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Risk endogeneity at the lender/investor-of-last-resort*

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Abstract

We address the question to what extent a central bank can de-risk its balance sheet by unconventional monetary policy operations. To this end, we propose a novel risk measurement framework to empirically study the time-variation in central bank portfolio credit risks associated with such operations. The framework accommodates a large number of bank and sovereign counterparties, joint tail dependence, skewness, and time-varying dependence parameters. In an application to selected items from the consolidated Eurosystem's weekly balance sheet between 2009 and 2015, we find that unconventional monetary policy operations generated beneficial risk spill-overs across monetary policy operations, causing overall risk to be nonlinear in exposures. Some policy operations reduced rather than increased overall risk.

Keywords: Credit risk; risk measurement; central bank; lender-of-last-resort; unconventional monetary policy.

JEL classification: G21, C33.

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Non-technical summary

Can a central bank de-risk its balance sheet by *extending* the scope of its operations? During the euro area sovereign debt crisis between 2010 and 2012, severe liquidity squeezes and market malfunctions forced the Eurosystem – the European Central Bank (ECB) and its 17 national central banks at the time – to act as a LOLR to the entire financial system. Large-scale central bank lending to banks ensured the proper functioning of the financial system and, with it, the transmission of monetary policy. In addition, the Eurosystem also acted as an investor-of-last-resort (IOLR) in stressed markets, for example when it purchased sovereign bonds in illiquid secondary markets within its Securities Markets Programme (SMP) between 2010 and 2012.

The Eurosystem’s actions as a large-scale lender- and investor-of-last-resort during the euro area sovereign debt crisis had a first-order impact on the size, composition, and, ultimately, the credit riskiness of its balance sheet. At the time, its policies raised concerns about the central bank taking excessive risks. Particular concern emerged about the materialization of credit risk and its effect on the central bank’s reputation, credibility, independence, and ultimately its ability to steer inflation towards its target of close to but below 2% over the medium term.

Against this background, we ask: Can central bank liquidity provision or asset purchases during a liquidity crisis reduce risk in net terms? This could happen if risk taking in one part of the balance sheet (e.g., more asset purchases) de-risks other balance sheet positions (e.g., the collateralized lending portfolio) by a commensurate or even larger amount. How economically important can such risk spillovers be across policy operations? Were the Eurosystem’s financial buffers at all times sufficiently high to match its portfolio tail risks? Finally, did past operations differ in terms of impact per unit of risk?

The methodological part of this paper proposes a novel credit risk measurement framework which allows us to study the above questions. The framework is based on a tractable high-dimensional dependence function that can accommodate a large number of bank and sovereign counterparties. The empirical part of this paper applies our high-dimensional framework to monetary policy exposures taken from the Eurosystem’s weekly consolidated balance sheet between 2009 and 2015. Corresponding weekly point-in-time risk measures

are obtained from Moody's Analytics (for banks) or are inferred from CDS spreads (for sovereigns).

We focus on three main findings. First, we find that LOLR- and IOLR-implied credit risks are usually negatively related in our sample. Taking risk in one part of the central bank's balance sheet (e.g., the announcement of asset purchases within the SMP) tended to de-risk other positions (e.g., collateralized lending from previous LTROs). Vice versa, the allotment of two large-scale VLTRO credit operations each decreased the one-year-ahead expected shortfall of the SMP asset portfolio. This negative relationship implies that central bank risks can be nonlinear in exposures. In bad times, increasing size increases risk less than proportionally. Conversely, reducing balance sheet size may not reduce total risk by as much as one would expect by linear scaling. Arguably, the documented risk spillovers call for a measured approach towards reducing balance sheet size after a financial crisis.

Second, some unconventional policy operations did not add risk to the Eurosystem's balance sheet in net terms. For example, we find that the initial OMT announcement de-risked the Eurosystem's balance sheet by €41.4 bn in 99% expected shortfall (ES). As another example, we estimate that the allotment of the first VLTRO increased the overall 99% ES, but only marginally so, by €0.8 bn. Total expected loss decreased, by €1.4 bn. We conclude that, in extreme situations, a central bank can de-risk its balance sheet by doing more, in line with Bagehot's well-known assertion that occasionally "only the brave plan is the safe plan." Such risk reductions are not guaranteed, however, and counterexamples exist when risk reductions did not occur.

Third, our risk estimates allow us to study past unconventional monetary policies in terms of their ex-post 'risk efficiency'. Risk efficiency is the notion that a certain amount of expected policy impact should be achieved with a minimum level of additional balance sheet risk. We find that the ECB's OMT program was particularly risk efficient ex-post since its announcement shifted long-term inflation expectations from deflationary tendencies toward the ECB's target of close to but below two percent, decreased sovereign benchmark bond yields for stressed euro area countries, while *lowering* the risk inherent in the central bank's balance sheet. The first allotment of VLTRO funds appears to have been somewhat more risk-efficient than the second allotment. The SMP, despite its benefits documented elsewhere, does not appear to have been a particularly risk-efficient policy measure.

1 Introduction

For at least 150 years, going back to [Thornton \(1802\)](#) and [Bagehot \(1873\)](#), central bankers have wondered to what extent they make rather than take their own balance sheet risks during turbulent times. Theoretically, the possibility of the central bank influencing its own risk is uncontroversial. In the context of a pure illiquidity crisis without solvency concerns, for example, the simple announcement by a central bank to act as a lender-of-last-resort (LOLR) to the entire financial system in line with Bagehot-inspired principles¹ could shift the economy from a ‘bad’ to a ‘good’ equilibrium, causing all illiquidity-related credit risks to quickly disappear at virtually no cost or additional central bank balance sheet risk; see e.g. [Diamond and Dybvig \(1983\)](#), [Allen and Gale \(2000\)](#), and [Rochet and Vives \(2004\)](#). Whether this possibility is empirically relevant, however, is unclear as reality rarely resembles the typical textbook case. In addition, empirical studies of central bank portfolio credit risks are rare, primarily because the required data are almost always confidential.

It is uncontroversial that lending freely in line with [Bagehot \(1873\)](#)-inspired principles as well as purchasing financial assets during a liquidity crisis can increase the credit risk of a central bank’s balance sheet. How different lender- and investor-of-last-resort policies interact from a risk perspective, however, is currently less clear. Specifically, we ask: Can *increased* central bank liquidity provision or asset purchases during a liquidity crisis *reduce* bottom line central bank risks? This could happen if risk-taking in one part of the balance sheet (e.g., more asset purchases) de-risks other balance sheet positions (e.g., the collateralized lending portfolio) by a commensurate or even larger amount. Focusing on the euro area during the sovereign debt crisis between 2010 and 2012, how economically important were such risk spillovers across monetary policy operations? Were the Eurosystem’s financial buffers at all times sufficiently high to match the portfolio tail risks? Did past unconventional operations differ in terms of impact per unit of risk? Finally, can *other* central banks’ policy announcements spill over and affect the Eurosystem’s credit risks?

¹[Bagehot \(1873\)](#) famously argued that the lender-of-last-resort should lend freely to solvent banks, against good collateral valued at pre-crisis levels, and at a penalty rate; see also [Rochet and Vives \(2004\)](#) and [Freixas et al. \(2004\)](#).

During the euro area sovereign debt crisis between 2010 and 2012, severe liquidity squeezes and market malfunctions forced the Eurosystem – the European Central Bank (ECB) and its then 17 national central banks (NCBs) – to act as a LOLR to the entire financial system; see e.g. [ECB \(2014\)](#), [Drechsler et al. \(2016\)](#), and [de Andoain et al. \(2016\)](#). Large-scale central bank lending to banks ensured the proper functioning of the financial system and, with it, the transmission of monetary policy. Such lending occurred mainly via main refinancing operations (MROs), multiple long-term refinancing operations (LTROs) with maturities of up to one year, two very-long-term refinancing operations (VLTROs) with a three-year maturity, as well as targeted LTROs (TLTROs), all backed by repeated expansions of the set of eligible collateral. In addition, the Eurosystem also acted as an investor-of-last-resort (IOLR) in stressed markets. For example, it purchased sovereign bonds in illiquid secondary markets within its Securities Markets Programme (SMP) between 2010 and 2012, and committed to doing so again under certain circumstances within its Outright Monetary Transactions (OMT) program as announced in August 2012.

The Eurosystem’s actions as a large-scale lender- and investor-of-last-resort during the euro area sovereign debt crisis had a first-order impact on the size, composition, and, ultimately, the risk of its balance sheet. At the time, its policies raised substantial concerns about the central bank taking excessive risks (and supporting moral hazard) by helping troubled banks. Particular concerns related to the materialization of credit risk and its effect on the central bank’s reputation, credibility, independence, and ultimately its ability to steer inflation towards its target of close to but below 2% over the medium term. The credit risk concerns were so pronounced at the time that some media reports referred to the ECB unflatteringly as the ECBB: Europe’s Central Bad Bank; see e.g. [Brendel and Pauly \(2011\)](#) and [Böhme \(2014\)](#). The Eurosystem’s experience during the euro area sovereign debt crisis is, however, an ideal laboratory to study the impact of a central bank’s unconventional policies on the risks inherent in its balance sheet.

The methodological part of this paper proposes a novel credit risk measurement framework that allows us to study the above questions. The framework is based on a tractable high-dimensional dependence (copula) function that can accommodate a large number of

bank and sovereign counterparties simultaneously. The model is state-of-the-art in that it allows us to capture extreme joint tail dependence (fat tails), time-varying volatility and correlation parameters, as well as a potential asymmetry in the correlation dynamics. Our framework thus combines elements of earlier models put forward in [Creal et al. \(2011\)](#), [Creal et al. \(2014\)](#), and [Lucas et al. \(2014, 2017\)](#), which are here modified to accommodate a large number of counterparties and asymmetric correlation dynamics.

The central bank's risk management function is different from that of a commercial bank in at least three ways. First, unlike for commercial banks, risk and profitability are not first-order measures of success for a central bank. When taking monetary policy decisions the financial consequences for the central bank's profit and loss statement are usually not a primary concern. If a central bank endures sustained losses, however, its independence may be, or perceived to be, impinged, which in turn may have consequences for its ability to achieve its goals. Further, central bank profits are almost always distributed to sovereign treasuries, thus contributing to the public budget. In this sense, central bank profits have fiscal consequences; see e.g. [Del Negro and Sims \(2015\)](#). Because of this, and increasingly since the financial crisis, central banks as public institutions face scrutiny over their activities and financial risks.

Second, commercial banks, by engaging in maturity transformation, are by their very nature exposed to liquidity shocks. Central banks are uniquely able to provide liquidity-support in a liquidity crisis owing to the fact that they are never liquidity-constrained in the currency they issue; see e.g. [Reis \(2015\)](#), and [Bindseil and Laeven \(2017\)](#). Consequently, the default risk of the central bank in its domestic currency liabilities is zero at all times.

Finally, a small or medium-sized commercial bank is unlikely to be able to materially influence financial risks and risk correlations associated with the bank-sovereign nexus. Commercial banks are 'risk takers' in more than one sense – risk management is primarily about expediently choosing exposures at *given* risks. This is inherently less true for central banks, and as we show later particularly during a financial crisis.

The empirical part of this paper applies our high-dimensional credit risk framework to exposures associated with the Eurosystem's major conventional and unconventional monetary

policy operations. Exposures are taken from the Eurosystem’s balance sheet and measured at a weekly frequency between 2009 and 2015. Point-in-time risk measures are obtained from Moody’s Analytics (for banks) or are inferred from CDS spreads (for sovereigns), also at a weekly frequency. All risk model parameters are estimated by the method of maximum likelihood. Standard portfolio risk measures, such as the expected loss and expected shortfall, are subsequently obtained through Monte Carlo simulation. We compare the model-implied portfolio credit risks shortly before and after key policy announcements to study the time differences associated with different monetary policy operations. A ‘high-frequency’ (weekly) assessment allows us to identify the effect of each policy on the relevant portfolio credit risks; see e.g. [Rogers et al. \(2014\)](#), [Krishnamurthy et al. \(2018\)](#), and [Fratzcher and Rieth \(2018\)](#) for similar event study approaches. To distinguish size from balance sheet composition effects we consider changes in portfolio credit risks both in absolute terms and in percentages of total assets.

We focus on four empirical findings. First, we find that LOLR- and IOLR-implied credit risks are usually negatively related in our sample. Taking risk in one part of the central bank’s balance sheet (e.g., the announcement of SMP asset purchases) tended to de-risk other positions (e.g., collateralized lending from previous LTROs). Vice versa, the allotment of two large-scale VLTRO credit operations each decreased the expected shortfall of the SMP asset portfolio. As a result, central bank risks can be nonlinear in exposures. In bad times, increasing size increases risk less than proportionally. Conversely, reducing balance sheet size may not reduce total risk by as much as one would expect by linear scaling. Risk spillovers between monetary policy operations are economically significant, and are similar in sign and magnitude around the time of the policy announcements. Arguably, the documented risk spillovers call for gradualism in reducing balance sheet size after a financial crisis.

Second, some unconventional policy operations reduced rather than added risk to the Eurosystem’s balance sheet in bottom line terms. For example, we find that the initial OMT announcement de-risked the Eurosystem’s balance sheet by €41.4 bn in 99% expected shortfall (ES). The announcement of OMT technical details in September 2012 was associated with a further reduction in 99% ES of €18.1 bn. As another example, the allotment

of the first VLTRO in late 2011 raised the 99% ES associated with VLTRO lending from zero to approximately €27.6 bn. However, the allotment also sharply reduced the need for shorter-term central bank funding, and in addition de-risked the SMP asset portfolio as banks invested some of the additional liquidity in government bonds, mitigating sovereign funding stress (see, e.g., [Drechsler et al., 2016](#)). The overall 99% ES increased, but only marginally so, by €0.8 bn. Total expected loss decreased, by €1.4 bn. We conclude that, in extreme situations, a central bank can de-risk its balance sheet by doing more, in line with Bagehot's well-known assertion that occasionally "only the brave plan is the safe plan."

