so called convertibility risk) unwarranted, as they derived from the wrong perception that a sovereign in financial difficulty would abandon the

after the Governing Council meeting, the ECB announced that it *'may undertake outright open market operations of a size adequate to reach its objective'*.[39] On 6 September the ECB eventually announced a number of technical features of the OMT programme.

The announcement of the OMT signaled determination and strength, and succeeded in calming market tensions (Figure 15). The effectiveness of the announcement of OMT in influencing financial market conditions (especially if compared with the SMP) is probably related to the fact that purchases are in principle unlimited, subject to conditionality on compliance with a macroeconomic adjustment programme, and have greater transparency.[40] In the following years risk has never reached the level of 2012, despite the huge increase of the Eurosystem's balance sheet.

Figure 15. Risk (€ billion), Inflation expectations (percentage values) and Systemic stress indicator around the *'whatever it takes'* statement (26 July 2012)

Source: ECB and own calculations.

Although successful, the OMT was politically controversial. The commitment to preserve the euro as a stable currency was unanimous within the Governing Council. Still, there was no mystery that the Bundesbank had expressed its reservations about purchasing sovereign bonds.[41] The decision to launch the OMT was later challenged before the German constitutional court by members of the German Bundestag.

euro and return to its domestic currency. To the extent that the size of these sovereign premia was hampering the functioning of the monetary policy transmission channel, addressing them was in the remit of the ECB.

[39] ECB (2012). Although the operational details would have been communicated over the following weeks, during the Q&A session with journalists, it was made clear that the new programme would have been *'very different from the previous Securities Market Programme'*. The following aspects were mentioned: i) explicit conditionality; ii) full transparency about the countries where OMT would be undertaken and about the amounts; iii) focus on the shorter part of the yield curve; iv) review of the issue of the seniority of the Eurosystem claims.

[40] Altavilla, Giannone and Lenza (2016) find evidence that the OMT announcement significantly lowered yield spreads of sovereign bonds, especially for stressed euro area countries. Acharya *et al.* (2018), and Krishnamurthy, Nagel and Vissing-Jorgensen (2017) show significantly positive effects on banks' equity prices after the OMT announcement.

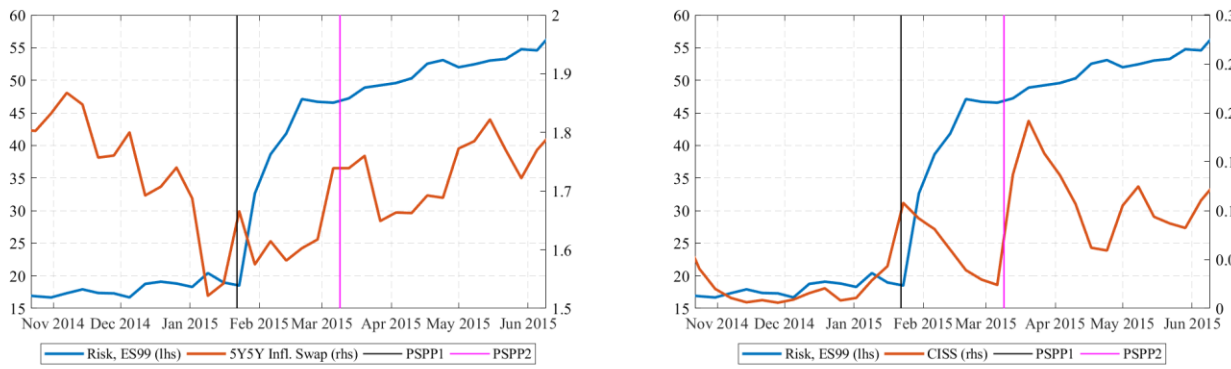
[41] These diverging views were explicitly acknowledged on 6 September 2012 during the press conference in which the President of the ECB announced the details of the OMT.

APP

The Eurosystem Asset Purchase Programme (APP) started in the last quarter of 2014 with the purchases of covered bonds and asset-backed securities under the CBPP3 and ABSPP, respectively. In the face of weaker than expected inflation dynamics and signs of decrease of inflation expectations even at long horizons, on 22 January 2015 the Governing Council decided to adopt further quantitative measures to expand the size and change the composition of the Eurosystem's balance sheet, supplementing the previous two programmes with additional purchases of securities issued by euro area governments, agencies and EU institutions (Public Sector Purchase Programme, PSPP).[42] The programme was further extended to the corporate sector (CSPP) in June 2016.

In contrast to the OMT, the APP was not launched in a period of market tension, so its limited impact on financial stability risk does not come as a surprise. Figure 16 shows the evolution of risk, price stability and financial stability indicators around the announcement of the extension of APP to the public sector (22 January 2015, PSPP1) and the actual start of the purchases (9 march 2015, PSPP2). The evolution of risk around 22 January 2015 is affected by the large ELA operations in Greece, that started just a few days later.

Figure 16. Risk (€ billion), Inflation expectations (percentage values) and Systemic stress indicator around the extension of APP to the public sector (22 January 2015 and 9 March 2015)



Source: ECB and own calculations.

As with the OMT, also the launch of the APP was challenged in court.[43]

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[42] For an analysis of the macroeconomic effects of the APP in counteracting the falling inflation expectations, see Neri (2021).

[43] The complainants — a group of about 1,750 people, led by German economists and law professors — first brought their case in 2015. They argued that the ECB was straying into monetary financing of governments, which is illegal under the EU treaty. The case was referred to the European Court of Justice, which ruled in favor of the ECB in 2018; the case went back to the German constitutional court, which on 5 May 2020 formally rejected the plaintiff's case (there was no monetary financing) but ruled the essential aspects of PSPP to be unconstitutional under German law.

