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SYSTEMIC RISK SPILLOVERS ACROSS THE EURO AREA

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ABSTRACT

The high degree of financial contagion across the Euro area during the sovereign debt crisis highlighted the importance of systemic risk. In this paper we employ a Global VAR (GVAR) model to analyse the systemic risk spillovers across the Euro area and to assess their role in the transmission of monetary policy. The results indicate a strong interconnectedness among core countries and also that peripheral economies have a disproportionate importance in spreading systemic risk. A systemic risk shock results in economic slowdown domestically and causes negative spillovers to the rest of the EMU economies. To examine how monetary policy impacts systemic risk, we incorporate high-frequency monetary surprises into the model. We find evidence of the risk-taking channel during normal times, whereas the relationship is reversed in the period of the ZLB with expansionary shocks to result in a more stable financial system. Our findings indicate that the signalling channel is the main driver of this effect and that the initiation of the QE program boosts the economic activity but results in higher systemic risk. Finally, our results suggest that spillovers play an important role in the transmission of the monetary policy and that there is evidence of significant heterogeneity amongst countries' responses with core countries to benefit the most from changes in monetary policy.

Keywords: Systemic risk ; Global VAR model ; Eurozone; High-frequency monetary policy shocks

JEL classification: C32 ; E44 ; F36 ; F45

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1 Introduction

In the aftermath of the recent financial crisis the international transmission of financial stress has been a focal point of research and policy analysis. In 2011, Christine Lagarde, the then Managing Director of the IMF, argued that international financial exposures are *"transmitting weakness and spreading fear"* across markets and countries. The collapse of systemically important financial institutions highlighted the importance of monitoring the risk spillovers among countries. The cross-country financial linkages, and not the trade relationships, were the main stress transmission mechanism in both the US subprime mortgage and the Eurozone debt crises (Grant, 2016). The European monetary union (EMU) is a special case because on the one hand there is significant heterogeneity amongst countries and on the other hand, there is high financial integration. The latter, despite all the direct and indirect benefits, could lead to more costly crises, since economic activity is exposed to both domestic and regional (or global) financial shocks (Kose et al., 2009 and Park & Mercado, 2014).

Due to the strong financial contagion in the euro banking system, a country level systemic risk event may become aggravated and lead to a widespread negative effect on the union-wide financial stability (Allen et al., 2011).[3] According to the joint report of Financial Stability Board (FSB), International Monetary Fund (IMF) and Bank for International Settlements (BIS), 2009, systemic risk is defined as the disruption of the flow of financial services, caused by an institution or by part of the financial system, that could have an adverse effect on the real economy. The primary objective of this paper is to examine the systemic risk spillovers across the Euro area. To capture systemic risk, we adopt the $\Delta CoVaR$ measure[4], which we then incorporate into a GVAR model that allows us to capture cross-country spillovers. The $\Delta CoVaR$ methodology introduced by Adrian & Brunnermeier (2016)[5] and we extend it to the country level by employing an aggregate version for a market capitalization portfolio of the financial institutions for each country. $\Delta CoVaR$ is one of the most widely used measures[6] and its main advantage is that is based on micro-data, so it is more informative than country-level measures that are based on government securities.[7]

The evidence suggests that Italy, Spain and Germany are the most systemically important countries in the monetary union. However, shocks in some of the smaller countries (Ireland) can also have a sizeable impact at the union level. We observe that core countries (namely Germany, France, the Netherlands, Belgium, Austria and Finland) are highly interconnected but their spillovers to the rest of the union members are low. On the other hand, the systemic risk shocks in the peripheral countries (Italy, Spain, Greece, Portugal and Ireland) have a considerably larger effect on all the

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[3] Brutti & Sauré (2015) argue that cross-border financial exposures were an important transmission channel and they argue that a fragile foreign banking system could constitute a liability to the rest of the union members.

[4] For robustness purposes, we also use as an alternative indicator, the Composite Systemic Stress Index ($CISS$) provided by the ECB database.

[5] Numerous studies focus on the estimation of systemic risk, however there is no commonly accepted measure in the literature. Bisias et al. (2012) present an extended survey of the different measures grouped by their features. Each group captures a different aspect of systemic risk, such as contagion, volatility, liquidity, macroeconomic environment and institution-specific measures (see also Benoit et al., 2017).

[6] According to Google scholar, the $\Delta CoVaR$ methodology has been referenced by more than 2500 papers.

[7] For the estimation we include financial firms beyond the banking sector such as insurance companies, real estate firms and financial services institutions. See also the recent work from Jin & De Simone (2020) expands the analysis of the euro systemic risk beyond the banking sector by focusing on investment funds.

EMU members. An important aspect of the definition of systemic risk is that it has potential adverse consequences for the real economy (Adrian & Brunnermeier, 2016). Therefore, we examine the impact of systemic risk shocks on economic activity. The results show that an unexpected increase in systemic risk leads to a slowdown in the real economy domestically and causes negative spillovers to the rest of the EMU economies.

Finally, we examine the impact of monetary policy on systemic risk and we quantify what percentage of the response can be attributed to risk spillovers. This one of the first papers to analyse separately the effect of conventional and unconventional monetary policy shocks on financial stability[8] and the findings present some novel policy implications. For the identification approach, we employ the high-frequency shock series provided by Altavilla et al. (2019).[9] Our results indicate that the impact of monetary policy is not homogeneous across time and that, during the ZLB, the relationship is being reversed; expansionary shocks result in a decrease in systemic risk. We then decompose and analyse the effect of the different transmission channels of unconventional monetary policy: interest rate (target), expectations (signalling/forward guidance) and QE. The findings indicate that the effect is heterogeneous across the different channels. An accomodative signalling shock mitigates systemic risk, whereas policy rate and QE shocks have the opposite effect. The findings also suggest that there is significant heterogeneity amongst countries with core economies to benefit the most in terms of growth and financial stability. In addition, we provide evidence that the spillover channel plays an important role on the transmission of monetary policy shocks. Lastly, our results indicate that the relationship is bidirectional and that the ECB systematically reacts to systemic risk variation with expansionary asset purchasing programs or by lowering the policy rate.