A reduction in net risk is by no means guaranteed, however. For example, the asset purchases that were implemented in the week following the SMP's initial announcement on Sunday 09 May 2010 raised the 99% ES of the SMP portfolio from zero to approximately €7.3 bn. The policy announcement and the initial purchases spilled over and helped de-risk the collateralized lending book to some extent. The total 99% ES, however, still increased, by €5.1 bn. As a second example, also the extension of the SMP to include Spain and Italy in August 2011 did not reduce total balance sheet risk. In addition, this time the effect did not spill over to reduce the risk of the other monetary policy portfolios. We conjecture that this exception may be related to the pronounced controversy regarding the extension of the SMP at that time.

Third, our risk estimates allow us to study past unconventional monetary policies in terms of their ex-post 'risk efficiency'. Risk efficiency is the notion that an expected policy impact should be achieved with a minimum level of additional balance sheet risk. Put differently, policy impact should be maximal given a certain level of additional balance sheet risk. Given an estimate of policy impact (e.g., a change in long-term inflation swap rates around the time of a policy announcement) and an appropriate estimate of risk (e.g., a change in expected losses), it is possible to evaluate different policies ex-post by scaling the former by the latter. Doing so, we find that the ECB's OMT program was particularly ex-post risk efficient. Its announcement shifted long-term inflation expectations from deflationary tendencies toward the ECB's target of close to but below two percent, decreased sovereign benchmark bond yields of stressed euro area countries, while *removing* risk from the central bank's balance

sheet. The first allotment of VLTRO funds appears to have been more risk-efficient than its second installment. The SMP, despite its benefits documented elsewhere (e.g. [Eser and Schwaab \(2016\)](#), [Ghysels et al. \(2017\)](#)), does not appear to have been a particularly risk-efficient policy measure as defined above.

Finally, we ask to what extent policy announcements of *other* central banks have influenced the Eurosystem's risks. For example, the Federal Reserve's announcement to 'taper off' asset purchases on 22 May 2013, or the announcement by the Swiss National Bank to unpeg the Swiss Franc from the Euro on 15 January 2015, could in principle have had a pronounced impact on the Eurosystem's portfolio credit risks via an impact on the euro area financial sector or its risk correlations with sovereigns. We do not find this to be the case. Our expected loss and expected shortfall estimates barely move around these times.

Our findings can have important implications for the design of central banks' post-crisis operational frameworks. In addition, they can inform a debate on how to balance the need for a lender/investor-of-last-resort during liquidity crises with recent banking-sector regulations that seek to lower the frequency of such crises. As one key takeaway, a certain amount of excess liquidity for monetary policy purposes can be achieved via both credit operations and asset purchases. We find that collateralized credit operations imply substantially less credit risks (by at least one order of magnitude in our crisis sample) than outright sovereign bond holdings per €1 bn of liquidity owing to a double recourse in the collateralized lending case. Implementing monetary policy via credit operations rather than asset holdings, whenever possible, therefore appears preferable from a risk efficiency perspective. Second, expanding the set of eligible assets during a liquidity crisis could help mitigate the procyclicality inherent in some central bank's risk protection frameworks. Our results suggest that doing so does not automatically increase a central bank's credit risks, and particularly so if the relevant haircuts are set in an appropriate way.

Our study relates to at least four directions of current research. First, several studies investigate the central bank's role of LOLR and IOLR during a liquidity crisis. Important contributions include [Bagehot \(1873\)](#), [Diamond and Dybvig \(1983\)](#), [Allen and Gale \(2000\)](#), [Rochet and Vives \(2004\)](#), and [Drechsler et al. \(2016\)](#). [Freixas et al. \(2004\)](#) provide a survey;

see also [Bindseil \(2014\)](#) for a textbook treatment.

Second, a nascent strand of literature applies stress-testing methods to central banks' assets and income. [Carpenter et al. \(2013\)](#) and [Greenlaw et al. \(2013\)](#) stress-test the Federal Reserve's ability to send positive remittances to the U.S. Treasury given that a large-scale sovereign bond portfolio exposes the Fed (and thus indirectly the Treasury) to interest rate risk. [Christensen et al. \(2015\)](#) advocate the use of probability-based stress tests, and find that the risk of temporarily suspended Fed remittances to the Treasury is small but non-negligible (at approximately 10%). Finally, [Del Negro and Sims \(2015\)](#) consider conditions under which a central bank might need to withhold seigniorage, or request recapitalization from the treasury, in order to maintain its monetary policy commitments.

Third, we effectively apply 'market risk' methods to solve a 'credit risk' problem. As a result, we connect a growing literature on non-Gaussian volatility and dependence modeling with another growing literature on portfolio credit risk and loan loss simulation. Time-varying parameter models for volatility and dependence have been considered, for example, by [Engle \(2002\)](#), [Demarta and McNeil \(2005\)](#), [Creal et al. \(2011\)](#), [Zhang et al. \(2011\)](#), and [Engle and Kelly \(2012\)](#). At the same time, credit risk models and portfolio tail risk measures have been studied, for example, by [Vasicek \(1987\)](#), [Lucas et al. \(2001, 2003\)](#), [Gordy \(2000, 2003\)](#), [Giesecke and Kim \(2011\)](#), [Koopman et al. \(2012\)](#), and [Giesecke et al. \(2015\)](#). We argue that our combined framework yields the best of these two worlds: portfolio credit risk measures (at, say, a one-year-ahead horizon) that are available at a market risk frequency (such as daily or weekly) for portfolio credit risk monitoring and impact assessments in real time. Such frameworks are urgently needed at financial institutions, including central banks.

Finally, to introduce time-variation into our empirical model specification we endow our model with observation-driven dynamics based on the score of the conditional predictive log-density. Score-driven time-varying parameter models are an active area of recent research, see for example [Creal et al. \(2011, 2013\)](#), [Harvey \(2013\)](#), [Creal et al. \(2014\)](#), [Harvey and Luati \(2014\)](#), [Massacci \(2016\)](#), [Oh and Patton \(2018\)](#), [Lucas et al. \(2018\)](#), and many more.² For an information theoretical motivation for the use of score-driven models, see [Blasques](#)

²We refer to <http://www.gasmodel.com> for an extensive enumeration of recent work in this area.

et al. (2015), and for a forecasting perspective Koopman et al. (2016).

The remainder of the paper is set up as follows. Section 2 presents our exposure and risk data. Section 3 introduces our high-dimensional credit risk measurement framework. Section 4 applies the framework to a subset of the Eurosystem’s balance sheet. Section 5 concludes. A Web Appendix presents additional results and technical details.

2 Eurosystem operations and data

We are interested in studying the time variation in Eurosystem portfolio credit risks, with a particular focus on such risks just before and after monetary policy announcements. We focus on six key announcements that are related to three unconventional monetary policy operations during the euro area sovereign debt crisis: the SMP, the VLTROs, and the OMT. This section first discusses these operations, and subsequently presents the relevant point-in-time risk data.

2.1 (Un)conventional monetary policy operations

The Eurosystem adjusts the money supply in the euro area mainly via so-called refinancing operations. Eurosystem refinancing operations between 2009 and 2015 included main refinancing operations (MROs), long-term refinancing operations (LTROs), very-long-term refinancing operations (VLTROs), and targeted long-term refinancing operations (TLTROs).

Before the onset of the global financial crisis in 2007, MROs and three-month LTROs were sufficient to steer short-term interest rates, to manage aggregate liquidity, and to signal the monetary policy stance in the euro area. Following the onset of the global financial crisis, however, the Eurosystem was forced to significantly extend the scale and maturity of its operations to include one-year LTROs and three-year VLTROs. TLTROs were set up in June 2014 mainly to further support (subsidize) bank lending to the non-financial sector. Between 2010 and 2012 the Eurosystem also conducted asset purchases within its SMP program.

Figure 1 plots selected items of the Eurosystem’s weekly balance sheet between 2009

Figure 1: Eurosystem collateralized lending and SMP exposures

Total collateralized lending exposures associated with different liquidity operations (MRO, LTRO<1y, LTRO1y, VLTRO3y, TLTRO), as well as sovereign bond holdings from purchases within the Securities Markets Programme (SMP). Vertical axis is in trillion euro. Data is weekly between 2009 and 2015. The SMP1 horizontal line refers to the initial announcement of the SMP on 10 May 2010. SMP2 marks the cross-sectional extension of the program on 08 August 2011. VLTRO1 marks the allotment of the first three-year VLTRO on 20 December 2011. VLTRO2 marks the allotment of the second three-year VLTRO on 28 February 2012. OMT1 marks the initial announcement of the OMT on 02 August 2012. OMT2 marks the announcement of the OMT's technical details on 06 September 2012.

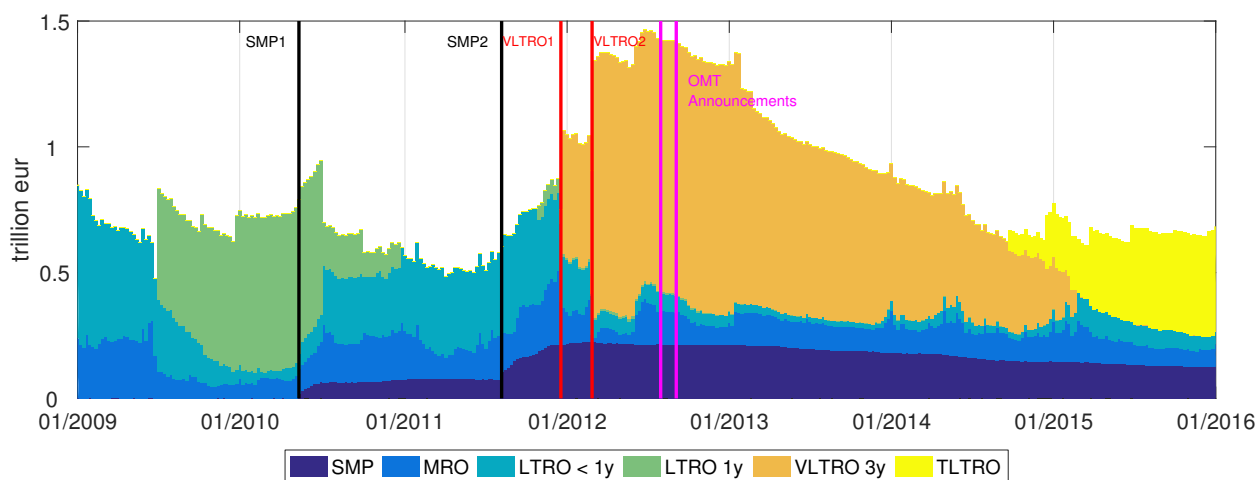
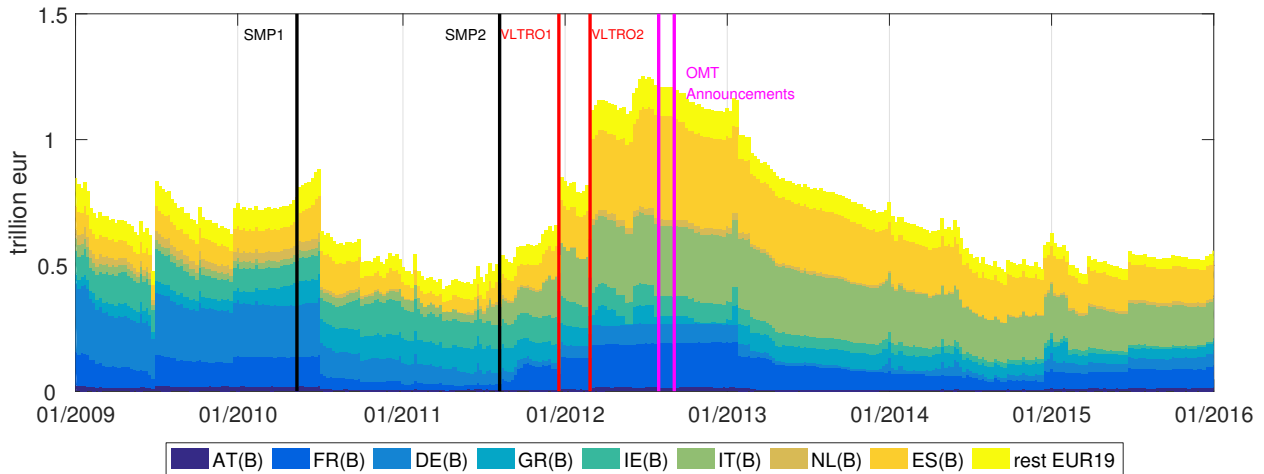


Figure 2: Eurosystem collateralized lending across countries

Exposures across different euro area countries from five liquidity-providing operations; see Figure 1. The vertical axis is in trillion euro. Vertical lines indicate the events described in Figure 1. Data is weekly between 2009 and 2015.



and 2015.³ We distinguish five different liquidity operations: MRO, LTRO<1y, LTRO1y, VLTRO3y, and TLTRO. The figure also plots the par value of assets held in the SMP portfolio. Clearly, the Eurosystem’s balance sheet varied in size, composition, and thus credit riskiness during the course of the global financial crisis and euro area sovereign debt crisis. A peak in total assets was reached at the height of the debt crisis in mid-2012, at approximately €1.5 trn, following two VLTROs and SMP government bond purchases.