PEPP

Soon after the outbreak of the Covid-19 pandemic throughout Europe at the beginning of March 2020, the expectations built up in the market about a strong and quick reaction from the ECB in view of the fast deterioration of the economic outlook. However, in the face of increasing turmoil in the euro sovereign debt market, in early March an official statement by the President of the ECB did not point to any concrete action and merely signaled that the central bank *'stands ready to take appropriate and targeted measures, as necessary and commensurate with the underlying risks'*.[44] The first measures to address the effect of the pandemic were announced on 12 March. These included additional LTROs, more favourable terms applied to TLTRO III operations and a temporary envelope of additional net asset purchases for the APP, by €120 billion, until the end of 2020.[45]

After some stress indicators in the euro money market had reached levels close to the historical highs of 2008 and 2012, on 18 March 2020 the Pandemic Emergency Purchase Programme (PEPP) announcement came as a strong positive surprise, with most commentators acknowledging that it was a game changer, supporting tighter intra-EMU spreads. The flexible implementation of the purchases over time, across asset classes and among jurisdictions, reinforced the perception of the ECB's determination to act.[46] The package was strengthened on 22 April with the ECB decision to grandfather the eligibility of marketable assets used as collateral, in order to mitigate the impact of possible future rating downgrades on collateral availability for euro area counterparties.[47]

However, after an initial positive market response, intra-EMU credit spreads rapidly started to increase again. The tightening in the euro area financial conditions — largely offsetting monetary and fiscal efforts — had been sparked by a split among EU countries over how additional public spending would have ultimately been funded.[48] PEPP started to be seen as unable to address reemerging concerns on sovereign debt sustainability and the long-term viability of the single currency area was again perceived at risk.

The period of market turmoil came to an end on 18 May, after a press conference in which Chancellor Merkel and President Macron outlined a plan to create additional €500 billion of spending power. Italian

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[44] ECB (2020a). On 3 March the Federal Reserve lowered the target range for the federal funds rate by 0.5 percentage points (to 1-1.25 percent) and the discount rate from 2.25 to 1.75 percent.

[45] ECB (2020b).

[46] Time-wise flexibility allows the central bank to adjust the pace of asset purchases to market conditions. Bernardini and Conti (2021) show that this type of flexibility in the implementation of the programme significantly contributed to its effectiveness.

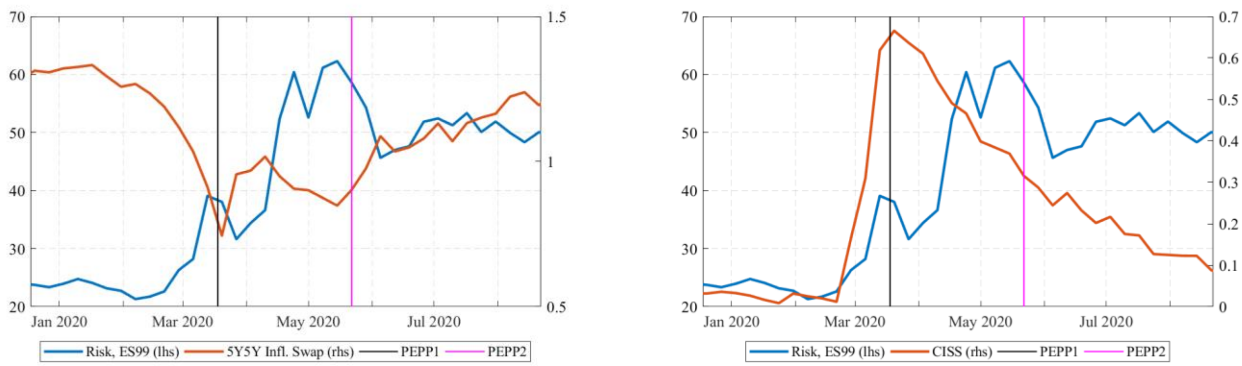
[47] ECB (2020c). The ECB also said it *'may decide, if and when necessary, to take additional measures to further mitigate the impact of rating downgrades, particularly with a view to ensuring the smooth transmission of its monetary policy in all jurisdictions of the euro area'*. Investors were particularly concerned by a potential downgrade of Italy's sovereign debt ratings, with Standard & Poor's set to announce a decision about that on Friday 24 April 2020. S&P later confirmed the rating and the negative outlook.

[48] It is also worth recalling the unexpected downgrade of Italy's credit rating by Fitch Ratings late on 28 April and the German Federal Court ruling that the PSPP partly violates the German constitution on 6 May 2020. The latter made it highly likely that German critics of the ECB would challenge the PEPP, too.

and Greek government bonds sharply rallied after the announcement, sending their yields to three-month lows. Before then, Eurosystem risk had peaked at 62 billion on 15 May 2020, according to our estimates.