The paper is related to the literature of financial contagion in the euro area. Contagion is defined as the phenomenon of a negative shock spreading rapidly across the financial system (Covi et al., 2019).[10] There are different methodological approaches in the literature to capture interconnectedness among firms or countries. Firstly, there are market data-based (systemic risk) measures that capture the contagion by exploiting high frequency data on stock markets and Credit Default Swaps (CDS). For instance, Billio et al. (2012) introduce various alternative econometric techniques to capture connectedness such as principal component analysis (PCA) and Granger causality.[11] More recently, Covi et al. (2019) propose a Contagion Mapping (CoMap) methodology to analyse the degree of contagion following an exogenous shock via counterparty credit and funding risks.[12] Our approach differs from the other papers in the literature since we estimate the systemic risk at the country level and we capture the contagion by analysing (exogenous) shocks to the other member countries or regions.

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[8] See also the recent work by Kabundi & De Simone (2020).

[9] In the benchmark model, we include the shadow rate by Wu & Xia (2016), which however is not widely acceptable as an appropriate identification for monetary policy shocks. For that purpose use the high-frequency identification which constitutes a more informative external instrument based on the response of government assets minutes after the announcements of the monetary policy decisions.

[10] Contagion is defined as the increase in probability of a crisis domestically after the occurrence of a crisis in a foreign country (Kaminsky & Reinhart, 2000 and Grant, 2016). In addition Forbes & Rigobon (2002) define contagion as is a significant increase in cross-country linkages after a shock to one country.

[11] On the latter, there is the more recent work of Gómez-Puig & Sosvilla-Rivero (2014) focused on the EMU.

[12] Hüser (2015) provides a survey of the literature on network analysis, which can be used to assess the structure of the financial system and the degree of interconnectedness among firms.

From a methodological point of view, this paper belongs to the literature of GVAR modelling. A systemic event could be caused endogenously from within the financial system or by an exogenous shock (see *ECB report*, 2009). In order to examine these exogenous shocks and the international transmission of systemic risk shocks across the Euro area, we employ a GVAR model that captures cross-country interdependencies with monetary policy being the common factor in all examined countries. This is the first paper, to the best of our knowledge, that applies the GVAR framework to the concept of systemic risk. The framework is a common approach to model the global economy and the financial linkages amongst countries. For instance, Galesi & Sgherri (2009) provide evidence of strong comovements of financial markets in 27 developed and emerging European economies. They find considerable cross-country linkage across Europe but also significant exposure to US shocks. Similarly, Dovern & van Roye (2014) incorporate a Financial Stress Index (FSI) in the GVAR model and they show that a shock in the US has a significant impact on the global markets. They also find that co-movements of financial stress across countries increases during the period of a major crisis. Other papers also analyse the financial spillovers by focusing on the transmission of liquidity and credit shocks (see Chudik & Fratzscher, 2011 and Eickmeier & Ng, 2015).

The GVAR literature has also been extended to the Euro area and it has been applied to various contexts such as fiscal spillovers (Hebous & Zimmermann, 2013 and Ricci-Risquete & Ramajo-Hernández, 2015), trade (Bussière et al., 2009) and house prices (Vansteenkiste & Hiebert, 2011). Another strand of the euro area GVAR literature focuses on the euro area financial contagion although not for the concept of systemic risk. Bicu & Candelon (2013) apply the model based on balance sheet data and sectoral CDS premia, to estimate the interconnectedness of the Eurozone banking sectors. They find significant spillovers in between sovereign and banking risk measures, domestically but also across borders.[13] Caporale & Girardi (2013) also find a strong link between euro area spreads and they show how the fiscal imbalances lead to financial imbalances. All of the papers in the euro area GVAR literature argue that there are significant spillovers in terms of economic activity and financial stability. To measure the degree of interconnectedness, we quantify the impact of country-level systemic risk shocks to the union aggregate level.

The paper also contributes to the literature of monetary policy and systemic risk. Much of the existing literature supports that low interest rates lead to excessive risk taking by financial institutions, the so-called risk-taking channel. Various studies have covered different indicators of risk-taking activity and they find evidence for the transmission channel. Neuenkirch & Nöckel (2018) and Dell'Ariccia et al. (2014) use data from lending surveys and argue that low interest rates result to greater bank risk-taking in the EMU and the US respectively. Similar findings are presented by Delis & Kouretas (2011) who use a large panel dataset related bank-lending channel and by Dell'Ariccia et al. (2017) that have access on data on US banks' internal ratings on loans to businesses. However, there is no extended literature in terms of financial stability and the "systemic risk-taking channel". Kabundi & De Simone (2020) identify this gap in the literature and analyse the systemic risk responses following conventional and unconventional monetary policy shocks identified using sign restrictions and they find evidence of the risk-taking channel. In addition, Faia & Karau (2019)

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[13] Castrén et al. (2010) employ a GVAR model to assess the exposure of euro sector credit quality, measured by the expected default frequency, to domestic and global macroeconomic shocks.

include systemic risk measures in a VAR model and shadow rates as instruments of monetary policy. The present similar results but also evidence of a price puzzle, which indicates that the identification of the monetary shock is problematic. This is an issue that the high-frequency identification approach overcomes and also allows us to decompose the effect of the different forms of policy and transmission channels. Kapinos (2020) highlights the importance of analysing different transmission channels separately. He constructs a shadow nominal interest rate for the US and he finds that expansionary monetary news shocks lead to a decrease in systemic risk, unlike monetary surprises. Our findings shed light into the heterogeneous effect of monetary policy on systemic risk across different time periods and policy tools.