Figure 2 plots the Eurosystem’s country-level collateralized lending exposures, aggregated over the five liquidity-providing operations of Figure 1. The largest share of VLTRO funds was tapped by banks in Italy and Spain, and also Greece, Ireland, and Portugal. These sovereigns (and their banks) were perceived by markets to be particularly affected by the euro area sovereign debt crisis. Banks from non-stressed countries such as Germany and France were less liquidity-constrained and therefore relied less heavily on Eurosystem funding during the crisis.

The remainder of this subsection briefly reviews the three major unconventional monetary policy operations in chronological order: the SMP, the VLTROs, and the OMT. Each of these

³The Eurosystem’s balance sheet is public; see <http://sdw.ecb.europa.eu/browse.do?node=9691110>.

had a substantial impact on asset prices, point-in-time credit risks, and time-varying risk correlations; see, e.g., [ECB \(2014\)](#) for a survey.

The SMP

The SMP was announced on 10 May 2010, with the objective to help restoring the monetary policy transmission mechanism by addressing the malfunctioning of certain government bond markets. The SMP consisted of interventions in the form of outright purchases which were aimed at improving the functioning of these bond markets by providing “depth and liquidity;” see [González-Páramo \(2011\)](#). Implicit in the notion of market malfunctioning is the notion that government bond yields can be unjustifiably high and volatile. For example, market-malfunctioning can reflect the over-pricing of risk due to illiquidity as well as contagion across countries; see [Constâncio \(2011\)](#). SMP purchases were not intended to affect the money supply. For this reason the purchases were sterilized at the time.

SMP interventions occurred in government debt securities markets between 2010 and 2012 and initially focused on Greece, Ireland, and Portugal. The SMP was extended to include Spain and Italy on 08 August 2011. Approximately €214 billion (bn) of bonds were acquired between 2010 and early 2012; see [ECB \(2013a\)](#). The SMP’s weekly cross-country breakdown of the purchase data is confidential at the time of writing. However, the Eurosystem released its total cross-country SMP portfolio holdings at the end of 2012 in its 2013 Annual Report. At the end of 2012, the Eurosystem held approximately €99.0bn in Italian sovereign bonds, €30.8bn in Greek debt, €43.7bn in Spanish debt, €21.6bn in Portuguese debt, and €13.6bn in Irish bonds; see [ECB \(2013a\)](#). For impact assessments of SMP purchases on bond yields, CDS spreads, and liquidity risk premia see e.g. [Eser and Schwaab \(2016\)](#), [Ghysels et al. \(2017\)](#), and [De Pooter et al. \(2018\)](#).

The VLTROs

Two large-scale VLTROs were announced on 08 December 2011, and subsequently allotted to banks on 21 December 2011 and 29 February 2012. The first installment provided more than 500 banks with €489 bn at a low (1%) interest rate for the exceptionally long period

of three years. The second installment in 2012 was even larger, and provided more than 800 euro area banks with €530 billion in three-year low-interest loans. By loading up on VLTRO funds stressed banks could make sure they had enough cash to pay off their own maturing debts, and at the same time keep operating and lending to the non-financial sector. Incidentally, banks used some of the money to also load up on domestic government bonds, temporarily bringing down sovereign yields. This eased the debt crisis, but may also have affected the bank-sovereign nexus (risk dependence) at the time; see e.g. [Acharya and Steffen \(2015\)](#).

The OMT

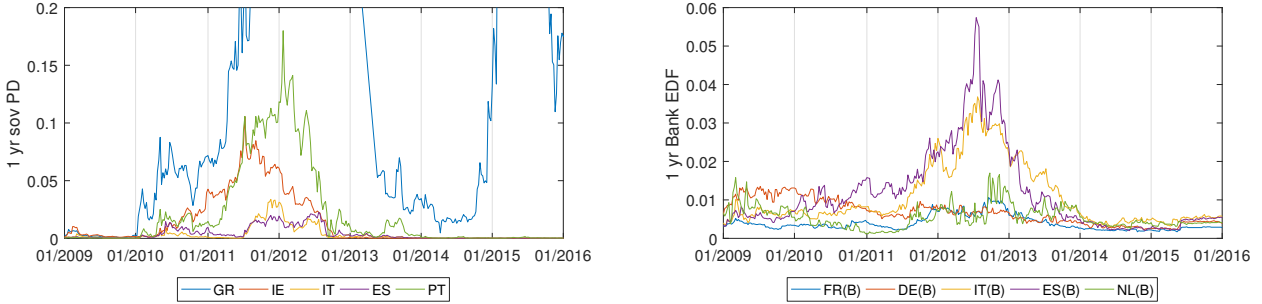
On 26 July 2012, the president of the ECB pledged to do “whatever it takes” to preserve the euro, and that “it will be enough.” The announcement of Outright Monetary Transactions (OMT), a new conditional asset purchase program, followed shortly afterwards on 02 August; see [ECB \(2012\)](#). The OMT technical details were announced on 06 September 2012. The details clarified that the OMT replaced the SMP, and that, within the OMT, the ECB could potentially undertake purchases (“outright transactions”) in secondary euro area sovereign bond markets provided certain conditions were met. OMT interventions were stipulated to be potentially limitless, to focus on short-maturity bonds, and to be conditional on the bond-issuing countries agreeing to and complying with certain domestic economic measures determined by euro area heads of state. In the years since its inception, the OMT never had to be used. Nevertheless, its announcement is widely credited for ending the acute phase of the sovereign debt crisis by restoring confidence; see e.g. [Wessel \(2013\)](#).

2.2 Bank and sovereign EDFs

We rely on expected default frequency (EDF) data from Moody’s Analytics, formerly Moody’s KMV, when assigning point-in-time probabilities of default (PDs) to Eurosystem bank counterparties. EDFs are point-in-time forecasts of physical default hazard rates, and are based on a proprietary firm value model that takes firm equity values and balance sheet information as inputs; see [Crosbie and Bohn \(2003\)](#) for details. EDFs are standard credit risk

Figure 3: Sovereign and banking sector EDFs

Left panel: CDS-implied-EDFs for five SMP sovereigns. Right panel: country-level banking sector EDF indices for the five largest euro area countries: Germany, France, Italy, Spain, and the Netherlands. Data is weekly between 2009 and 2015.



measurements and are routinely used in the financial industry and credit risk literature; see for example [Lando \(2003\)](#), [Duffie et al. \(2007\)](#) and [Duffie et al. \(2009\)](#). We focus on the one-year-ahead horizon for data availability reasons and to align our estimates with the common annual reporting frequency.⁴

EDF measures are available for listed banks only. Many Eurosystem bank counterparties, however, are not listed. At the same time, some parsimony is required when considering many bank counterparties. We address both issues by using one-year-ahead median EDFs at the country-level to measure point-in-time banking sector risk. EDF indices based on averages weighted by total bank assets are also available, but appear less reliable. The right panel of [Figure 3](#) plots our EDF indices for the ‘big-5’ euro area countries: Germany, France, Italy, Spain, and the Netherlands. During the crisis, most Eurosystem liquidity was taken up by banks located in these countries; see [Figure 2](#). Banking sector EDF measures differ widely across countries, and peak around mid-2012.

Unfortunately, firm-value based EDF measures are unavailable for sovereign counterparties. We therefore need to infer physical PDs from observed sovereign CDS spreads. Web

⁴ Risk measures for different year-ahead horizons, when available, tend to be highly correlated. For example, the first principal component typically describes most of the total variation in a panel of CDS spreads across different maturities; see e.g. [Longstaff et al. \(2011\)](#). There is no instance of 1-year CDS rates falling significantly (by more than one standard deviation) and the 10-year rate increasing at the same time in our CDS spread data referencing the five SMP countries. As a result, we expect results based on one-year-ahead risk measures to be indicative of longer-term risk perceptions as well.

Appendix A provides the details of our approach. To summarize, we first invert the CDS pricing formula of O’Kane (2008) to obtain risk-neutral default probabilities. We do this at each point in time for multiple CDS contracts at different maturities between 1 and 10 years. Second, we convert the risk-neutral probabilities into physical ones using the nonlinear mapping fitted by Heynderickx et al. (2016). Finally, we fit a Nelson Siegel curve to the term structure of CDS-implied-EDFs, and integrate the curve over the [0,1] year interval to obtain one-year-ahead CDS-implied-EDFs. The left panel of Figure 3 presents our sovereign risk measures for the five SMP countries.

3 Statistical model

3.1 Portfolio risk measures

Credit losses at time $t = 1, \dots, T$ over a one-year-ahead horizon are only known with certainty after the year has passed, and uncertain (random) at time t . The probability distribution of ex-ante credit losses is therefore a key concern for risk measurement. We model total credit losses $\ell_t(k)$ associated with potentially many counterparties $i = 1, \dots, N_t(k)$ as

$$\ell_t(k) = \sum_{i=1}^{N_t(k)} \ell_{it}(k) = \sum_{i=1}^{N_t(k)} \text{EAD}_{it}(k) \cdot \text{LGD}_{it} \cdot 1(\text{default}_{it}), \quad (1)$$

where $k = 1, \dots, K$ denotes monetary policy operations (e.g., LTRO lending or SMP asset holdings), $\ell_{it}(k)$ is the counterparty-specific one-year-ahead loss between week $t+1$ and $t+52$, $\text{EAD}_{it}(k)$ is the exposure-at-default associated with counterparty i and policy operation k , $\text{LGD}_{it} \in [0, 1]$ is the loss-given-default as a fraction of $\text{EAD}_{it}(k)$, and $1(\text{default}_{it})$ is an indicator function that takes the value of one if and only if counterparty i defaults. $N_t(k)$ is the total number of both bank and sovereign counterparties. A default happens when the log-asset value of counterparty i falls below its counterparty-specific default threshold; see e.g. Merton (1974) and CreditMetrics (2007). The loss $\ell_{it}(k)$ is random because it is a function of three random terms, EAD_{it} , LGD_{it} , and the default indicator. Total losses from monetary policy operations are given by $\ell_t = \sum_{k=1}^K \ell_t(k)$. We focus on the one-year-ahead

horizon as it coincides with typical reporting frequencies.

Portfolio risk measures are typically based on moments or quantiles of the ex-ante loss distribution. We focus on standard risk measures such as the expected loss, value-at-risk at a given confidence level γ , and expected shortfall at confidence level γ . These risk measures are given respectively by

$$\begin{aligned}\text{EL}(k)_t &= \mathbb{E}[\ell_t(k)], \\ \Pr[\ell_t(k) \geq \text{VaR}^\gamma(\ell_t(k))] &= 1 - \gamma, \\ \text{ES}(k)_t^\gamma &= \mathbb{E}[\ell_t(k) \mid \ell_t(k) \geq \text{VaR}^\gamma(\ell_t(k))],\end{aligned}$$

where $\mathbb{E}[\cdot]$ is the expectation over all sources of randomness in (1). The expected shortfall $\text{ES}(k)_t^\gamma$ is often interpreted as the “average VaR in the tail,” and is typically more sensitive to the shape of the tail of the loss distribution. The subscript t indicates that the time series of portfolio risk measures is available at a higher than annual frequency (e.g., weekly).

The remainder of this section reviews the modeling of the ingredients of (1) from right to left: dependent defaults, LGD, and EAD.

3.2 Copula model for dependent defaults

During and after the Great Financial Crisis the Gaussian copula was occasionally referred to as “the formula that killed Wall Street;” see e.g. [Salmon \(2009\)](#). Since then a consensus emerged that key features of good risk models should include joint fat tails of individual risks, non-Gaussian copula dependence (to account for dependence in tail areas), time variation in parameters, and potential asymmetries in dependence; see e.g. [McNeil et al. \(2015, Ch. 7\)](#). Our model for dependent defaults follows closely from the frameworks developed in [Creal et al. \(2011\)](#) and [Lucas et al. \(2014, 2017\)](#). To tailor the model to the problem at hand, however, we need to modify it to accommodate a large number of bank and sovereign counterparties. In addition, owing to high dimensions, we seek to capture joint tail dependence and a potential asymmetry in the copula in a computationally straightforward and reliable way.

Following the seminal framework of [Merton \(1974\)](#) and [CreditMetrics \(2007\)](#), we assume that a counterparty i defaults if and only if its log asset value falls short of a certain default threshold. We assume that this happens when *changes* from current log asset values to future ones are sufficiently negative. Specifically, we assume that a default occurs with a time-varying default probability p_{it} , where

$$p_{it} = \Pr[\tilde{y}_{it} < \tau_{it}] = F(\tau_{it}) \Leftrightarrow \tau_{it} = F^{-1}(p_{it}), \quad (2)$$

where \tilde{y}_{it} is a one-year-ahead change in log asset value, τ_{it} is a default threshold expressed as a log return, and F is the CDF of \tilde{y}_{it} . We stress that (2) is different from a typical [Merton \(1974\)](#) model in at least two ways. First, unlike [Merton \(1974\)](#), p_{it} is treated as an observed *input* in our model. Second, τ_{it} does not have an economic interpretation in terms of debt levels of the firm. Rather, τ_{it} is chosen at each point in time and for each counterparty such that the marginal default probability implied by the multivariate (copula) model coincides with the observed market-implied default probability for that counterparty at that time; see the last equality in (2). The reduced form character of (2) ensures that the model can be used for sovereigns as well, for which asset values are a less intuitive notion.