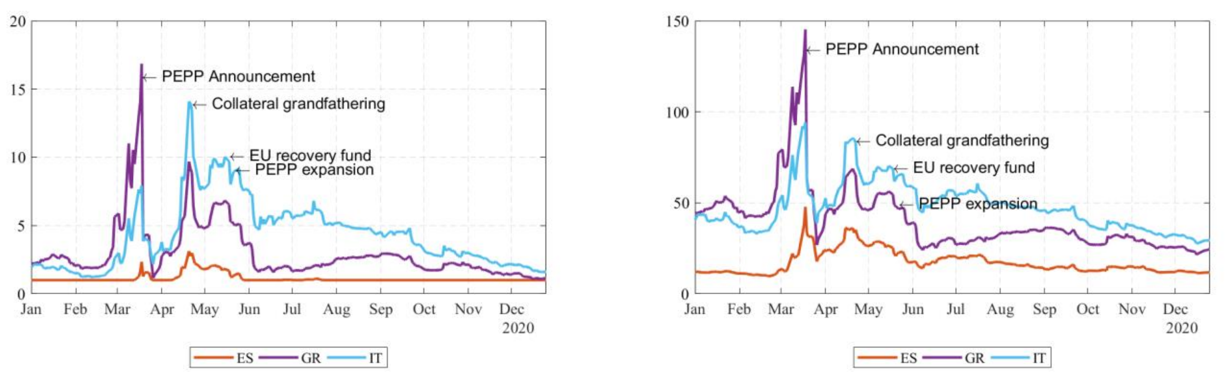
On 22 May 2020 the publication of the minutes of the Governing Council meeting held on 30 April confirmed that the ECB would *'stand ready'* to expand the PEPP response to the pandemic, if needed to tackle the economic and financial turmoil. Finally, on 4 June 2020 the ECB announced that it will buy an extra €600 billion of bonds, a move larger than most economists' expectations, taking the PEPP to €1.35 trillion in total. Italian and Greek government bonds rallied after the announcement (see Figure 17 and Figure 18).

Figure 17. Risk (€ billion), Inflation expectations (percentage values) and Systemic stress indicator around the PEPP announcement and follow-up (18 March and 22 May 2020)



Source: ECB and own calculations.

Figure 18. 1-year and 5-year CDS-I-EDF of Spain, Greece and Italy (basis points) during 2020



Source: Moody's Credit Edge.

Table 4 summarizes the change in risk, inflation expectations and the financial stability indicator three weeks after the monetary policy announcements described in this Section.

Table 4. Change in Risk, Inflation expectations and Systemic stress indicator after the monetary policy announcements

	3 weeks after announcement		
	ΔRisk (%)	ΔInfl (bp)	ΔCISS (%)
SMP1 (10 May 2010)	+56	-14	+33
SMP2 (7 August 2011)	+14	-18	+3
OMT (26 July 2012)	-12	+16	-29
PSPP1 (22 January 2015)	+123	-6	-36
PSPP2 (9 March 2015)	+5	-8	+106
PEPP1 (18 March 2020)	-6	+21	-14
PEPP2 (22 May 2020)	-20	+13	-13

Source: own calculations.

8. Exposure at default of the PEPP: current holdings *vs* financial envelope

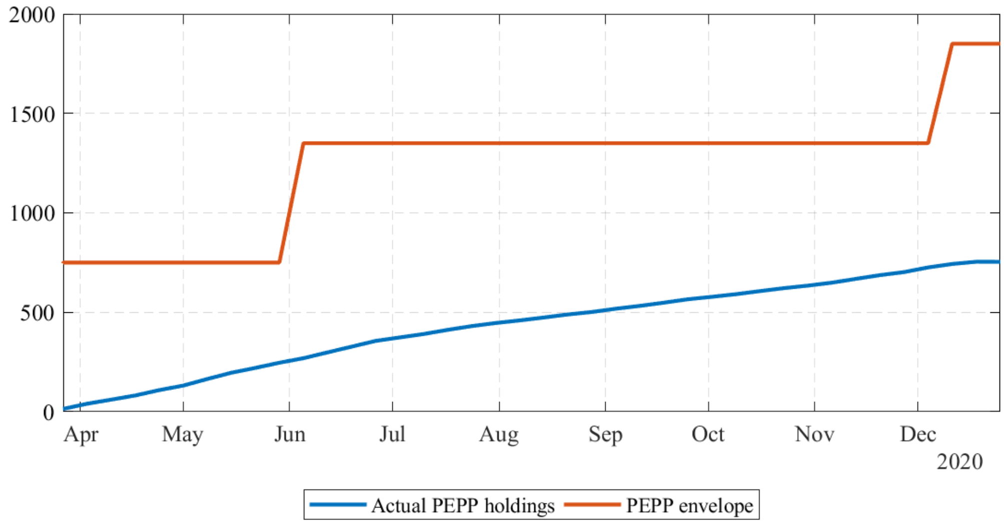
The risk estimates reported in Section 5 are obtained under the assumption that purchase programmes exposures are equal to the holdings at the reference date. This may lead to an underestimation of risk for those programmes which are ‘active’ on each date, since at the end of the 1-year horizon holdings might be larger than at the beginning of the period.

The difference between current and potential holdings at the end of the 1-year horizon could be neglected for most programmes, taking into account the long sample period of our analysis (eleven years): at some point, programmes eventually reach their maximum amount (the ‘total envelope’), which is reflected in the corresponding risk estimates. However, this is not the case of PEPP, which was on-going at the end of 2020.

In this Section we thus estimate risk using the most conservative assumption regarding the potential exposure at the end of the 1-year horizon, namely we employ the total PEPP envelope (instead of the PEPP actual exposure). In other words, we estimate risk as if the whole PEPP amount had been purchased at the time of each new announcement.

The initial PEPP envelope was €750 billion, which was increased by €600 billion on 4 June 2020 and by €500 billion on 10 December, for a final value of €1,850 billion. Figure 19 shows the current PEPP exposures against its total envelope over time.

Figure 19. PEPP holdings and total envelope (€ billion)



On average, total envelopes are four times larger than current exposures.