The remainder of the paper proceeds as follows. In Section 2, we present the $\Delta CoVaR$ methodology and the construction of the systemic risk index. Section 3 describes the GVAR methodology. In Section 4, we discuss the empirical findings of systemic risk shocks at the regional and euro area level. Section 5 focuses on the relationship between systemic risk and monetary policy. We present the responses of systemic risk following a monetary policy shock, but also the reaction of the central bank after an unexpected increase in systemic risk. Finally, Section 6 concludes.

2 Measuring Systemic Risk

A number of different systemic risk measures have been proposed in the literature, however there is not a commonly accepted method. For our analysis, we apply one of the most popular systemic risk methodologies, $\Delta CoVaR$, proposed by Adrian & Brunnermeier (2016).[14] The $\Delta CoVaR$ method is a widely-used measure of systemic risk and has been applied in a variety of contexts. For instance, Bernal et al. (2014) apply the method for the different financial sub-sectors and they find that the financial services and the banking sector are more systemically important than the insurance firms in the Eurozone, whereas the latter is the systemically riskiest financial sector in the United States for the same period of time.[15] Similarly, Black et al. (2016) measure the systemic importance of the euro area banking institutions[16] and their results suggest that since the 2011 sovereign debt crisis Italian and Spanish banks increased their marginal contribution to the aggregate systemic risk.[17] In a similar context, Reboredo & Ugolini (2015) apply the $\Delta CoVaR$ methodology for the European sovereign debt markets and they find that the markets were coupled but after the offset of the crisis, stressed economies, such as Portugal, present a significant increase in systemic risk. More recently, Faia & Karau (2019) analyse the impact of US and Euro area monetary policy shocks on systemic risk by employing two different versions of $\Delta CoVaR$.

The method builds on the concept of Value-at-Risk (VaR), which is arguably one of the most widely used risk measures for investors and policymakers. However it cannot be used for macroprudential purposes since it does not take into

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[14] We also employ the $CISS$ measure constructed by Holló et al. (2012) as an alternative measure of systemic risk. The main findings are provided in the Appendix, Figure A3 and Table A5 and more detailed results are available upon request.

[15] Dungey et al. (2020) employ the $\Delta CoVaR$ methodology to examine the systemic importance of US industrial firms.

[16] They construct a distress premium based on the $\Delta CoVaR$ methodology.

[17] Varotto & Zhao (2018) examine the characteristics of banking institutions and their systemic importance. They support that banks size is a primary driver of the most common systemic risk indicators. For the estimation of systemic risk they employ various measures including $\Delta CoVaR$ and MES.

consideration the links amongst firms. To capture this aspect of risk, Adrian & Brunnermeier (2016) develop the concept of $CoVaR_q^{s|i}$, defined as the VaR_q of the entire financial system when the firm i is under distress (returns equal to its VaR_q). The VaR, at q% confidence level,of an institution is defined by:

$$P(R^i \leq VaR_q^i) = q, \tag{1}$$

Similarly, $CoVaR$ is defined as:

$$P(R^s \leq CoVaR_q^{s|i} \mid R^i = VaR_q^i) = q, \tag{2}$$

In equation (2), R^i and R^s denote the returns of institution i and of the financial system index respectively.[18] The systemic importance of an institution can be measured by focusing on its marginal contribution to the system's risk. For this purpose they take the difference between the $CoVaR_q$ with the one estimated in normal times (q = 0.5). $\Delta CoVaR$ captures the risk spillovers from a firm across the financial system.

The mathematical definition for $\Delta CoVaR$ of firm i is:

$$\Delta CoVaR_q^i = CoVaR_q^{s|R^i=VaR_q} - CoVaR_q^{s|R^i=VaR_{0.5}}. \tag{3}$$

To estimate the dynamic $\Delta CoVaR$ we assume that the variation of asset returns is based on a set of state variables. These variables are not considered to be factors of systemic risk, but they can capture time variation in the conditional moments of the returns. For this purpose, we use the change in the three-month government bond yield, the yield curve, the liquidity spread and returns of the market index.[19]

The estimation of the dynamic version is described in the steps below:

1. Dynamic VaR: $VaR_t^i(q) = \hat{a}_q^i + \hat{c}_q^i S_{t-1}$
2. Dynamic Conditional VaR: $CoVaR_t^{s|i}(q) = \hat{a}_q^{s|i} + \hat{b}_q^{s|i} VaR_t^i(q) + \widehat{c^{s|i}} S_{t-1}$
3. Systemic risk: $\Delta CoVaR_t^{s|i}(q) = CoVaR_t^{s|i}(q) - CoVaR_t^{s|i}(0.5)$

In the first step we run the quantile regression of the returns of each individual firm with the country's state variables (S_{t-1}) to calculate the estimates $\hat{a}_q^i$ and $\hat{c}_q^i$. By replacing the values back to the first equation, we obtain the dynamic representation of the VaR^i. Similarly in the second step, we compute the dynamic $CoVaR^i$ by running the regression of the tail of the returns of the system with the VaR^i of the examined firm and the state variables. Finally, to obtain the systemic risk measure we take the difference between the $CoVaR$ at the left tail ($q\%$) of the distribution of the returns and the one estimated at the median.