When modeling dependent defaults, we link default indicators using a Student's t copula function. In particular, we assume that one-year-ahead changes in log-asset values \tilde{y}_{it} are generated by a high-dimensional multivariate Student's t density

$$\tilde{y}_{it} = \mu_{it} + \sqrt{\zeta_t} L_{it}^{(k)} z_t, \quad i = 1, \dots, N_t(k), \quad (3)$$

where $z_t \sim N(0, I_{N_t(k)})$ is a vector of standard normal risk terms, $L_{it}^{(k)}$ is the i th row of $L_t^{(k)}$, $L_t^{(k)}$ is the Choleski factor of the Student's t covariance matrix $\Omega_t^{(k)} = L_t^{(k)} L_t^{(k)'}$, $\zeta_t \sim \text{IG}(\frac{\nu}{2}, \frac{\nu}{2})$ is an inverse-gamma distributed scalar mixing variable that generates the fat tails in the copula, and ν is a degrees of freedom parameter that can be estimated. The covariance matrix $\Omega_t^{(k)}$ depends on k because different counterparties participate in different monetary policy operations. We can fix $\mu_{it} = 0$ in (3) without loss of generality since copula quantiles

shift linearly with the mean.

Lucas et al. (2014) find that default dependence across euro area sovereigns is asymmetric, and well-captured by a (Generalized Hyperbolic) skewed- t copula. Lucas et al. (2017) confirm this finding for banks. Rather than modeling any potential asymmetry in default dependence via (3), however, we introduce asymmetry in a novel way via the transition equation governing the correlation parameters in $\Omega_t^{(k)}$ as detailed in the next subsection. This has the advantage that the quantiles of a standard t -density can be used in the estimation of the copula parameters. These quantiles are almost always tabulated and thus quickly available in standard software packages. By contrast, quantiles of skewed densities such as the Generalized Hyperbolic skewed- t density used in Lucas et al. (2014) are not usually tabulated and need to be solved for numerically. Repeated numerical integration within a line search is time-consuming in high-dimensional applications, and in practice less reliable when τ_{it} is far in the tail.

3.3 Score-driven copula dynamics

The time-varying covariance matrix $\Omega_t^{(k)}$ introduced below (3) is typically of a high dimension. For example, more than 800 banks participated in the Eurosystem’s second VLTRO program. The high dimensions and time-varying size of $\Omega_t^{(k)}$ imply that it is difficult to model directly. We address this issue by working with block equi-correlations within and across countries. This approach specifies $\Omega_t^{(k)}$ as a function of a much smaller covariance matrix Σ_t that is independent of k . We refer to e.g. Engle and Kelly (2012) and Lucas et al. (2017) for theory and empirical applications based on dynamic (block-)equicorrelation matrices.

The smaller covariance matrix Σ_t is specified to depend on a vector of latent correlation factors f_t . Specifically, $\Omega_t^{(k)} = \Omega_t^{(k)}(\Sigma_t(f_t))$, where $\Sigma_t(f_t) \in \mathbb{R}^{D \times D}$, and $D \ll N_t(k)$. Our empirical application below considers nine banking sector risk indices and five SMP countries, thus $D = 14 \ll N_t(k)$ at any t and k . The mapping of matrix elements $\Omega_t^{(k)}(i, j) = \Sigma_t(l(i), m(j))$ is surjective but not injective (i.e. any element of Σ_t typically appears multiple times in $\Omega_t^{(k)}$). All bank correlation pairs across countries can be taken from Σ_t . The within-country correlation pairs – the off-diagonal elements in the diagonal blocks of $\Omega_t^{(k)}$ – cannot

be read off Σ_t . We proceed by assuming that the within-country bank correlations are equal to the respective maximum (bank) row entry of Σ_t . As a result banks within each country are as correlated as the maximum estimated bank correlation pair across borders at that time t . We expect this approach to yield realistic within-country correlations given the single market for financial services and a substantial degree of cross-border banking sector integration in the euro area; see e.g. ECB (2013b) and Lucas et al. (2017). In any case, our results reported in Section 4 are robust to scaling up the within-country correlations.

Our approach for modeling $\Sigma_t(f_t)$ builds on the approach of Creal et al. (2011). In this framework, the Choleski decomposition of Σ_t is specified in terms its hyperspheric (polar) coordinates and the factors $f_t \in R^{(D-1)(D-2)/2 \times 1}$ specify the relevant ‘angles’ of these coordinates. This setup ensures that Σ_t is always positive definite and symmetric.⁵

The D -dimensional multivariate Student’s t density implied by the mixture (3) is given by

$$p(\tilde{y}_t; \Sigma_t, \nu) = \frac{\Gamma((\nu + D)/2)}{\Gamma(\nu/2)[(\nu - 2)\pi]^{D/2} |\Sigma_t|^{1/2}} \cdot \left[1 + \frac{\tilde{y}_t' \Sigma_t^{-1} \tilde{y}_t}{(\nu - 2)} \right]^{-\frac{\nu+D}{2}}, \quad (4)$$

where Σ_t is used instead of $\Omega_t^{(k)}$, $\Gamma(\cdot)$ is the gamma function, and ν is the degrees of freedom parameter. The dynamics of f_t are specified by the transition equation

$$f_{t+1} = \omega \cdot \text{vech}(\rho(\bar{\Sigma})) + A \cdot S_t \nabla_t + B \cdot f_t, \quad (5)$$

where ω , A , and B are parameters and matrices to be estimated, $\text{vech}(\rho(\bar{\Sigma})) \in R^{(D-1)(D-2)/2 \times 1}$ contains appropriately transformed unconditional correlations, the scaling matrix S_t is chosen as the inverse conditional Fisher information matrix $E_{t-1} [\nabla_t \nabla_t']^{-1}$, and ∇_t is the score

⁵ The correlation matrix $\Omega_t^{(k)}$ obtained from Σ_t is symmetric but not guaranteed to be positive definite. In case the Choleski decomposition of $\Omega_t^{(k)}$ fails we apply an eigenvalue (spectral) decomposition to the symmetric matrix and adjust negative eigenvalues to zero. The Choleski factor is then easily obtained. This is a standard procedure when correlation matrices are ill-conditioned. In our sample the thus regularized matrices are close approximations to the original $\Omega_t^{(k)}$ s. The average (over t) Frobenius norm of the matrix differences is less than 10^{-5} per element for all k . We use the square-root of $\Omega_t^{(k)}$ when generating draws from (3); it is not required at the parameter estimation stage.

of (4) given by

$$\begin{aligned}\nabla_t &= \frac{\partial \text{vech}(\Sigma_t(f_t))'}{\partial f_t} \cdot \frac{\partial \log p(y_t; \Sigma_t, \nu)}{\partial \text{vech}(\Sigma_t)} \\ &= \frac{1}{2} \Psi_t' \mathcal{D}'_D(\Sigma_t^{-1} \otimes \Sigma_t^{-1}) \left[\frac{(\nu + D)}{\nu - 2 + y_t' \Sigma_t^{-1} y_t} (y_t \otimes y_t) - \text{vec}(\Sigma_t) \right],\end{aligned}\quad (6)$$

where \log denotes the natural logarithm, Ψ_t is the derivative $\partial \text{vech}(\Sigma_t)/\partial f_t'$, \mathcal{D}_D is the duplication matrix as defined in [Abadir and Magnus \(2005\)](#), and \otimes denotes Kronecker multiplication.

The transition equation (5) adjusts f_t at every step using the scaled score $S_t \nabla_t$ of the conditional density at time t . This can be regarded as a steepest ascent improvement of the time-varying parameter using the local (at time t) likelihood fit of the model. The scaled score is a martingale difference sequence with mean zero, and acts as an innovation term. The coefficients in A and B can be restricted so that the process f_t is covariance stationary. The initial value f_1 is most conveniently initialized at the unconditional mean of the stationary process.

To accommodate a possibly asymmetric response in the correlation dynamics, we extend the score (6) slightly as

$$\nabla_t = \frac{1}{2} \Psi_t' \mathcal{D}'_D(\Sigma_t^{-1} \otimes \Sigma_t^{-1}) \left[\frac{(\nu + k)}{\nu - 2 + y_t' \Sigma_t^{-1} y_t} (y_t \otimes y_t) - \text{vec}(\Sigma_t) + C \cdot (y_t^+ \otimes y_t^+) \right], \quad (7)$$

where the i th element of y_t^+ equals $y_{it}^+ = \max(0, y_{it})$, and C is a scalar (or diagonal matrix) to be estimated. Clearly, (7) reduces to (6) for $C = 0$. Values of $C \neq 0$, however, allow the correlations to react differently to increasing versus decreasing marginal risks. The asymmetry in the conditional correlation dynamics carries over to skewness in the unconditional distribution of \tilde{y}_{it} , similar to features well-known from the familiar GARCH model with leverage; see e.g. [Glosten et al. \(1993\)](#).

The covariance $\Sigma_t(f_t)$ is fitted to weekly log-changes in observed bank and sovereign EDFs. Web Appendix B discusses our univariate modeling strategy for changes in marginal risks. The scaling function S_t in (5) is available in closed form; see Web Appendix C for

details.

3.4 Loss-given-default

Portfolio risk levels depend substantially on the assumptions made in the modeling of the loss (fraction)-given-default. We distinguish two separate cases: bank and sovereign counterparties.

Collateralized lending to banks within the Eurosystem’s liquidity facilities implies a double recourse. If a bank defaults, the central bank can access the pledged collateral and sell it in the market to cover its losses. Conservatively calibrated haircuts on the market value of pledged assets ensure that a sufficient amount of collateral is almost always available to cover losses. Haircuts are higher for more volatile, longer duration, and more credit-risky claims. For example, so-called non-marketable assets carry valuation haircuts of up to 65%. As a result, historical counterparty-level LGDs have been approximately zero for most central banks, owing to conservative ex-ante risk protection frameworks and haircuts.

The case of Lehman brothers can serve as an (extreme) example. Its German subsidiary, Lehman Brothers Bankhaus, defaulted on the Eurosystem on 15 September 2008. In the weeks leading up to the default, out-of-fashion mortgage-backed-securities had been posted as collateral. These were highly non-liquid and non-marketable at the time. In addition, an untypically large amount of central bank liquidity had been withdrawn just prior to the default. Even so, the posted collateral was ultimately sufficient to recover all losses. The workout-LGD was zero as a result; see [Bundesbank \(2015\)](#).

A substantial loss to the central bank may nevertheless occur in extreme scenarios when both banks and their collateral default simultaneously. This was a valid concern during the sovereign debt crisis. A subset of banks pledged bonds issued by their domestic government, or bank bonds that were eligible only because they were also government-guaranteed. This exposed the central bank to substantial “wrong way risk,” as bank and sovereign risks are highly positively dependent in the data.

We incorporate the above observations as follows. For a bank counterparty i , we model

LGD stochastically as

$$\text{LGD}_{it} = 0.02 + 0.58 \cdot 1 \{ \tilde{y}_{jt} < \tau_{jt} \text{ for at least one SMP country } j \}.$$

i.e., $\text{LGD}_{it} = 0.02$ if bank counterparty i defaults but no SMP counterparty $j \neq i$ defaults. The LGD increases to 60% if bank i defaults and a (any) SMP sovereign defaults as well (in the same simulation) and a sovereign debt crisis were to ensue as a result. The 2% value for bank workout LGDs is not unrealistically low, as explained above. The 60% stressed LGD is chosen in line with international evidence on sovereign bond haircuts; see e.g. [Cruces and Trebesch \(2013, Table 1\)](#).

In case of a sovereign counterparty, e.g., for government bonds acquired within the SMP, only a single recourse applies. We set the LGD to 60% should such a default be observed,

$$\text{LGD}_{jt} = 0.60 \cdot 1 \{ \tilde{y}_{jt} < \tau_{jt} \text{ for SMP country } j \}.$$

More elaborate specifications for LGD are clearly also possible. The present approach, however, is parsimonious and conservative, while still sufficiently flexible to capture the issues of systematic variation of LGDs with defaults as well as wrong-way risk between banks and sovereigns.

3.5 Exposures-at-default

Exposures-at-default $\text{EAD}_{it}(k)$ in (1) can, but do not have to, coincide with currently observed exposure $\text{EXP}_{it}(k)$. Recall that in the case of Lehman Brothers Bankhaus, exposures increased substantially in the weeks prior to the observed default. Similarly, the OMT would likely be activated in extremely bad states of the world. To keep things simple and interpretable, however, we assume that $\text{EAD}_{it}(k) = \text{EXP}_{it}(k)$.

We do not have access to all counterparty-specific exposures (loan amounts) over time in our sample. Instead, we have access to the weekly aggregate exposures at the (country(j), operation(k)) level. In addition, we know the number of banks $N_t(j, k)$ that have accessed

monetary policy operation k in week t and country j .⁶ We therefore proceed under the assumption that exposures $a_{i,kt}$ for $i = 1, \dots, N_t(j, k)$ within country j are Pareto-distributed, in line with e.g. [Janicki and Prescott \(2006\)](#). We thus draw counterparty-specific exposures according to $P(a_{i,jkt}) \propto (a_{i,jkt})^{-1/\xi}$ for a given value of ξ as

$$\text{EXP}_{i,jkt} = \frac{a_{i,jkt}}{\sum_{i=1}^{N_t(j,k)} a_{i,jkt}} \cdot \text{CountryExp}_{jkt}^{\text{observed}},$$

in this way dividing up the observed aggregate bank lending volume per country and policy operation over $N_t(j, k)$ banks. We chose $1/\xi = 2$ in line with [Janicki and Prescott \(2006\)](#) to construct the relative shares. We checked that this is approximately consistent with the cross-section of total bank liabilities in the euro area between 2009 and 2015 using the [Hill \(1975\)](#) estimator.