Figure 20 shows how risk would change if the PEPP current exposures were replaced by the total PEPP envelopes. The (unchanged) values before March 2020 are reported for reference.

Figure 20. Risk under different assumptions for PEPP exposure (€ billion)

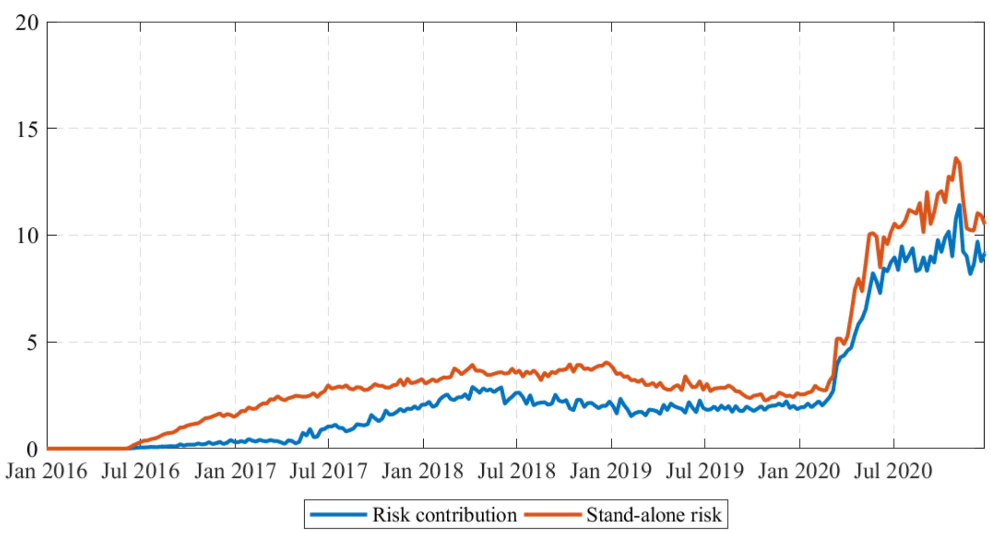
At the end of 2020 the difference between these two risk estimates is around 20 per cent. Although at different levels, the risk profile is very similar between the two variables, and the conclusions drawn in Section 5 remain broadly valid even when risk is computed over the PEPP total envelope.

9. The corporate portfolio: stand-alone risk and through-the-cycle risk

The risk estimates reported in Section 5 show that the corporate sector component of risk is growing and accounts for 21 percent of total risk at the end of 2020. Corporate issuers, unlike sovereigns and structured finance instruments (covered bonds and ABSs), display on average larger PDs, and their risk is non-negligible even at moderate confidence levels. In this respect, we note that the only financial losses suffered so far by the Eurosystem have originated from the CSPP portfolio. This Section provides a focus on two issues related to the risk of the corporate portfolio.

First, we calculate the stand-alone risk of the corporate portfolio (namely the risk of the portfolio when considered in isolation, ignoring the diversification effect with other exposures) at the usual 99 per cent confidence level. Figure 21 shows a comparison of the stand-alone risk with the risk contribution of the corporate portfolio to total risk: on average, the former is about twice as large as the latter before March 2020. This difference is due to the diversification effect: losses in the worst 1 per cent tail for the entire monetary policy exposure of the Eurosystem are dominated by sovereign default scenarios, which are by far the most severe for the Eurosystem because of the very large exposure; these scenarios crowd out most corporate default scenarios in ES99. After March 2020, the difference between the stand-alone risk and the risk contribution of corporates becomes smaller, because sovereign risk significantly decreases and corporate defaults end up into the tail to a much larger extent.

Figure 21. Risk contribution and stand-alone risk of corporate holdings (€ billion)



Next, we estimate through-the-cycle (TTC) EDFs for the corporate portfolio. The EDFs used so far provide an early warning signal about sudden changes in default risk and are employed to produce point-in-time (PIT), market-based risk estimates. However, a broad credit risk assessment would involve both PIT and TTC default probabilities. In certain circumstances, e.g. concerning long-term decision-making or setting capital buffers, the use of TTC PDs may be more appropriate, as they isolate the issuer's underlying credit trend from the macro credit cycle. The resulting default probability estimates thus display a lower volatility over the cycle. Moody's provides TTC PDs (that is TTC EDFs) for corporate issuers.[49] Table 5 reports some statistics on the difference between TTC EDFs and standard EDFs. On average, TTC EDFs tend to be lower than standard EDFs before 2014 and higher afterward.

Table 5. Difference between TTC EDFs and standard EDFs (percentage values)

	Avg.	Percentiles				
		5th	25th	50th	75th	95th
2010-2013	-0.18	-0.64	-0.07	0.00	0.02	0.17
2014-2017	0.04	-0.10	0.00	0.02	0.07	0.25
2018-2020	0.02	-0.11	0.01	0.02	0.07	0.23

Figure 22 compares the EDF indices (i.e., the median of the EDFs in our sample, see Section 4) for corporate issuers in Germany and Italy. As expected, TTC EDFs exhibit lower variability than standard EDFs, and can be viewed as long-term averages around which standard EDFs fluctuate over time.