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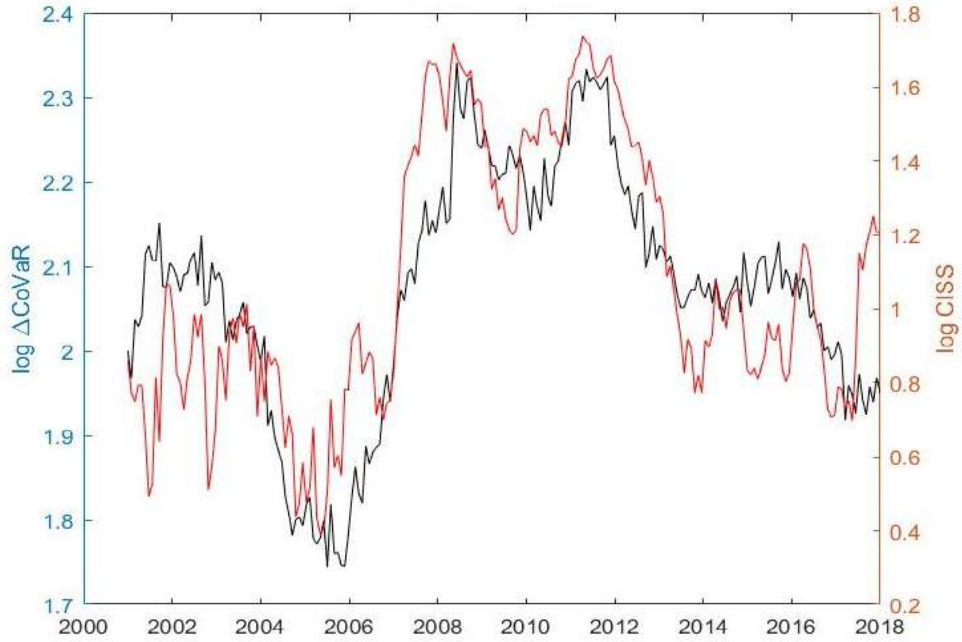
[18] The paper by Adrian & Brunnermeier (2016) estimates firms' returns based on growth rates of market-valued total financial assets. In our approach since not all the financial firms provide high frequency data, the estimation is based only on Price and Market Capitalization data.

[19] In the Appendix, Tables A1 and A2, report the variables used in the model and in the estimation of the systemic risk index.

For the cross-country analysis, we estimate the level of systemic risk at the country level by introducing an aggregate version of the $\Delta CoVaR$ measure. Therefore, we compute the systemic risk for a market capitalization weighted portfolio of financial firms including banks, financial services, real estate and insurance companies.[20]A similar approach has been adopted by Rodríguez-Moreno & Peña (2013) for a portfolio of European and US stocks. The estimation of systemic risk is at the national and not the European level to isolate potential cross-border externalities at this stage[21]. For comparison purposes, we transform the $\Delta CoVaR$ into a systemic risk index with 2002m1 being the base year. The following graph compares the logarithmic transformations of the euro area index and the $CISS$ index from the ECB database. Although the estimation methods are different[22], we observe that they provide very similar results.

Figure 1: Systemic risk in the Euro Area



Notes: The figure reports the systemic risk estimation for the euro area based on two alternative measures. The black line illustrates the $\Delta CoVaR$ country-level index and the red line the Composite Systemic Stress Index ($CISS$) provided by Eurozone database. Both measures are expressed in log values. The examined period is 2001m1-2018m12.

Figure 2 illustrates the systemic risk index (in logarithms) for the eleven examined economies. We observe that the Great Recession in 2008 and the sovereign debt crisis in 2012 both led to a considerable increase in systemic risk. For individual countries, we observe two patterns. Core countries affected mostly by the 2008 global financial crisis. Systemic risk was also high for all peripheral countries, which however were more exposed to the debt crisis and they present their peak value at 2012.

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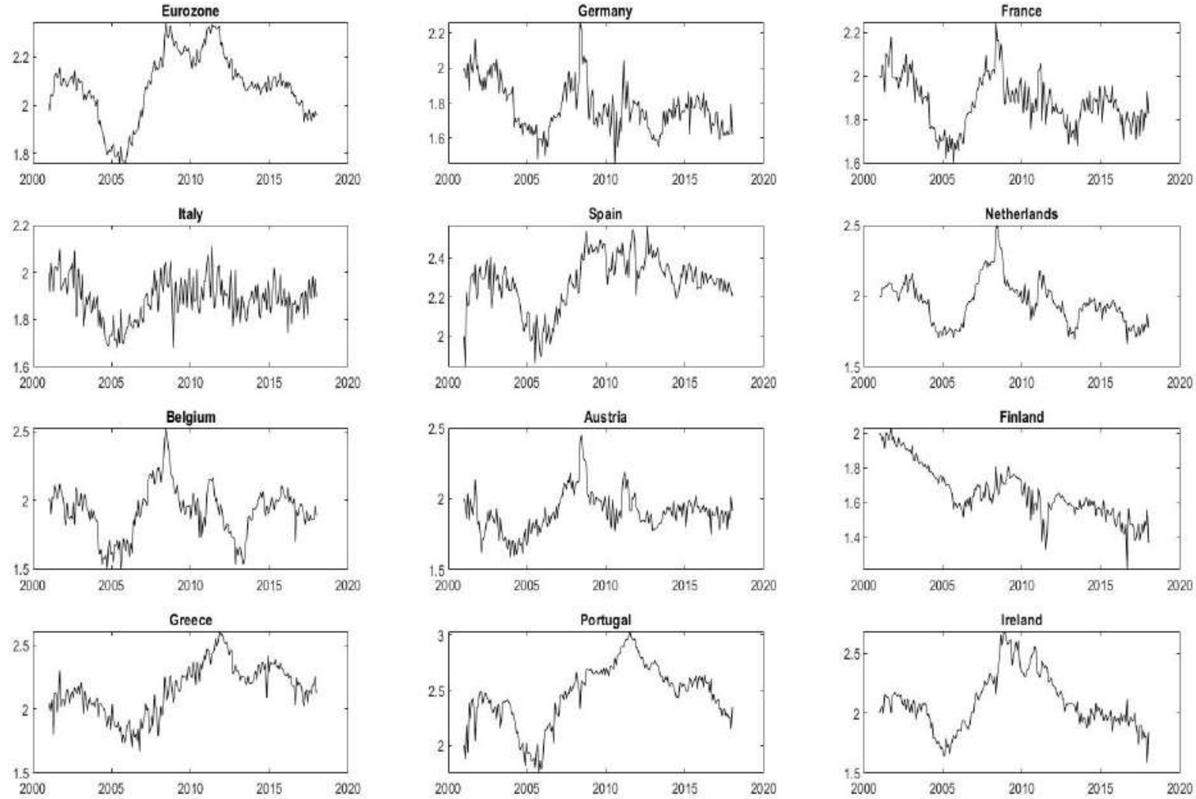
[20] The data series are provided by Datastream and for the selection of the financial institutions we used the constituents of the countries' DS Financials Index. Fo robustness, we use weights based on a 6 month moving-average Market Capitalization and the systemic risk indices is identical.