3.6 Parameter estimation

Observation-driven multivariate time series models such as (2)–(5) are attractive because the log-likelihood is known in closed form. Parameter estimation is standard as a result. This is a key advantage over alternative parameter-driven risk frameworks, as e.g. considered in [Koopman et al. \(2011, 2012\)](#), and [Azizpour et al. \(2017\)](#), for which the log-likelihood is not available in closed form and parameter estimation is non-standard. For a given set of observations y_1, \dots, y_T , the vector of unknown copula parameters $\theta = \{\omega, A, B, C, \nu\}$ can be estimated by maximizing the log-likelihood function with respect to θ , that is

$$\hat{\theta} = \arg \max_{\theta} \sum_{t=1}^T \log p(y_t | f_t; \theta), \quad (8)$$

where $p(y_t | f_t; \theta) = p(y_t; \Omega(\Sigma_t(f_t)), \nu)$ is the multivariate Student's t density for the vector y_t containing the observed log-changes in bank and sovereign one-year-ahead EDF measures for all counterparties observed at time t . The evaluation of $\log p(y_t | f_t; \theta)$ is easily incorporated in the filtering process for f_t as described in [Section 3.3](#). The maximization in (8) can

⁶The identities of the $N_t(j, k)$ Eurosystem counterparties are confidential. For a detailed study of who borrows from the Eurosystem as a lender-of-last-resort see [Drechsler et al. \(2016\)](#).

be carried out using a conveniently chosen quasi-Newton optimization method. The sub-covariance matrix $\Omega^{(k)}$ for program k can be obtained directly from the general matrix $\Omega(\Sigma_t(f_t))$.

For the empirical application, we reduce the computational burden of parameter estimation in two ways. First, we proceed in two steps and estimate the parameters of D marginal models with time varying volatility for each series of log EDF changes. As is standard, we transform the outcomes using the probability integral transform and subsequently estimate the copula parameters. This approach is standard in the literature; see e.g. Joe (2005) and Fan and Patton (2014). Second, we assume that matrices A , B , and C in the factor transition equation (5) are scalars, such that $\theta = \{\omega, A, B, C, \nu\} \in \mathbb{R}^5$ is a vector of relatively low dimension.

4 Empirical results

Our empirical study is structured around five interrelated questions. What were the expected losses associated with each Eurosystem unconventional monetary policy operation during the sovereign debt crisis? Were the portfolio tail risks at all times covered by Eurosystem financial buffers? How important were spillovers across different monetary policy operations during the sovereign debt crisis? To what extent did unconventional policies differ in terms of ex-post risk efficiency? Finally, do other central banks' policy announcements spill over to the Eurosystem's risks?

4.1 Model specification and parameter estimates

For model selection, we are most interested in whether non-Gaussian dependence and the novel leverage term in (5) are preferred by the data. Table 1 reports parameter estimates for three different specifications of the copula model (2)–(7). The model parameters are estimated from $D = 9 + 5 = 14$ multivariate time series of daily log changes in banking sector and sovereign EDFs. Univariate Student's t models with time-varying volatility and leverage are used to model the marginal dynamics for each series separately; see Web Appendix B.

Table 1: Parameter estimates

Parameter estimates for the copula model (4)–(7) fitted to weekly log changes in $D = 14$ banking sector and sovereign EDFs between 03 October 2008 and 11 March 2016 ($T = 389$). The same univariate models are used; see Web Appendix B. The first model specification enforces a multivariate Gaussian copula by setting $C = \nu^{-1} = 0$. The second and third specifications refer to a symmetric and asymmetric t copula, respectively. Standard errors in parentheses are constructed from the numerical second derivatives of the log-likelihood function.

| | N copula | Student's t copula | |
|----------|------------------|--------------------------|------------------------------|
| | | symmetric ($C = 0$) | asymmetric ($C \neq 0$) |
| ω | 0.999 (0.003) | 0.977 (0.005) | 0.988 (0.007) |
| A | 0.007 (0.003) | 0.007 (0.003) | 0.008 (0.002) |
| B | 0.864 (0.082) | 0.953 (0.034) | 0.969 (0.013) |
| C | - - | - - | -0.555 (0.206) |
| ν | - - | 11.964 (0.991) | 11.970 (0.982) |
| logLik | 1487.61 | 1629.49 | 1631.83 |
| AICc | -2969.2 | -3251.0 | -3253.6 |

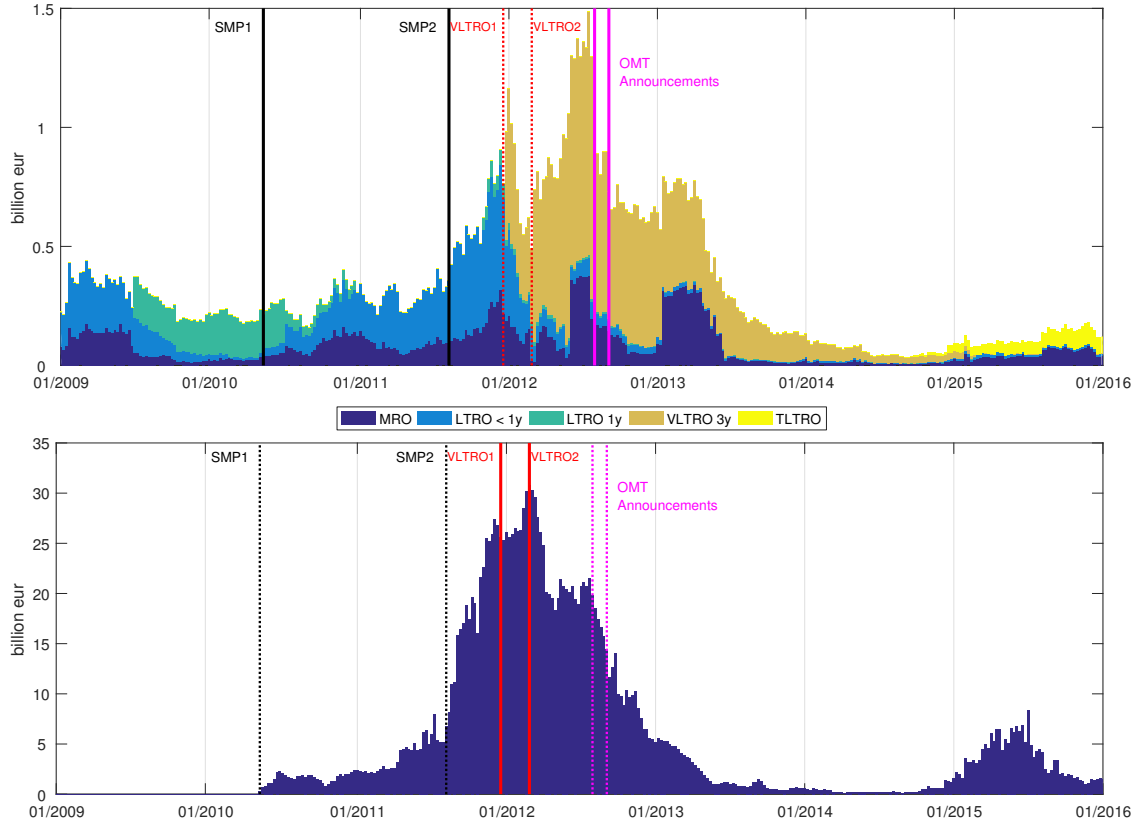
Gaussian dependence is a special case of our model, with $\nu^{-1} = C = 0$. This joint restriction, however, is strongly rejected by the data in a likelihood-ratio test. Turning to the two t copula specifications, allowing for an asymmetric response of the correlation factors is preferred by the data based on the log-likelihood fit and information criteria. The increase in log-likelihood is significant at the 5% level. Web Appendix D shows that model choice can have a small-to-moderate effect on our expected shortfall estimates. Mean loss estimates are less sensitive. The degree-of-freedom parameter $\nu \approx 12$ allows for a moderate degree of joint tail dependence in the copula.⁷ Parameter $C < 0$ implies that correlations *increase* more quickly in bad times than they decrease in good times.⁸ Experimenting with block-specific C parameters did not lead to significantly improved log-likelihoods. We select the asymmetric t copula specification for the remainder of the analysis based on likelihood fit and information criteria. Using this specification, we combine model parsimony with the ability to explore a rich set of hypotheses given the data at hand.

⁷The degree-of-freedom parameters ν for the marginal univariate models are substantially lower, and vary between approximately three and eight; see Web Appendix B.

⁸This is related to our use of polar coordinates (cosines) when mapping f_t into Σ_t ; see Web Appendix C.

Figure 4: Expected losses for collateralized lending and SMP portfolios

Top panel: one-year-ahead expected losses from liquidity providing operations at a weekly frequency. Bottom panel: one-year-ahead expected losses from SMP assets. Vertical lines indicate the announcement of the SMP on 10 May 2010 and its cross-sectional extension on 08 August 2011, the allotment of two VLTROs on 21 December 2011 and 28 February 2012, and two announcements regarding the Outright Monetary Transactions (OMT) in August and September 2012. The vertical axis is in billion euro. Data is weekly between 2009 and 2015.



4.2 Expected losses

A large literature studies the beneficial impact of Eurosystem unconventional monetary policies during the euro area sovereign debt crisis on financial markets and macroeconomic outcomes; see e.g. [Eser and Schwaab \(2016\)](#), [Krishnamurthy et al. \(2018\)](#), and [Fratzcher and Rietz \(2018\)](#), among many others. By contrast, the potential downsides of unconventional policies, e.g. in terms of increased balance sheet risk, have received less attention.

Figure 4 plots estimated one-year-ahead expected losses from Eurosystem collateralized lending operations (top panel) and SMP asset purchases (bottom panel). Expected losses

are additive across operations, and therefore stacked vertically in the top panel of Figure 4. The mean of the loss density is calculated by simulation, using 200,000 draws at each time t . For each simulation, we keep track of exceedances of \tilde{y}_{it} below their respective calibrated thresholds at time t as well as the outcomes for LGD and EAD, as described in Section 3. The risk estimates combine all exposure data, marginal risks, as well as all $14(14-1)/2=91$ time-varying correlation estimates into a single time series per operation.

The expected losses in Figure 4 reflect, first, a clear deterioration of financial conditions since the beginning of the euro area sovereign debt crisis in the spring of 2010, and second, a clear turning of the tide around mid-2012. Expected losses for both collateralized lending and SMP exposures peak in mid-2012 at around approximately €1.5 bn and €30 bn, respectively. The pronounced difference in risk is explained by the double recourse in the case of collateralized lending. In addition, Figure 4 hints at the presence of beneficial spillovers across monetary policy operations. For example, the OMT announcements appear to have had a pronounced impact on the expected losses associated with the collateralized lending and SMP asset portfolios.

4.3 Financial buffers and portfolio tail risk

This section studies whether the Eurosystem was at all times sufficiently able to withstand the materialization of a 99% ES-sized credit loss.

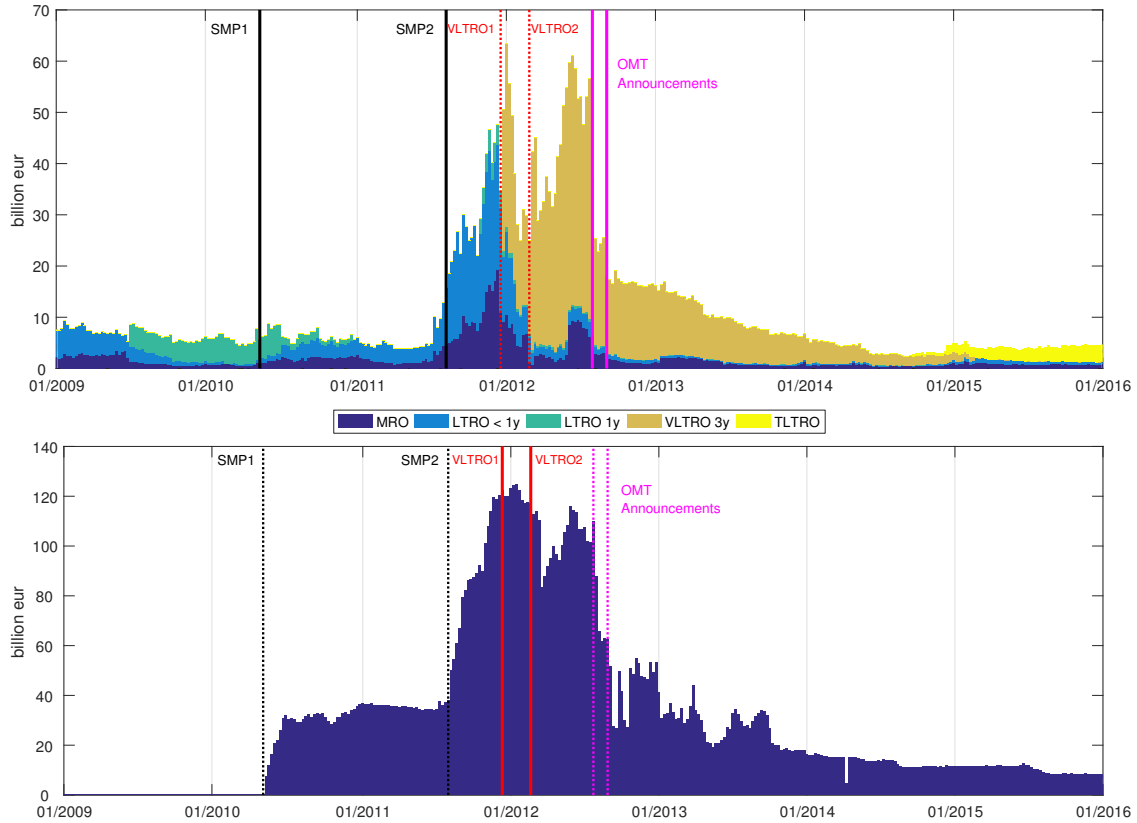
The top and bottom panel of Figure 5 plot the 99% ES associated with five collateralized lending operations and SMP assets. The ES estimates exhibit pronounced time series variation, peaking in 2012 at approximately €60 bn for the collateralized lending operations and at approximately €120 bn for the SMP portfolio. All portfolio tail risks collapse sharply following the OMT announcements.