Figure 22. Country-sector corporate EDF indices (basis points)

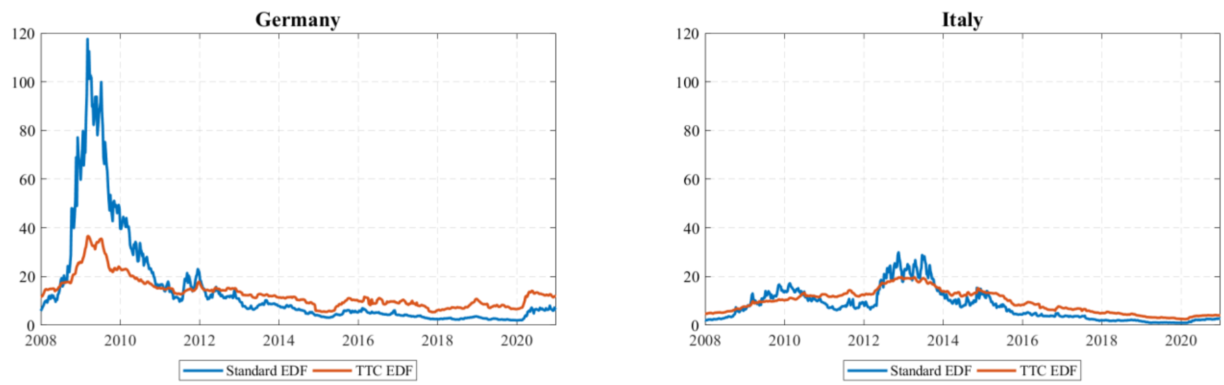
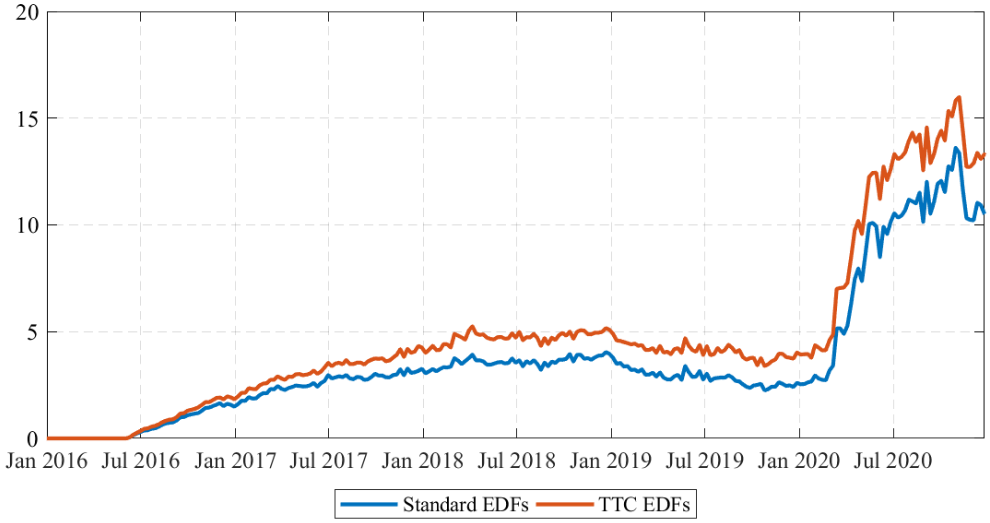


Figure 23 shows that since the launch of the CSPP in June 2016, risk calculated with TTC EDFs is larger than risk based on standard (PIT) EDFs, while the dynamics of the credit risk of the corporate portfolio remains broadly the same.

The increase in the contribution of corporate risk to total central bank risk and the fact that EDFs for corporates are lower than their TTC levels at the end of our sample period suggest that the corporate segment is where the credit risk borne by the Eurosystem might concentrate in the medium term.

[49] Moody's Analytics (2018).

Figure 23. Stand-alone risk of corporate holdings - standard EDFs and TTC EDFs (€ billion)



10. Conclusions

We show the evolution of financial risk on the monetary policy and ELA operations of the Eurosystem over the last decade using a methodology that relies on probabilities of default over a 1-year horizon inferred from real-time market data.

While from 2010 to 2020 the Eurosystem exposure arising from monetary policy operations grew by more than three times, financial risk estimated with our model at the end of the period is much lower than that measured at the peak of the sovereign debt crisis in 2012. The launch of the OMT succeeded in quelling market turmoil and reducing the risk of the Eurosystem. These effects seem to be long lasting.

Financial risk mainly accrues to the Eurosystem from outright purchase holdings (as part of APP and PEPP) rather than from credit operations, as the risk on the latter is attenuated by collateral and valuation haircuts, whereas risk on the bond holdings is unmitigated and directly exposes the central bank to financial market distress.

During the episodes of severe market tensions, financial risk appears as largely endogenous for the central bank, although to an extent that is admittedly difficult to assess with accuracy. This would call for a risk management mind-set that complements the use of standard quantitative methods for risk measurement with other economic considerations of more general nature.

A closer look at the events surrounding some key monetary policy decisions reveals that the decrease in financial risk brought about by the announcement of OMT and PEPP is associated with an improvement in inflation expectations and the mitigation of the stress index in financial markets. The APP announcement managed to stop at least temporarily the ongoing trend in deflationary expectations. These findings, together with the broader pattern of Eurosystem risk from 2012 onwards, provide a clear indication about the risk-efficiency of these monetary policy measures.

Our results are robust under different methodological assumptions regarding exposures, probabilities of default and default codependency structure.

To conclude, we show that a market-driven measure of default risk offers an important perspective on two issues, namely the risk endogeneity and the risk efficiency of different monetary policy decisions. Our findings raise important questions concerning the methodology for and interpretation of the estimates of financial risk for the central bank. Risk estimates based on point-in-time, market-driven, 1-year PDs and current exposures represent an accurate picture of risk over a short-term period based on all available information. These risk measures might be complemented with through-the-cycle estimates, which adopt a longer term perspective and could corroborate risk management decisions. Some results on this topic are provided for the corporate portfolios. A further analysis of these issues is left for future research.