[21] See Buch et al. (2019) for the differences and the drivers of euro area systemic risk at the national and European level.

[22] The estimation of $CISS$ is based on basic portfolio theory and five stress sub-indexes from the money, bond, equity and foreign exchange markets. See Holló et al. (2012) for the detailed estimation of the index.

Figure 2: Systemic risk in the Euro Area economies



Notes: The figure reports the log$\Delta CoVaR$ index (base year: 2001) for the eleven examined euro area economies and the euro area. The estimation is based on Price and Market Capitalization data, provided by Datastream, for a portfolio of domestic financial institutions such as banks, insurance, real estate and financial services companies. The examined period is 2001m1-2018m12.

3 The GVAR framework

The GVAR methodology was introduced by Pesaran et al. (2004) and extended by Dees et al. (2007). The structure of the model takes into consideration the international financial spillovers across the Euro area. This is the first paper, to the best of our knowledge, that includes systemic risk measures to account for financial stability. We incorporate eleven Eurozone countries and three macroeconomic variables for each country (Y) ; logGDP[23], Prices (logHICP) and the systemic risk index. Each country (indexed by $i = 1, ..., 11$) is modelled as a small open economy with an error-correction model that includes domestic and foreign variables. The mathematical representation of the VAR model with exogenous variables (VARX (p, q)) is:

$$Y_{i,t} = a_i + \sum_{j=1}^{p} A_{i,j} Y_{i,t-j} + \sum_{j=0}^{q} B_{i,j} Y^*_{i,t-j} + \sum_{j=0}^{q} C_{i,j} X_{t-j} + \epsilon_{i,t} \tag{4}$$

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[23] We estimate the monthly GDP based on Chow-Lin interpolation using the quarterly GDP data provided by Eurostat and the (monthly) industrial production index provided by FED of St.Louis.

In equation (4) $A_{i,j}$ is a matrix of coefficients related to the lags of the domestic variables and $B_{i,j}$ and $C_{i,j}$ are the matrices of coefficients for foreign and global variables respectively. Country specific shocks (ϵ_i) are assumed to be serially uncorrelated mean zero with a non-singular covariance matrix. To capture spillovers across the monetary union, each national economy is also affected by a GDP-weighted matrix[24] of foreign variables (Y^*) as presented in Equation (5). To ensure consistency, the foreign variables are treated as weekly exogenous, which implies that each country is treated as a small economy with the domestic macroeconomic variables to have no long-run impact to foreign variables, allowing however short-run feedback effects. Therefore, the international spillovers could have a short-term effect but not a long-term impact on the examined domestic economy.

$$Y^*_{i,t} = \sum_{i \neq j}^{N=11} w_{i,j} Y_{j,t} \qquad , with \sum_{i \neq j}^{N=11} w_{i,j} = 1 \tag{5}$$

Monetary policy is the common factor (X_t) for all the countries and can affect the real economy directly and indirectly through spillovers from the other euro area members. It is modelled as a function of the aggregate output, prices and systemic risk ($\tilde{Y}$) to capture the ECB's response to macroeconomic developments in the union.

$$X_t = b_x + \sum_{j=1}^{p_x} D_j X_{t-j} + \sum_{j=1}^{q_x} \tilde{Y}_{t-j} + u_{x,t} \tag{6}$$

In the first stage, we estimate each individual country's VARX separately (see Equation 4). We select the lag order based on the Akaike Information Criterion (AIC) and we impose a limit to the number of lags for the foreign variables ($q_{max} = 1$) to secure model stability.[25] The results are robust for different lag selection based on the Schwarz Bayesian criterion (SBC).[26] In the second step, all the country models are stacked in to create the GVAR model where all the variables are endogenous. Specifically, Z_t is a vector of all variables included (Y_t, Y_t')':[27]

$$A_{i,0} Z_{i,t} = a_0 + \sum_{j=1}^{p} A_{i,j} Z_{t-j} + \epsilon_{i,t} \tag{7}$$

We then use the weights (w) that capture bilateral exposure across countries and we define G = $A_i w_i$ to obtain:

$$G_0 Y_{i,t} = a_0 + \sum_{j=1}^{p} G_j Y_{t-j} + \epsilon_{i,t} \tag{8}$$

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[24] Using GDP weights is the norm for the GVAR literature. The estimation is based on the average quarterly GDP data provided by Eurostat for the period 2001-2018 (see Appendix, Table A3). The results are similar if we use trade weights instead (see Appendix, Table A5).

[25] We also set the lags of the feedback equation equal to one with alternative lag selections to provide similar results. Similar assumptions have been made by Caporale & Girardi (2013). In the Appendix, Table A4 presents the optimal ordering based on the Akaike information criterion (AIC).

[26] See Appendix Table A5, which presents the sensitivity analysis for alternative lag selection criteria.

[27] We neglect the global variables (X_t) for simplicity and we only use the domestic lags (p) since by construction are always greater than the foreign variables lags (q).