When our EL and ES estimates are scaled by the corresponding policy's exposure, the SMP assets are substantially more risky per €1 bn of exposures than the collateralized lending operations. Risk per unit of exposure often differs by more than an order of magnitude. We refer to Web Appendix E for details.

For a commercial bank, financial buffers against a large portfolio loss typically include

Figure 5: ES 99% for collateralized lending and SMP portfolios

Top panel: 99% expected shortfall in €bn for five Eurosystem collateralized lending operations. Bottom panel: 99% ES for SMP asset portfolio. Six vertical lines mark the events described in Section 2.1. Data is weekly between 2009 and 2015.



accounting items such as the current year’s (projected) annual income, revaluation reserves in the balance sheet, general risk provisions, and paid-in equity capital. We adopt a similar notion of financial buffers for the Eurosystem. We recall, however, that a central bank is never liquidity constrained in the currency they issue, so that the notion of financial (solvency) buffers is much less appropriate.

Since the financial crisis in 2008, the Eurosystem as a whole has built up relatively large financial buffers, including from part of the stream of seignorage revenues generated by banknote issuance. Those buffers are mainly in the form 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 items stood at €88 bn, €407 bn and €57

bn, respectively, at the end of 2012; see [ECB \(2013b, p. 44\)](#). The overall financial buffers therefore stood at €552 bn. Comparing these balance sheet items with our ES estimates in [Figure 5](#) we conclude that the Eurosystem’s buffers were at all times sufficient to withstand an ES99%-sized credit loss, even at the peak of the euro area sovereign debt crisis.

4.4 Risk spillovers across monetary policy operations

The riskiness of the Eurosystem’s balance sheet depends on the financial health of its counterparties, which in turn depends on central bank liquidity provision to and asset purchases from those same counterparties. This two-way interdependence can give rise to a pronounced nonlinearity in the central bank balance sheet risks, e.g. as the economy switches from a ‘bad’ equilibrium to a ‘good’ one.

The high (weekly) frequency of the risk estimates plotted in [Figures 4](#) and [5](#) allow us to identify the impact of certain key ECB announcements on those risks. [Table 2](#) presents our risk estimates (EL and 99% ES) shortly before and after six key policy announcements. [Web Appendix E](#) presents the analogous results in per cent of the corresponding exposures.⁹

We focus on two main results. First, LOLR- and IOLR-implied credit risks are usually negatively related in our sample. Taking risk in one part of the central bank’s balance sheet (e.g., the announcement of SMP asset purchases in May 2010) tended to de-risk other positions (e.g., collateralized lending from previous LTROs, by approximately €2.2 bn). Vice versa, the allotment of the two large-scale VLTRO credit operations each decreased the expected shortfall of the SMP asset portfolio (by €2.1 bn and €3.3 bn, respectively). This negative relationship strongly suggests that central bank risks can be nonlinear (concave) in exposures. Increasing size increased overall risk less than proportionally, and by less than one would have expected holding PDs and risk dependence fixed at pre-announcement levels. This suggests that increasing balance sheet size during a liquidity crisis is unlikely to increase risk by as much as one would expect from linearly scaling up current portfolio risks with future exposures. Similarly, in the context of ultimately unwinding balance sheet positions, reducing the size of the balance sheet after the crisis may not reduce total risk by as much

⁹SMP-related exposures only build up gradually over time. We return to this issue in [Section 4.5](#).

Table 2: Portfolio credit risks around key policy announcements

Portfolio credit risks for different monetary policy operations around six policy announcements: the SMP announcement on 10 May 2010, the cross-sectional extension of the SMP on 08 August 2011, the allocation of the first VLTRO on 20 December 2011 and of the second VLTRO on 20 February 2012, OMT announcement on 02 August 2012, and the announcement of the OMT's technical details on 06 September 2012.

| SMP1 | 07/05/2010 | | 14/05/2010 | | Δ EL | Δ ES(99%) |
|--------------|------------------|------------------|------------------|------------------|-------------|------------------|
| | EL | ES(99%) | EL | ES(99%) | | |
| SMP | 0.0 [0.0 0.0] | 0.0 [0.0 0.0] | 0.3 [0.3 0.3] | 7.3 [7.3 7.4] | 0.3 | 7.3 |
| MRO | 0.0 [0.0 0.0] | 1.1 [0.9 1.2] | 0.0 [0.0 0.0] | 1.0 [0.8 1.0] | 0.0 | -0.1 |
| LTRO<1y | 0.0 [0.0 0.0] | 0.6 [0.5 0.7] | 0.0 [0.0 0.0] | 0.5 [0.5 0.6] | -0.0 | -0.1 |
| LTRO1y | 0.2 [0.2 0.2] | 6.2 [5.1 6.4] | 0.2 [0.2 0.2] | 4.1 [4.1 4.7] | -0.0 | -2.1 |
| Total | 0.2 | 7.9 | 0.5 | 13.0 | 0.3 | 5.1 |

| SMP2 | 05/08/2011 | | 12/08/2011 | | Δ EL | Δ ES(99%) |
|--------------|------------------|---------------------|------------------|---------------------|-------------|------------------|
| | EL | ES(99%) | EL | ES(99%) | | |
| SMP | 5.2 [5.2 5.2] | 38.0 [37.7 38.2] | 6.7 [6.7 6.8] | 49.9 [49.3 50.1] | 1.5 | 11.9 |
| MRO | 0.1 [0.1 0.1] | 4.5 [4.0 4.8] | 0.1 [0.1 0.1] | 4.8 [4.2 5.5] | 0.0 | 0.4 |
| LTRO<1y | 0.2 [0.2 0.2] | 8.5 [7.0 9.2] | 0.3 [0.2 0.3] | 10.9 [9.0 11.1] | 0.0 | 2.4 |
| Total | 5.5 | 51.0 | 7.1 | 65.6 | 1.5 | 14.7 |

| VLTRO1 | 16/12/2011 | | 30/12/2011 | | Δ EL | Δ ES(99%) |
|---------------|---------------------|------------------------|---------------------|------------------------|-------------|------------------|
| | EL | ES(99%) | EL | ES(99%) | | |
| SMP | 26.8 [26.7 26.9] | 122.2 [121.9 122.5] | 25.3 [25.3 25.4] | 120.1 [119.4 120.4] | -1.5 | -2.1 |
| MRO | 0.3 [0.3 0.3] | 19.3 [17.7 21.3] | 0.2 [0.2 0.2] | 9.1 [8.5 10.0] | -0.1 | -10.2 |
| LTRO<1y | 0.5 [0.5 0.5] | 24.4 [21.3 24.7] | 0.3 [0.3 0.3] | 12.8 [12.0 13.6] | -0.2 | -11.5 |
| LTRO1y | 0.1 [0.1 0.1] | 3.9 [3.5 4.1] | 0.0 [0.0 0.0] | 1.0 [0.9 1.0] | -0.0 | -2.9 |
| VLTRO3y | 0.0 [0.0 0.0] | 0.0 [0.0 0.0] | 0.5 [0.4 0.5] | 27.6 [26.0 28.8] | 0.5 | 27.6 |
| Total | 27.7 | 169.8 | 26.3 | 170.6 | -1.4 | 0.8 |

as one would expect from linear scaling. Arguably, the documented risk spillovers call for a measured approach towards reducing balance sheet size after a financial crisis.

Second, a subset of unconventional monetary policies reduced (rather than added to) overall balance sheet risk. For example, the first OMT announcement de-risked the Eurosystem's balance sheet by €41.4 bn (99%-ES). The announcement of OMT technical details on 06 September 2012 was also associated with a strong further reduction of €18.1 bn in 99%

Table 2: Portfolio credit risks around key policy announcements; ctd.

Portfolio credit risks for different monetary policy operations around six policy announcements: the SMP announcement on 10 May 2010, the cross-sectional extension of the SMP on 08 August 2011, the allocation of the first VLTRO on 20 December 2011 and of the second VLTRO on 20 February 2012, OMT announcement on 02 August 2012, and the announcement of the OMT's technical details on 06 September 2012.

| VLTRO2 | 24/02/2012 | | 09/03/2012 | | Δ EL | Δ ES(99%) |
|---------------|-------------|---------------|-------------|---------------|-------------|------------------|
| | EL | ES(99%) | EL | ES(99%) | | |
| SMP | 30.2 | 117.2 | 30.2 | 113.9 | 0.0 | -3.3 |
| | [30.1 30.2] | [116.1 118.3] | [30.2 30.3] | [112.2 114.5] | | |
| MRO | 0.2 | 6.7 | 0.0 | 0.7 | -0.1 | -6.0 |
| | [0.1 0.2] | [6.5 7.2] | [0.0 0.0] | [0.7 0.8] | | |
| LTRO<1y | 0.1 | 5.2 | 0.1 | 2.3 | -0.1 | -2.9 |
| | [0.1 0.1] | [4.6 5.4] | [0.1 0.1] | [2.0 2.4] | | |
| LTRO1y | 0.0 | 0.5 | 0.0 | 0.6 | 0.0 | 0.1 |
| | [0.0 0.0] | [0.5 0.6] | [0.0 0.0] | [0.5 0.6] | | |
| VLTRO3y | 0.3 | 17.3 | 0.6 | 38.6 | 0.3 | 21.3 |
| | [0.3 0.3] | [15.1 19.0] | [0.6 0.6] | [34.1 39.3] | | |
| Total | 30.8 | 147.0 | 31.0 | 156.1 | 0.2 | 9.1 |

| OMT1 | 27/07/2012 | | 03/08/2012 | | Δ EL | Δ ES(99%) |
|-------------|-------------|---------------|-------------|-------------|-------------|------------------|
| | EL | ES(99%) | EL | ES(99%) | | |
| SMP | 21.5 | 109.8 | 19.8 | 87.8 | -1.7 | -22.0 |
| | [21.4 21.5] | [107.9 110.4] | [19.8 19.9] | [85.8 88.6] | | |
| MRO | 0.2 | 6.2 | 0.2 | 4.5 | -0.0 | -1.8 |
| | [0.2 0.2] | [5.4 6.7] | [0.2 0.2] | [3.9 4.7] | | |
| LTRO<1y | 0.1 | 2.9 | 0.1 | 1.9 | -0.0 | -1.1 |
| | [0.1 0.1] | [2.7 3.5] | [0.1 0.1] | [1.9 2.4] | | |
| LTRO1y | 0.0 | 0.4 | 0.0 | 0.3 | -0.0 | -0.1 |
| | [0.0 0.0] | [0.4 0.4] | [0.0 0.0] | [0.3 0.3] | | |
| VLTRO3y | 1.0 | 47.0 | 0.8 | 30.5 | -0.2 | -16.5 |
| | [0.9 1.0] | [38.3 47.7] | [0.8 0.8] | [29.4 33.8] | | |
| Total | 22.8 | 166.4 | 20.9 | 125.0 | -1.9 | -41.4 |

| OMT2 | 31/08/2012 | | 07/09/2012 | | Δ EL | Δ ES(99%) |
|-------------|-------------|-------------|-------------|-------------|-------------|------------------|
| | EL | ES(99%) | EL | ES(99%) | | |
| SMP | 15.8 | 62.4 | 14.5 | 51.5 | -1.3 | -10.8 |
| | [15.7 15.8] | [61.0 63.0] | [14.4 14.5] | [51.1 52.5] | | |
| MRO | 0.2 | 3.1 | 0.1 | 2.0 | -0.0 | -1.1 |
| | [0.2 0.2] | [2.4 2.9] | [0.1 0.1] | [1.8 2.1] | | |
| LTRO<1y | 0.0 | 1.3 | 0.0 | 1.0 | -0.0 | -0.3 |
| | [0.0 0.1] | [1.1 1.4] | [0.0 0.0] | [0.9 1.1] | | |
| LTRO1y | 0.0 | 0.2 | 0.0 | 0.2 | -0.0 | -0.1 |
| | [0.0 0.0] | [0.2 0.2] | [0.0 0.0] | [0.1 0.2] | | |
| VLTRO3y | 0.7 | 20.9 | 0.5 | 15.0 | -0.1 | -5.9 |
| | [0.6 0.7] | [18.7 21.7] | [0.5 0.6] | [14.7 16.2] | | |
| Total | 16.6 | 87.8 | 15.2 | 69.7 | -1.5 | -18.1 |

ES. As another example, the allotment of the first VLTRO in December 2011 raised the 99% ES associated with VLTRO lending from zero to approximately €27.6 bn. However, it also sharply reduced the need for shorter-term MRO and LTRO funding, and de-risked the SMP

asset portfolio (as banks invested some of the VLTRO additional liquidity in government bonds; see e.g. [Acharya and Steffen \(2015\)](#) and [Drechsler et al. \(2016\)](#)). As a result, the overall 99% ES increased, but only marginally so, by €0.8 bn. Expected losses declined by €1.4 bn. We conclude that, in extreme conditions, a central bank can de-risk its balance sheet by doing more.