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Abbreviations

ABS	Asset-Backed Security
ABSPP	Asset-Backed Securities Purchase Programme
AH	After Haircuts
APP	Asset Purchase Programme
BH	Before Haircuts
BV	Book Value
CBPP	Covered Bond Purchase Programme
CDS	Credit Default Swap
CDS-I-EDF	CDS-Implied-EDF
CISS	Composite Indicator of Systemic Stress
CSPP	Corporate Sector Purchase Programme
EAD	Exposure-at-Default
ECB	European Central Bank
EDF	Expected Default Frequency
ELA	Emergency Liquidity Assistance
ES99	Expected Shortfall at 99 percent confidence level
EU	European Union
EUREP	Eurosystem repo facility for non-euro area central banks
FV	Face Value
KMV	Moody's proprietary model originally developed by Kealhofer, McQuown and Vasicek
L	Loss
NCB	National Central Bank (member of the Eurosystem)
OMO	Open Market Operations
OMT	Outright Monetary Transactions
PD	Probability of Default
PELTRO	Pandemic Emergency Longer-Term Refinancing Operations
PEPP	Pandemic Emergency Purchase Programme
PIT	Point-In-Time
PSPP	Public Sector Purchase Programme
RR	Recovery Rate
SIO	Scorecard-Indicated Outcome (an intermediate rating provided by Moody's)
SMP	Securities Market Programme
TLTRO	Targeted Longer-Term Refinancing Operations
TTC	Through-The-Cycle
UP	Unconventional Policies
VLTRO	Very Long-Term Refinancing Operations

Appendix

A. Estimation of the Student t distribution

The defaults of issuers, monetary policy and ELA counterparties are simulated with a multivariate Student *t* distribution whose parameters are (i) the correlation matrix and (ii) the degrees of freedom.

The choice of the multivariate distribution does not have an impact on the simulated default rates of individual issuers, which are by construction equal to the assumed PDs (up to the Monte Carlo error, see Section 2). Nevertheless, the distribution determines the simulated joint default rates (i.e. the number of scenarios where many debtors jointly default, leading to the largest losses).

We use the log-changes of the country-sector EDF indices (defined in Section 4) as input data for the estimation of both parameters of the multivariate distribution, as described below. The idea of using the correlation between (a monotonous transformation of) the probability of default as a proxy for the correlation between the debtors is quite common (see e.g. Caballero *et al.*, 2020). The log-changes function maps the domain of the EDF, which is the [0, 1] interval, to the real axis, where the Student *t* distribution is defined. We also check that other transformations have a negligible impact on the results.[50]

The estimation is performed in two steps.

First, we estimate the correlation matrix. The correlations between debtors are set equal to the correlations between the log-changes of the country-sector EDF indices (out of the diagonal). As an example, the correlation between any Italian bank and any German corporate is set equal to the correlation between the log-changes of the Italian bank EDF index and the log-changes of the German corporate EDF index. If two debtors belong to the same country-sector group, than the correlation is set equal to either 100 percent, if they are sovereigns (since we have a single sovereign for each country), or to the maximum correlation among those previously estimated for the sector. For instance, the correlation between two Italian banks is set equal to the maximum correlation between the log-changes of the Italian bank EDF index and the log-changes of the EDF indices of all the other banks.

Second, the degrees of freedom are obtained by means of maximum likelihood estimation, conditionally on the previously estimated correlation matrix:

$$dof = argmax_{\theta} \sum_{i=1}^{N} log\, f(\theta; \rho, \Delta logEDF_i)$$

where f denotes the multivariate Student *t* density function, N is the number of observations, θ denotes the degrees of freedom (to be estimated), ρ is the correlation matrix (estimated in the first step).

Both parameters are estimated with a moving average rolling approach using the last three years of data. This means that on each date risks are estimated using a different correlation matrix and a different value

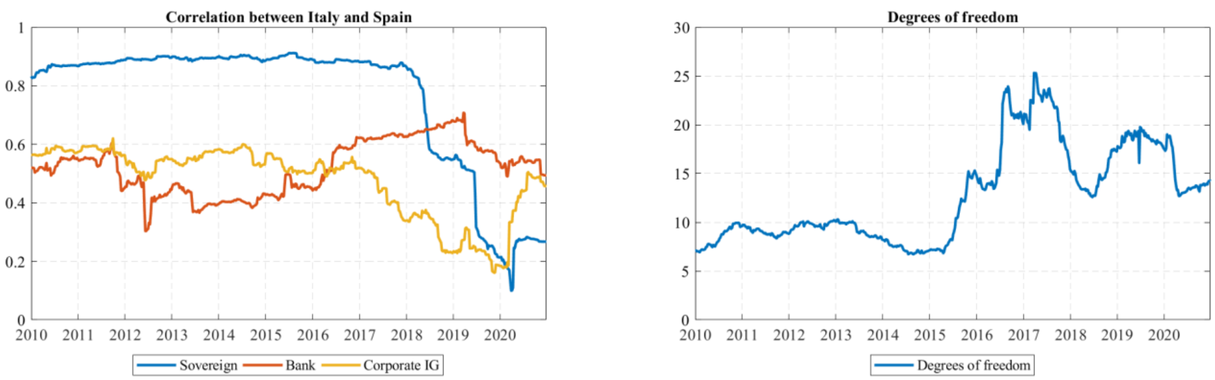
[50] More specifically, we test an alternative estimation based on the changes in normal quantiles of the EDF indices, which is another common transformation (the quantile of the probability of default is sometimes referred to as distance-to-default).

for the degrees of freedom (see Figure 24). The resulting risk estimates are thus fully out-of-sample, i.e. they reflect the 'true' market risk perception at any date.