Multiplying both parts of equation (8) by Go^{-1}, we obtain the autoregressive representation of the model:

$$Y_{i,t} = b_0 + \sum_{j=1}^{p} F_j Y_{t-j} + \eta_{i,t} \tag{9}$$

where $b_0 = Go^{-1}a_0$, $F_j = Go^{-1}G_j$ and η_t = $Go^{-1}\epsilon_t$

The dynamic properties of the model are analyzed by using Generalized Impulse Response Functions (GIRFs), introduced by Koop et al. (1996) and adapted to VAR framework in Pesaran & Shin (1998). We follow Smith & Galesi (2017) SGIRF methodology, who identify structural shocks in a country by using the triangular approach by Sims (1980). Country shocks ($\epsilon_{i,t}$) are assumed to be uncorrelated with the shocks in the common variable equation (u_t). Alternative ordering of the variables should not affect the outcome as long as the contemporaneous correlations remain unrestricted. For a more detailed description of the model, we refer to Smith & Galesi (2017) and Chudik & Pesaran (2016).[28]

4 Systemic Risk Shocks

In this section we present the empirical findings about the impact of systemic risk spillovers across the Eurozone.[29] We employ monthly data for the period 2001 to 2018 to take advantage of the fact that all the countries had adopted the common currency and they appertain to the ECB's monetary authorities' regulations.[30] Initially, we analyse the response of a country's systemic risk following a euro area aggregate shock, in other words when all countries experience an unexpected one standard error (s.e.) increase in the level of risk. In addition, we analyse the impact of systemic risk shocks at a country and a euro-regional level. This is one of the first papers to look at cross-country spillovers, whereas most of the existing literature analyzes the monetary union as a whole or it only focuses on the largest economies. Finally, an important aspect of systemic risk is that it has (in theory) a negative effect on the real economy. Therefore, we analyse this relationship by examining the impact of an unexpected increase in the euro area systemic risk on output and also the role of spillovers in the transmission of the shock.

4.1 Euro Area Shocks

To investigate the degree of exposure of Eurozone economies to the rest of the union members, we present the SGIRFs following a union-wide systemic risk shock. In Figure 3, the red line depicts the dynamic response of systemic risk at the country level to an one standard error increase in the euro area's risk level. The results indicate that there is an unambiguous strong contagion amongst Eurozone economies. The transmission of the shock has immediate effect on the union members' financial systems and it fades out 10 periods after its occurrence.

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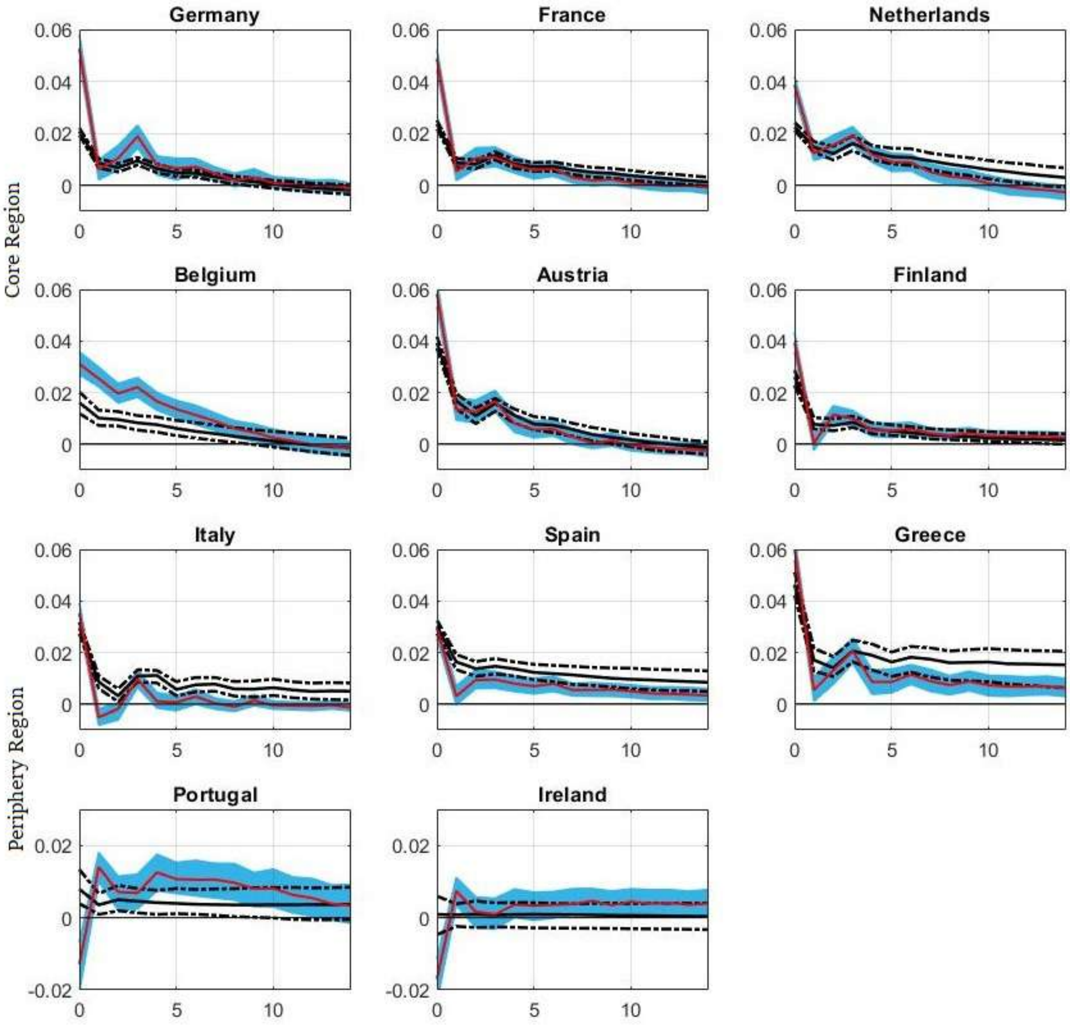
[28] For the estimation of the model, we use the Matlab codes from the GVAR Toolbox by Vanessa Smith.