Such risk reductions are not guaranteed, however. In particular the SMP2 announcement is an exception to the patterns described above; see [Table 2](#). I.e., the extension of the program to include Spain and Italy in August 2011 did not reduce the credit risks inherent in the collateralized lending book. It also did not lead to a reduction in total risk. This exception is probably related to the pronounced controversy regarding the extension of the SMP at that time.

4.5 Risk efficiency

Portfolio risk estimates are a prerequisite for evaluating policy operations in terms of their ‘risk efficiency’. Risk efficiency is the principle that a certain amount of expected policy impact should be achieved with a minimum level of balance sheet risk; see e.g. [ECB \(2015\)](#). Put differently, the impact of any policy operation should be maximal given a certain level of risk. Given an estimate of policy impact, such as, for example, a change in inflation swap rates or in bond yields around the time of a policy announcement, and given an estimate of additional risk, such as, for example, a change in expected losses or in expected shortfall as reported in [Figures 4 and 5](#), different policy operations can be evaluated by scaling the former by the latter. This is similar to the definition of a [Sharpe \(1966\)](#) return-to-risk ratio.

Scaling policy impact by additional risk is not unproblematic for at least three reasons. First, scaling impact by additional risk may create the impression that both are equally important for the central bank. This is not the case. Recall that, unlike for commercial banks, risk and profitability are not first-order measures of success for a central bank. Second, ex-ante risk efficiency deliberations are probably too uncertain to be of practical use. Ex-ante estimates of impact (and additional risk) are highly uncertain, particularly if the policy operation is unprecedented and risks change after the announcement. Finally, asset purchase

Table 3: Risk efficiency ratios

Economic benefit, additional central bank balance sheet risk, and efficiency ratio around six policy announcements. Benefit is proxied by the change in market prices for five-year five-year-out euro area inflation swap rates, or alternatively by the decrease in five-year benchmark bond yields for GIIPS countries (Greece, Ireland, Italy, Portugal, and Spain). Benefit entries are in percentage points. Additional balance sheet risk is measured in €bn. Double entries are omitted for clarity below the first panel. Ratios are in basis points per €bn for changes in inflation swap rates, and in percentage points per €bn for changes in GIIPS bond yields.

| Program | Econ. benefit | | Add. risk | | Ratio |
|-------------|---------------|------|-----------|-------|-------|
| SMP1 | d(infl. swap) | 0.01 | d(EL) | 0.3 | 4.9 |
| 07 May to | | 0.01 | d(ES) | 5.1 | 0.3 |
| 14 May 10 | -d(5y yields) | 2.66 | | 0.3 | 8.9 |
| | | 2.66 | | 5.1 | 0.5 |
| SMP2 | d(infl. swap) | 0.09 | d(EL) | 1.5 | 5.7 |
| 05 Aug to | | | d(ES) | 14.7 | 0.6 |
| 12 Aug 11 | -d(5y yields) | 1.08 | | | 0.7 |
| | | | | | 0.1 |
| OMT1 | d(infl. swap) | 0.09 | d(EL) | -1.9 | -4.9 |
| 27 Jul to | | | d(ES) | -41.4 | -0.2 |
| 03 Aug 12 | -d(5y yields) | 0.21 | | | -0.1 |
| | | | | | -0.0 |
| OMT2 | d(infl. swap) | 0.06 | d(EL) | -1.5 | -4.2 |
| 31 Aug to | | | d(ES) | -18.1 | -0.3 |
| 07 Sep 12 | -d(5y yields) | 0.88 | | | -0.6 |
| | | | | | -0.0 |

| Program | Econ. benefit | | Add. risk | | Ratio |
|---------------|---------------|-------|-----------|------|-------|
| VLTRO1 | d(infl. swap) | 0.10 | d(EL) | -1.4 | -7.3 |
| 16 Dec to | | | d(ES) | 0.8 | 12.8 |
| 30 Dec 11 | -d(5y yields) | 0.02 | | | 0.0 |
| | | | | | 0.0 |
| VLTRO2 | d(infl. swap) | -0.11 | d(EL) | 0.3 | -56.3 |
| 24 Feb to | | | d(ES) | 19.8 | -1.2 |
| 09 Mar 12 | -d(5y yields) | 1.00 | | | 5.0 |
| | | | | | 0.1 |

programs and credit operations are hard to compare in terms of ex-post risk efficiency. In the case of purchase programs, the policy impact includes the market's expectation about future purchases, while the associated credit risks only accumulate slowly over time. By contrast, the policy impact and credit risk of additional lending operations are more closely aligned. Table 3 presents the efficiency ratios of purchase programs and credit operations separately for this reason.

Table 3 reports four alternative 'risk efficiency ratios' for six major policy announcements during the euro area sovereign debt crisis; see Section 2. The policy impact could be as-

sessed in different ways. For example, impact could be proxied by the change in long-term inflation swap rates. This reflects the intuition that all monetary policy operations, including unconventional ones, are ultimately tied to the ECB’s single mandate of ensuring price stability, and that inflation was below target during the crisis. Alternatively, policy impact could be proxied by how much five-year benchmark bond yields decreased in stressed GIIPS countries (Greece, Ireland, Italy, Portugal, and Spain). This reflects the intuition that each policy operation was implemented during an escalating sovereign debt crisis. Both impacts are reported in Table 3. Additional risk could, similarly, be assessed in different ways. We consider the EL and the 99% ES for this purpose. The efficiency ratios in the final column of Table 3 are expressed in basis points per €1 bn (for changes in inflation swap rates), and in percentage points per €1 bn (for changes in GIIPS bond yields).

We focus on three findings. First, the OMT program was particularly risk efficient ex-post. Surprisingly, our risk efficiency ratio estimates can be negative. For instance, the two OMT-related announcements shifted long-term inflation expectations from deflationary tendencies toward the ECB’s target of close to but below two percent (beneficial) and decreased the five-year sovereign benchmark bond yields of stressed euro area countries (also beneficial), while *removing* risk from the central bank’s balance sheet. By contrast, the risk efficiency ratios associated with the SMP and VLTROs are not consistently negative.¹⁰

Second, the initial announcement of the SMP in 2010 appears to have been more risk efficient than its later cross-sectional extension in 2011. This is intuitive, as the second installment of the SMP focused on deeper and relatively less stressed debt markets. As a result, more bonds had to be purchased to have the same effect on liquidity risk premia. Since one key aim of the SMP was to add “depth and liquidity” to stressed government bond markets, it is natural to focus on its impact on GIIPS bond yields rather than a change in inflation swap rates. Overall, despite its benefits documented elsewhere (see, e.g., [Eser and](#)

¹⁰Scaling the SMP’s impact by the risk of total SMP exposures at the end of the program, instead of the exposures just one week after its announcement, would make the SMP appear even less risk-efficient compared to the other two programs. Scaling by maximum in-sample exposures could also be adopted for the VLTROs and OMT program. In this case, however, the efficiency ratios would remain unchanged as the VLTRO exposures materialize with their allotment in the same week, and no OMT interventions have taken place so far.

Schwaab, 2016), the SMP does not appear to have been a particularly risk-efficient policy ex post, particularly when compared to the two OMT announcements.¹¹

Finally, the first allotment of VLTRO decreased GIIPS bond yields and increased inflation without (initially) increasing the Eurosystem’s expected loss. By contrast, the second allotment was associated with both an increase in expected loss and 99% expected shortfall. As a result, the first allotment appears to have been more risk efficient than its second installment.

4.6 International risk spillovers

This section studies to what extent monetary policy announcements of *other* central banks can spill over to affect the Eurosystem’s risks. To this purpose we focus on three important policy announcements: the Federal Reserve’s announcement of “QE3” combined with forward guidance on short term interest rates on 13 September 2012, the “taper tantrum” following Fed communication on 22 May 2013, and the Swiss National Bank’s announcement to stop defending the peg of the Swiss franc to the euro on 15 January 2015. The first event is accommodative, while the second and third event are contractionary. Each of these had a major impact on domestic asset prices and volatilities at the time, and could in principle have impacted the Eurosystem’s risks.

Table 4 reports our risk estimates before and after these announcements. We focus on the Friday close before and after the announcement. Overall, other central banks’ policy announcements appear to have had only a minor impact on the Eurosystem’s risks. Changes in expected losses are typically below €1 bn. A potential exception is the Fed’s joint QE3 and forward guidance announcement in September 2012. At first glance, this announcement appears to have had a strong beneficial impact on the Eurosystem’s EL and 99% ES. The effect could also be attributable, however, to a lagged response to the ECB’s second OMT announcement one week earlier.

¹¹We also note the temporary increase in SMP-related expected losses around a Greek referendum in mid-2015 (see bottom panel of Figure 4), approximately five years after the bonds were acquired. While the economic benefits of the asset purchases accrued mostly on impact, the associated risks remain on the central bank’s balance sheet until the bonds mature.

Table 4: Portfolio credit risks around other central banks' announcements

Portfolio credit risks for different monetary policy operations around three policy announcements: *i*) the Federal Reserve's QE3 and forward guidance announcement on 13 September 2012; *ii*) the Federal Reserve's announcement of their withdrawal from the bond market on 22 May 2013, which resulted in the so-called "taper tantrum"; and *iii*) the announcement by the Swiss National Bank to unpeg the Swiss Franc from the Euro on 15 January 2015.

| Fed QE3 & FG, (following OMT2) | 07/09/2012 | | 14/09/2012 | | Δ EL | Δ ES(99%) |
|---|---------------------|---------------------|---------------------|---------------------|-------------|------------------|
| | EL | ES(99%) | EL | ES(99%) | | |
| SMP | 14.5 [14.4 14.5] | 51.5 [51.1 52.2] | 11.6 [11.6 11.7] | 27.7 [27.0 28.1] | -2.8 | -23.8 |
| MRO | 0.1 [0.1 0.1] | 2.0 [1.8 2.2] | 0.1 [0.1 0.1] | 1.9 [1.7 1.9] | -0.0 | -0.1 |
| LTRO<1y | 0.0 [0.0 0.0] | 1.0 [1.0 1.1] | 0.0 [0.0 0.0] | 0.8 [0.7 0.8] | -0.0 | -0.3 |
| LTRO1y | 0.0 [0.0 0.0] | 0.2 [0.1 0.2] | 0.0 [0.0 0.0] | 0.1 [0.1 0.1] | -0.0 | -0.0 |
| VLTRO3y | 0.5 [0.5 0.5] | 15.0 [14.8 16.1] | 0.5 [0.5 0.5] | 14.5 [13.9 15.2] | -0.0 | -0.6 |
| Total | 15.2 | 69.7 | 12.3 | 45.0 | -2.9 | -24.8 |

| Fed 'taper tantrum' | 17/05/2013 | | 24/05/2013 | | Δ EL | Δ ES(99%) |
|--------------------------------|------------------|---------------------|------------------|---------------------|-------------|------------------|
| | EL | ES(99%) | EL | ES(99%) | | |
| SMP | 1.2 [1.2 1.3] | 19.2 [18.9 19.5] | 1.0 [1.0 1.0] | 20.6 [20.3 21.1] | -0.3 | 1.4 |
| MRO | 0.2 [0.2 0.2] | 1.5 [1.4 1.5] | 0.2 [0.2 0.2] | 1.5 [1.5 1.6] | 0.0 | 0.1 |
| LTRO<1y | 0.0 [0.0 0.0] | 0.3 [0.3 0.3] | 0.0 [0.0 0.0] | 0.3 [0.3 0.3] | 0.0 | 0.0 |
| VLTRO3y | 0.2 [0.2 0.2] | 8.2 [8.1 8.3] | 0.2 [0.2 0.2] | 8.7 [8.4 8.7] | 0.0 | 0.5 |
| Total | 1.6 | 29.2 | 1.4 | 31.2 | -0.2 | 2.0 |

| SNB peg | 09/01/2015 | | 16/01/2015 | | Δ EL | Δ ES(99%) |
|----------------|------------------|---------------------|------------------|---------------------|-------------|------------------|
| | EL | ES(99%) | EL | ES(99%) | | |
| SMP | 2.2 [2.1 2.2] | 11.3 [11.3 11.5] | 2.0 [2.0 2.0] | 11.3 [11.3 11.4] | -0.2 | -0.0 |
| MRO | 0.0 [0.0 0.0] | 0.8 [0.8 0.9] | 0.0 [0.0 0.0] | 0.8 [0.8 0.8] | -0.0 | 0.0 |
| LTRO<1y | 0.0 [0.0 0.0] | 0.5 [0.5 0.5] | 0.0 [0.0 0.0] | 0.5 [0.5 0.5] | -0.0 | -0.0 |
| VLTRO3y | 0.0 [0.0 0.0] | 1.7 [1.6 1.7] | 0.0 [0.0 0.0] | 1.5 [1.4 1.5] | -0.0 | -0.2 |
| TLTRO | 0.0 [0.0 0.0] | 1.9 [1.8 1.9] | 0.0 [0.0 0.0] | 1.8 [1.8 1.9] | -0.0 | -0.1 |
| Total | 2.3 | 16.3 | 2.1 | 15.9 | -0.2 | -0.4 |

5 Conclusion

We introduced a tractable non-Gaussian framework to infer central bank balance sheet risks at a high (weekly) frequency. We applied our framework to a subset of Eurosystem monetary policy operations during the euro area sovereign debt crisis. Our results suggest that central banks can influence their credit risks, particularly when they act as lenders- and investors-of-last-resort during turbulent times. They can use this to their advantage when implementing monetary policy, and particularly try to obtain policy objectives in a risk efficient way. For instance, though increasing the amount of central bank liquidity in the financial system for monetary policy purposes can be achieved via both credit operations and asset purchases, we find that collateralized credit operations imply substantially less credit risks per unit of liquidity provision. It therefore seems preferable from a risk perspective to implement this part of monetary policy via credit operations rather than asset holdings, provided this is possible. Our results also suggest that such a policy implementation does not necessarily have to result in substantially increased central bank credit risks conditional on haircuts and eligibility criteria being set appropriately.