Figure 24 plots the estimated correlations between Italy and Spain for the sovereign sector, the bank sector and the (investment grade) corporate sector (left panel) and the degrees of freedom (right panel). We find that the estimated degrees of freedom are below 10 until 2016 and larger in the following years, implying a higher deviation from normality in the first half of our period (we recall that the Student *t* distribution approaches the Gaussian distribution as the degrees of freedom grow).

Section 6 reports robustness analysis for both parameters.

Figure 24. Time-varying Student *t* parameters



Source: own calculations.

Once the correlation matrix is estimated, we need the β coefficients (as defined in Section 2) such that:

$$\rho_{i,j} = \sum_{k=1}^{m} \beta_{i,k} \cdot \beta_{j,k}$$

or, in matrix form:

$$P = B \cdot B^T$$

where P is the correlation matrix and B is the matrix of the β coefficients. The above equation is always satisfied by setting B equal to the Cholesky decomposition of the correlation matrix P. However, this would yield a huge B matrix (the number of rows/columns would be equal to the number of debtors).

In practice, we employ a calibration approach that, with a negligible loss of information, significantly reduces the size of the model. We exploit the fact that correlations are defined only at country-sector level.

We set m = 36 and define the β coefficients at the country-sector level:

$$\beta_{i,k} = \beta_{G(i),k}$$

where *i* is the index of the debtor and *G(i)* is its country-sector group. All debtors belonging to the same group thus have exactly the same β coefficients.

Let *C* be the 36x36 matrix of the correlations between and within the country-sector groups, as explained at the beginning of this Section. The off-diagonal elements of this matrix are the correlations between groups, while the diagonal elements are the correlations within groups. By construction, the diagonal of *C* is not unity: the diagonal elements corresponding to sovereign groups are equal to 1 (since there is a single sovereign for each country), but the diagonal elements corresponding to bank and corporate groups are strictly lower than 1 (e.g. the correlation between Italian banks or between German corporates are lower than 1).

With these settings, the goal is to find a matrix B such that:

$$C = B \cdot B^T$$

Since *C* is generally not positive definite, we can no longer rely on the Cholesky decomposition. We follow instead an approach that has some similarities with the principal component analysis, in the sense that we remove from *C* some eigenvalues associated with low information.

First, a spectral decomposition of the matric *C* is performed:

$$C = V \cdot D \cdot V^T$$

where D is the diagonal matrix containing the eigenvalues of C, and *V* is the square matrix of the corresponding orthonormal eigenvectors. This can be estimated since *C* is symmetric by construction.

Second, the negative eigenvalues are set equal to 0:

$$D^+ = max(0, D)$$

Last, the matrix of coefficients β is obtained as:

$$\beta = V^T \cdot \sqrt{D^+}$$

The simulated correlation matrix will then be equal to:

$$C^+ = B \cdot B^T = V^T \cdot D^+ \cdot V$$

While C^+ is not exactly equal to *C*, their distance is very small: the average absolute difference between their elements is lower than 0.1% for all dates in our sample. This owes to the fact that *C* is quite close to being positive definite, and the information associated with negative eigenvalues is negligible.[51]

[51] As an example, the sum of the absolute value of the negative eigenvalues is only 4-6% (depending on the date) of the sum of the absolute value of all eigenvalues.

B. Further methodology details

1. Simulation of collateral

While risks on purchase programme holdings and counterparties are simulated over a 1-year horizon, collateral is simulated over a much shorter horizon, since collateral is assumed to be swiftly liquidated by the Eurosystem in the event of a counterparty default. More specifically, collateral is simulated over the time horizon that is deemed necessary for its smooth liquidation (time-to-liquidation, T2L). Table 6 reports the T2Ls used in our exercise, which are based on expert judgement. In most cases, a few weeks are considered sufficient to liquidate collateral. Noticeable exceptions are own-used assets,[52] simulated over a 1-year horizon to align their outcome to that of the counterparty, and credit claims, simulated over a 1-year horizon as well, to take into account their non-marketable nature and possible operational hurdles.

Table 6. Assumed time-to-liquidation for collateral (number of weeks)

Central governments	1
Local governments	2
Agencies & Supranational	2
Covered bonds	3
ABSs	6
Uncovered bank bonds	6
Corporate & other	6
Own-used collateral	52
Credit claims	52

In order to simulate collateral over a time horizon equal to the assumed T2L, the default thresholds (T_i, see Section 2) must be calculated on the T2L PDs (e.g., the default threshold of a government bond pledged as collateral is given by the Student *t* quantile of the 1-week PD). We inferred T2L PDs from 1-year PDs with the following formula, which assumes constant conditional default probabilities:

$$PD_{T2L} = 1 - \left(1 - PD_{1-year}\right)^{T2L}$$

We note that the same asset might be included in the purchase programme holdings as well as in the collateral pool. In such case, two different thresholds are considered: one for the purchase programme

52 Own-used assets are those assets for which issuer and counterparty are either the same or have close links. Currently, only covered bonds are accepted as own-used collateral.

holdings (based on the 1-year PD of the issuer) and one for the collateral (based on the T2L PD of the issuer).