[29] For the identification of the systemic risk shock, we use the standard Cholesky decomposition. Dovern & van Roye (2014) adopt a similar approach to identify FSI shocks in the GVAR framework.

[30] In the Appendix, Table A1 describes the data series and their sources.

Figure 3: Euro Area Systemic Risk Shock: SGIRFs of Systemic risk



Notes: The figure reports the SGIRFs of systemic risk in the 11 examined euro area economies, following for a union-wide systemic risk shock. The country level model includes 3 domestic variables; logGDP, logHICP and the log$\Delta CoVaR$ index and the shadow rate as a global variable to capture the monetary policy. The identification of the shock is based on the Cholesky decomposition and the sampling period is 2001m1-2018m12. The red line is the standard responses of the domestic systemic risk and the black line is the SGIRFs when we mute the spillover effect. The differences between the two indicate the impact of the direct contagion effect amongst euro area economies. The lag selection is based on the Akaike information criterion (AIC). The shaded area represents the 68% confidence level, which is based on 200 bootstrap iterations.

We then decompose the effect into the domestic and the spillover channel.[31] The black line represents the systemic risk responses following a euro area risk shock when we mute the vector of foreign variables. The difference between the two lines depicts the effect of the spillover channel. The degree of interconnectedness is considerably higher in the core countries, which are more exposed to systemic risk shocks at the union level. Moreover, a sizeable percentage of the variation of the SGIRFs can be attributed to the spillover channel as being observed by the difference between the responses with and without the foreign variables. The responses of the countries in the periphery are also significant but

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[31] According to Allen et al. (2011), one of the important costs of financially integrated markets is that domestic economies are exposed to foreign credit shocks.

smaller in magnitude on average. The stronger impact amongst peripheral countries is being observed in Greece, which was vulnerable probably due to the government debt crisis (see Grammatikos & Vermeulen, 2012). The responses in this region are driven mostly by domestic factors, whereas the exposure to core economies and the spillover effect are weak or insignificant.[32] Therefore, our results support that the main transmission channel of systemic risk is running from peripheral to core countries.[33] Financial stress spillovers is one of the main disadvantages of the high degree of financial integration in the monetary union, which in this case appears to be less beneficial for core economies.[34]

4.2 Euro-Regional and Country Shocks

The GVAR framework allows us to examine the systemic importance of individual countries. Table 1 illustrates the peak systemic risk responses following regional and country specific shocks.[35]A shock in the two euro area regions has similar effect for the euro area level of systemic risk. However, peripheral countries account only for one third of the union's GDP, based on our sample. This indicates that they are disproportionately systemically important in comparison to core countries. In addition, in line with the previous findings, we observe that spillovers are stronger from periphery to core economies (2.70) than from core to the periphery (0.66). If we focus at the country level, we observe that Italy and Spain are the most systemically important countries in the euro area.[36] The largest economy in the monetary union, Germany, is also systemically important, especially across the core countries.[37] We observe that core countries are highly interconnected with a country level shock having a strong impact on the rest of the economies of the region but a weak effect on peripheral economies. On the other hand, peripheral economies' shocks affect both regions. It is worth noticing that small economies appear to be also systemically important. Portugal and Ireland account only for 1.8% and 2.1% of Eurozone's GDP[38] respectively, but their contribution to aggregate systemic risk is significant. Finally, the impact of systemic risk shocks originating in Greece is relatively low at the union level. Therefore the findings support that Greece is more exposed to the union rather than the other way round.

Overall, the evidence suggests that peripheral countries are a significant source of systemic risk for the euro area. The need for monitoring the spillovers from the periphery has been documented before in the literature. According to Constancio (2012), contagion from the peripheral countries has contributed to union-wide financial stress, especially after July 2011 and the sovereign debt crisis. He also highlighted the strong degree of stress transmission from Italy and Spain to Greece, Portugal and Ireland's government bonds. Similarly, Caporale & Girardi (2013) analyse the spillovers

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[32] Although the transmission of systemic risk from core countries is weak, the empirical evidence in Table 1 suggest that there are risk spillovers from the other peripheral economies.

[33] Gorea & Radev (2014) find evidence of an active contagion transmission channel from the euro area periphery towards its core.

[34] As depicted in Figure 3, the increase in systemic risk is more than double when we take into consideration the spillover effect in countries as Germany and France.

[35] In the vast majority of the cases, the transmission of the systemic risk is immediate and the peak response is being observed in the first period after the occurrence of the shock.

[36] To quantify the systemic importance of a country, we look at the increase of the euro area aggregate systemic risk index following a country level shock as depicted in the first column of Table 1.

[37] Eller et al. (2017) apply a GVAR model to examine the international impact of a fiscal policy shock in Germany. Similarly to our findings they found that mostly core economies affected by the positive cross-border spillovers. The effect is positive but weaker for Periphery. They also recognize that the transmission of the shock is through the financial channel.

[38] The percentage is estimated based on the average quarterly GDP for the examined period 2001-2018.

in terms of borrowing cost from fiscal imbalances in the euro area economies. They find that negative externalities from Italy and other peripheral countries could lead to crowding out effects for the euro area consumption and an increase in the government bond rates in all countries and regions.