References

- Abadir, K. and J. Magnus (2005). *Matrix Algebra*. Cambridge University Press.
- Acharya, V. and S. Steffen (2015). The “greatest” carry trade ever? Understanding eurozone bank risks. *Journal of Financial Economics* 115, 215–236.
- Allen, F. and D. Gale (2000). Financial contagion. *Journal of Political Economy* 108 (1), 1–33.
- Azizpour, S., K. Giesecke, and G. Schwenkler (2017). Exploring the sources of default clustering. *Journal of Financial Economics*.
- Bagehot, W. (1873). *Lombard Street: A Description of the Money Market*. London: Henry S. King & Co.
- Bindseil, U. (2014). *Monetary policy operations and the financial system*. Oxford University Press.

- Bindseil, U. and L. Laeven (2017). Confusion about the lender-of-last-resort. *Vox EU*, www.voxeu.org.
- Blasques, F., S. J. Koopman, and A. Lucas (2015). Information theoretic optimality of observation driven time series models for continuous responses. *Biometrika* 102(2), 325–343.
- Böhme, H. (2014). The ECB is becoming Europe’s ‘bad bank’. *DW Business*, from 02.10.2014, obtained from <http://p.dw.com/p/1DPCF>.
- Brendel, M. and C. Pauly (2011). Europe’s Central Bad Bank: Junk bonds weigh heavy on ECB. *Der Spiegel*, on June 06, 2011.
- Bundesbank (2015). Bundesbank hat letzte Zahlung aus dem deutschen Lehman-Insolvenzverfahren erhalten. *press release dated 10 February 2015*.
- Carpenter, S. B., J. E. Ihrig, E. C. Klee, D. W. Quinn, and A. H. Boote (2013). The Federal Reserve’s balance sheet and earnings: A primer and projections. *Finance and Economics Discussion Series no. 2013-1*, Federal Reserve Board, January., 1–30.
- Christensen, J. H. E., J. A. Lopez, and G. D. Rudebusch (2015). A probability-based stress test of Federal Reserve assets and income. *Journal of Monetary Economics* 73, 26–43.
- Constâncio, V. (2011). Contagion and the European debt crisis. Keynote lecture at Bocconi University Milan on 10 October 2011.
- Creal, D., S. Koopman, and A. Lucas (2011). A dynamic multivariate heavy-tailed model for time-varying volatilities and correlations. *Journal of Business & Economic Statistics* 29(4), 552–563.
- Creal, D., S. Koopman, and A. Lucas (2013). Generalized autoregressive score models with applications. *Journal of Applied Econometrics* 28(5), 777–795.
- Creal, D., B. Schwaab, S. J. Koopman, and A. Lucas (2014). An observation driven mixed measurement dynamic factor model with application to credit risk. *The Review of Economics and Statistics* 96(5), 898–915.

- CreditMetrics (2007). CreditMetrics (TM) - Technical Document, RiskMetrics Group. www.riskmetrics.com/pdf/dnldtechdoc/CMTD1.pdf.
- Crosbie, P. and J. R. Bohn (2003). Modeling default risk. *Moody's KMV Company, available online.*
- Cruces, J. J. and C. Trebesch (2013). Sovereign defaults: The price of haircuts. *American Economic Journal: Macroeconomics* 5(3), 85–117.
- de Andoain, C. G., F. Heider, M. Hoerova, and S. Manganelli (2016). Lender-of-last-resort is as lending-of-last-resort does: Central bank liquidity provision and interbank market functioning in the euro area. *Journal of Financial Intermediation* 28, 32–47.
- De Pooter, M., R. Martin, and S. Pruitt (2018). The liquidity effects of official bond market intervention in Europe. *Journal of Financial and Quantitative Analysis* 53(1), 243–268.
- Del Negro, M. and C. A. Sims (2015). When does a Central Bank's balance sheet require fiscal support? *Federal Reserve Bank of New York Staff Reports* 701.
- Demarta, S. and A. J. McNeil (2005). The t copula and related copulas. *International Statistical Review* 73(1), 111–129.
- Diamond, D. W. and P. H. Dybvig (1983). Bank runs, deposit insurance, and liquidity. *The Journal of Political Economy* 91(3), 401–419.
- Drechsler, I., T. Drechsel, P. Schnabel, and D. Marques (2016). Who borrows from the lender of last resort? *Journal of Finance* 71(5), 1933–1974.
- Duffie, D., A. Eckner, G. Horel, and L. Saita (2009). Frailty correlated default. *Journal of Finance* 64(5), 2089–2123.
- Duffie, D., L. Saita, and K. Wang (2007). Multi-period corporate default prediction with stochastic covariates. *Journal of Financial Economics* 83(3), 635–665.
- ECB (2012). Technical features of Outright Monetary Transactions. ECB press release, 6 September 2012.
- ECB (2013a). ECB Annual Report. *European Central Bank, www.ecb.int*.

- ECB (2013b). ECB Monthly Bulletin, September 2013. *available at www.ecb.int*.
- ECB (2014). The determinants of euro area sovereign bond yield spreads during the crisis. ECB Monthly Bulletin article, May 2014.
- ECB (2015). The financial risk management of the Eurosystem's monetary policy operations. *European Central Bank, available at www.ecb.int*.
- Engle, R. (2002). Dynamic conditional correlation. *Journal of Business and Economic Statistics* 20(3), 339–350.
- Engle, R. and B. Kelly (2012). Dynamic equicorrelation. *Journal of Business & Economic Statistics* 30(2), 212–228.
- Eser, F. and B. Schwaab (2016). Evaluating the impact of unconventional monetary policy measures: Empirical evidence from the ECB's Securities Markets Programme. *Journal of Financial Economics* 119(1), 147–167.
- Fan, Y. and A. J. Patton (2014). Copulas in Econometrics. *Annual Review of Economics* 6, 179–200.
- Fratzscher, M. and M. Rieth (2018). Monetary policy, bank bailouts and the sovereign-bank risk nexus in the euro area. *Review of Finance, forthcoming*.
- Freixas, X., C. Giannini, G. Hoggarth, and F. Soussa (2004). Lender of last resort: What have we learned since Bagehot. *Journal of Financial Services Research* 18(1), 63–84.
- Ghysels, E., J. Idier, S. Manganelli, and O. Vergote (2017). A high frequency assessment of the ECB Securities Markets Programme. *Journal of European Economic Association* 15, 218–243.
- Giesecke, K. and B. Kim (2011). Systemic risk: What defaults are telling us. *Management Science* 57(8), 1387–1405.
- Giesecke, K., K. Spiliopoulos, R. B. Sowers, and J. A. Sirignano (2015). Large portfolio asymptotics for loss from default. *Mathematical Finance* 25(1), 77–114.
- Glosten, L. R., R. Jaganathan, and D. E. Runkle (1993). Relationship between the expected value and the volatility of the nominal excess return on stocks. *The Journal of Finance* 48, 1779–1801.

- González-Páramo, J.-M. (2011). The ECB’s monetary policy during the crisis. Closing speech at the Tenth Economic Policy Conference, Málaga, 21 October 2011.
- Gordy, M. (2000). A comparative anatomy of credit risk models. *Journal of Banking and Finance* 24, 119–149.
- Gordy, M. B. (2003). A risk-factor model foundation for ratings-based bank capital rules . *Journal of Financial Intermediation* 12(3), 199–232.
- Greenlaw, D., J. D. Hamilton, P. Hooper, and F. Mishkin (2013). Crunch time: Fiscal crises and the role of monetary policy. *Finance and Economics Discussion Series no. 2013-1, Federal Reserve Board, January.*, 1–30.
- Harvey, A. and A. Luati (2014). Filtering with heavy tails. *Journal of the American Statistical Association* 109(507), 1112–1122.
- Harvey, A. C. (2013). *Dynamic models for volatility and heavy tails*. Cambridge University Press.
- Heynderickx, W., J. Cariboni, W. Schoutens, and B. Smits (2016). The relationship between risk-neutral and actual default probabilities: the credit risk premium. *Applied Economics* 48, 4066–4081.
- Hill, B. (1975). A simple general approach to inference about the tail of a distribution. *The Annals of Statistics* 3(5), 1163–1174.
- Janicki, H. P. and E. S. Prescott (2006). Changes in the size distribution of U.S. banks: 1960-2005. *Federal Reserve Bank of Richmond Economic Quarterly* 92(4), 291–316.
- Joe, H. (2005). Asymptotic efficiency of the two-stage estimation method for copula-based models. *Journal of Multivariate Analysis* 94, 401–419.
- Koopman, S. J., A. Lucas, and M. Scharth (2016). Predicting time-varying parameters with parameter-driven and observation-driven models. *Review of Economics and Statistics* 98(1), 97–110.
- Koopman, S. J., A. Lucas, and B. Schwaab (2011). Modeling frailty correlated defaults using many macroeconomic covariates. *Journal of Econometrics* 162 (2), 312–325.

- Koopman, S. J., A. Lucas, and B. Schwaab (2012). Dynamic factor models with macro, frailty, and industry effects for u.s. default counts: the credit crisis of 2008. *Journal of Business and Economic Statistics* 30(4), 521–532.
- Krishnamurthy, A., S. Nagel, and A. Vissing-Jorgensen (2018). ECB policies involving government bond purchases: Impact and channels. *Review of Finance* 22(1), 1–44.
- Lando, D. (2003). *Credit risk modelling – Theory and applications*. Princeton University Press.
- Longstaff, F. A., J. Pan, L. H. Pedersen, and K. J. Singleton (2011). How sovereign is sovereign credit risk? *American Economic Journal: Macroeconomics* 3, 75–103.
- Lucas, A., P. Klaassen, P. Spreij, and S. Straetmans (2001). An analytic approach to credit risk of large corporate bond and loan portfolios. *Journal of Banking & Finance* 25(9), 1635–1664.
- Lucas, A., P. Klaassen, P. Spreij, and S. Straetmans (2003). Tail behaviour of credit loss distributions for general latent factor models. *Applied Mathematical Finance* 10(4), 337–357.
- Lucas, A., J. Schaumburg, and B. Schwaab (2018). Bank business models at zero interest rates. *Journal of Business & Economic Statistics*, in press.
- Lucas, A., B. Schwaab, and X. Zhang (2014). Conditional euro area sovereign default risk. *Journal of Business and Economic Statistics* 32(2), 271–284.
- Lucas, A., B. Schwaab, and X. Zhang (2017). Modeling financial sector joint tail risk in the euro area. *Journal of Applied Econometrics* 32(1), 171–191.
- Massacci, D. (2016). Tail risk dynamics in stock returns: Links to the macroeconomy and global markets connectedness. *Management Science* 63(9), 3072–3089.
- McNeil, A. J., R. Frey, and P. Embrechts (2015). *Quantitative Risk Management: Concepts, Techniques and Tools*. Princeton University Press.
- Merton, R. (1974). On the pricing of corporate debt: The risk structure of interest rates. *Journal of Finance* 29(2), 449–470.
- Nelson, C. R. and A. F. Siegel (1987). Parsimonious modeling of yield curves. *Journal of Business* 60, 473–489.

- Oh, D. H. and A. J. Patton (2018). Time-varying systemic risk: Evidence from a dynamic copula model of cds spreads. *Journal of Business & Economic Statistics*, to appear.
- O’Kane, D. (2008). *Modelling single-name and multi-name credit derivatives*. Wiley Finance.
- Reis, R. (2015). Different types of central bank insolvency and the central role of seignorage. *Journal of Monetary Economics* 73, 20–25.
- Rochet, J.-C. and X. Vives (2004). Coordination failures and the lender of last resort: Was Bagehot right after all? *Journal of the European Economic Association* 2(6), 1116–1147.
- Rogers, J. H., C. Scotti, and J. H. Wright (2014). Evaluating asset-market effects of unconventional monetary policy: a multi-country review. *Economic Policy* 29(80), 749–799.
- Rothenberg, T. (1971). Identification in parametric models. *Econometrica* 39(3), 577–91.
- Salmon, F. (2009). Recipe for disaster: The formula that killed Wall Street. *Business Magazine*, on 23 February 2009.
- Sharpe, W. F. (1966). Mutual fund performance. *Journal of Business* 39 (S1), 119–138.
- Thornton, H. (1802). *An enquiry into the nature and effects of paper credit of Great Britain*. Hatchard, London.
- Vasicek, O. (1987). Probability of loss on loan portfolio. *Working paper, Moody’s Analytics Corporation*.
- Wessel, D. (2013). How jawboning works. *Wall Street Journal*, January 9.
- Zhang, X., D. Creal, S. Koopman, and A. Lucas (2011). Modeling dynamic volatilities and correlations under skewness and fat tails. *Tinbergen Institute Discussion Paper*.

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