Finally, we aggregate credit claims pledged as collateral in order to reduce the computational burden. For each counterparty, we aggregate all credit claims into two different groups: one containing credit claims with a quality comparable to investment grade, and one containing the remaining credit claims.[53] These two groups are simulated as if they were a single instrument (i.e. as if they had the same debtor), with a PD equal to the weighted average of the individual PDs. By doing so the number of credit claim debtors shrinks from above 100,000 (the actual number of distinct debtors) to below 1,000. The approximation leans on the conservative side, since it reduces the degree of diversification within the collateral pool.

2. ELA operations

In theory, losses arising from ELA operations could be calculated with the same formula reported for the monetary policy credit operations (see Section 2). In practice, however, risks from ELA exposures have to be modelled with some suitable assumptions, as the data regarding the amount and composition of collateral are not available and the potential role of the government as the ultimate guarantor in case of a systemic crisis, or ELA granted to systemic relevant banks, should be taken into account.

As a first assumption, we set the EAD equal to the current exposure. This makes sense since in the ELA operations the exposure is decided by the NCB and cannot be arbitrarily increased by the counterparty, even if abundant collateral is available. In addition, we conservatively assume no over-collateralization:

$$EAD = \sum\nolimits_{a\ in\ collateral} AH_a = actual\ exposure$$

With regard to the composition of collateral, we distinguish between idiosyncratic ELA, where a single non-systemic bank is involved, and systemic ELA, where a relevant bank and/or a number of banks in the same jurisdiction resort to ELA. Both types are in turn divided into two different subtypes. More specifically we consider:

i. Idiosyncratic ELA – suspension. This is the case of a bank that relies on ELA after having been suspended from the monetary policy operations because of financial soundness issues. In this case we use for ELA the same collateral composition as that observed in the monetary policy operations right before the suspension;
ii. Idiosyncratic ELA – liquidity crisis. This is the case of a bank facing liquidity problems that resorts to ELA as an additional financing source while not being suspended from monetary policy operations. In this case we assume that ELA collateral entirely consists of credit claims, assuming that the most liquid assets – such as investment grade debt securities – are already pledged as collateral for the monetary policy operations;
iii. Systemic ELA – government support. This is the case of ELA granted to a systemic relevant bank or to a large number of banks in a jurisdiction, where an explicit support of the government is

[53] The credit claims accepted under the Additional Credit Claims regime fall under this second category.

present, for example in the form of promissory notes and/or guarantees. In this case, we assume that collateral consists of a government guarantee, which covers the entire ELA exposure. For the calculation of risk, we only simulate the counterparty and the government: if they both default, then a loss is realized; otherwise, the loss is zero;

iv. Systemic ELA – government crisis. This is the case of ELA granted to an entire banking system, which is facing a severe crisis because of a simultaneous sovereign debt crisis. In this case, we only simulate the sovereign: if it defaults, we assume that both the counterparty and the collateral automatically default, generating a loss in the ELA operations; otherwise, the loss is zero.

In the case of systemic ELA (type iii. and iv. above), where the collateral composition is not considered, the loss (if any) is computed as:

$$L = EXP \cdot \left(1 - \frac{30\%}{1 - H}\right)$$

where EXP is the actual exposure, 30 percent is the recovery rate and H is the average haircut.

3. Probability of default for covered bonds and ABSs

For covered bonds and ABSs[54] an adjustment is required to account for the fact that they exhibit a higher credit quality than their issuers. Since they are the least risky among the Eurosystem exposures,[55] we apply a simplified approach and divide the issuer's EDF by a predefined number, equal to 8.07 for covered bonds and 3.06 for ABSs. Such numbers are obtained by comparing the long-term default rates implied in the rating of these assets (as reported by rating agencies in their annual Default Studies)[56] with those implied by the rating of their issuers. In spite of the same average level of rating, we estimate a lower divisor (3.06) for ABSs than for covered bonds since ABS default rates are generally higher than non-ABS default rates, for any given rating level.

[54] By ABS we mean 'senior tranches of ABS', which are the only type of ABS eligible as collateral and for purchases.

[55] Covered bonds and ABSs have almost always an AA rating.

[56] For covered bonds we use the 'Global Corporates' default rates, since no covered bonds default was ever experienced in the past. For ABSs, we use the 'Structured Finance' default rates.

C. Dataset and software

We build a unique dataset for this study. It is made up of four tables:

1. purchase programme holdings table: each record contains the face and book value for any given combination of date/portfolio/issuer. The number of dates is 574, the number of portfolios ranges from 0 to 9,[57] depending on the date; the average number of issuers for any portfolio is 100, yielding a total number of records approximately equal to 260,000;
2. monetary policy credit operations table: each record contains the face value, before haircut and after haircut, for any given combination of date/counterparty/collateral issuer/collateral type. The number of dates is 574; the average number of counterparties by date is 1,500; the average number of collateral issuers for any date/counterparty is 15. Collateral type is a categorical variable that depends on the type of instrument, required for the assumptions on the recovery rates (e.g., covered bonds vs. uncovered bank bonds) and time-to-liquidation (e.g., market placed covered bonds vs. retained covered bonds). The total number of records is around 12 million;
3. ELA operations table: each record contains the face value, before haircut and after haircut, for any given combination of date/counterparty/collateral issuer/collateral type. The total number of records is around 8,000;
4. probability of default table: each record contains the PD for any given combination of date/debtor. The number of dates is 574, the number of debtors (either issuers or monetary policy counterparties) is approximatively 7,000, yielding a total number of records around 4 million.

Risk estimates are obtained with a C++ object-oriented program, while the calibration of the multivariate Student *t* parameters is performed with a Matlab script.

[57] CBPP1&2, SMP, CBPP3, ABSPP, PSPP, CSPP, PEPP-Covered, PEPP-Public, PEPP-Corporate.