Table 1: Country and Regional Systemic Risk Shocks

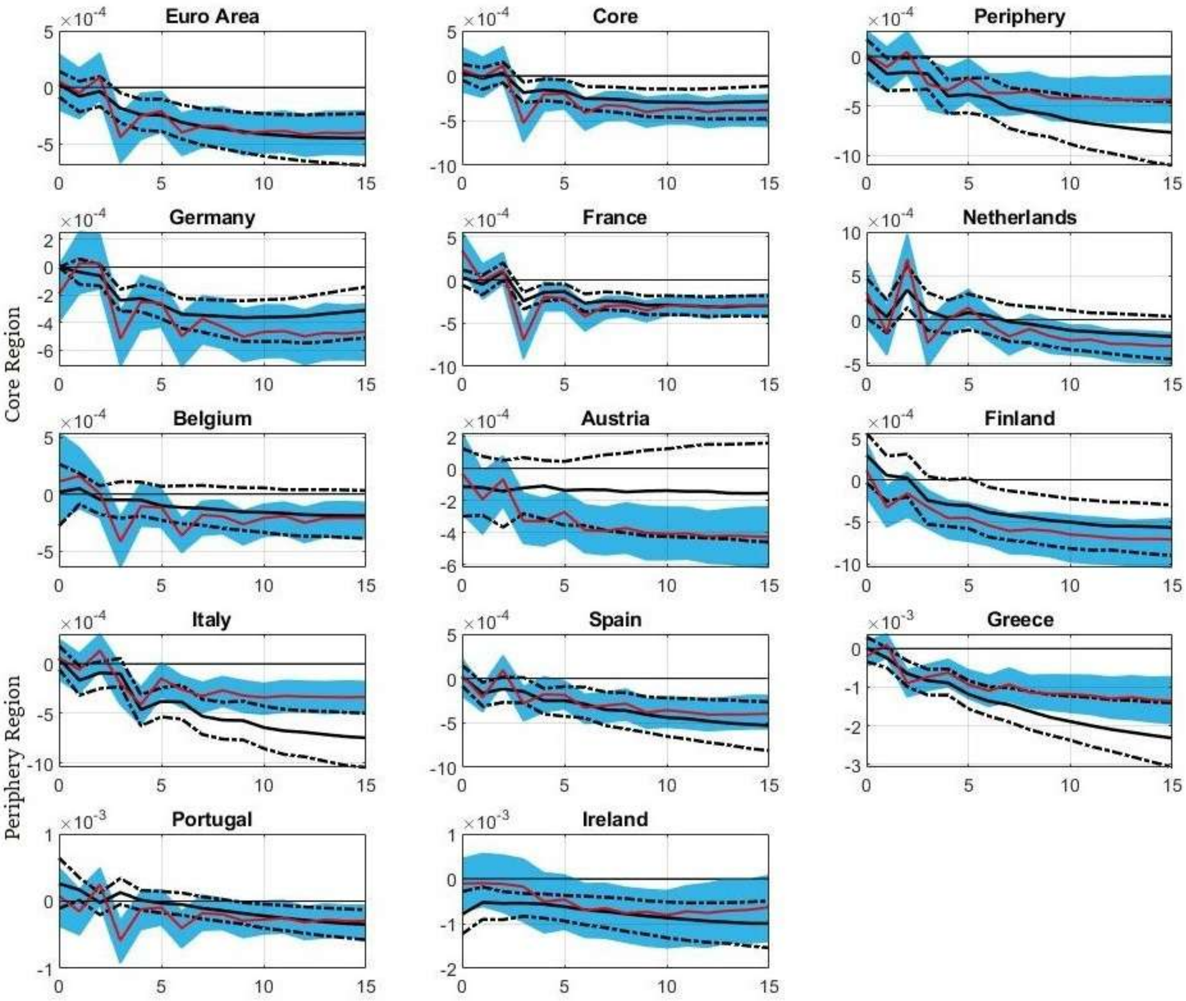
	Systemic Risk SGIRFs $(\times 10^{-2})$		
Regional Shocks	Euro Area	Core	Periphery
Core	2.92**	●	0.66**
Periphery	2.99**	2.70**	●
Country Shocks	Euro Area	Core	Periphery
GER	1.70**	3.04**	-0.32**
FRA	1.57**	2.21**	0.34**
NDL	1.43**	1.76**	0.79**
BEL	1.40**	1.68**	0.87**
AUS	0.81**	1.00**	0.43**
FIN	0.27**	0.36**	0.09**
ITA	2.93**	2.60**	3.57**
ESP	1.99**	1.72**	2.50**
GRE	0.45**	0.44**	0.48**
POR	0.67**	0.65**	0.70**
IRE	0.67**	0.65**	0.70**

Notes: The table illustrates the peak (positive) regional SGIRF for systemic risk following an one standard error increase in the systemic risk at regional and country level. For the identification of the shock we apply the Cholesky decomposition with the ordering being GDP, Prices and systemic risk. For the vast majority of the cases, the impact of systemic risk is immediate and the peak response is being observed in the first period after the shock occurs. Notation of ** and * indicate statistically significant results at 90% and 68% respectively.

4.3 Impact of systemic risk shocks on economic activity

The 2008 financial crisis highlighted how a systemic event, such as the collapse of Lehman Brothers, can substantially affect real economic activity. Monitoring financial stress has become a major concern for regulators especially since the Great Recession and the European sovereign debt crisis. The relationship between financial stress and business cycles is widely-documented in the literature. Bloom (2009) uses a structural framework to analyse how uncertainty affects economic activity. His result suggest that an uncertainty shock reduces investments and hiring and consequently leads to a sharp recession. Dovern & van Roye (2014) employs a GVAR model with Financial Stress Indexes (FSI) to capture the variation in financial markets. Their results indicate that US and global financial stress shocks have a lagged adverse effect on economic activity worldwide. Van Roye (2014) focuses on the euro area and most specifically on Germany and finds that when the stress index exceeds a certain threshold level, an increase in financial stress has a significant negative effect on economic activity.[39]

Figure 4: Euro Area Systemic Risk Shock: SGIRFs of GDP



Notes: The figure reports the responses of logGDP in the euro area regions and the 11 examined economies, following for a union-wide systemic risk shock. The country level model includes 3 domestic variables; logGDP, logHICP and the log$\Delta CoVaR$ index and the shadow rate as a global variable to capture the monetary policy. The identification of the shock is based on the Cholesky decomposition and the sampling period is 2001m1-2018m12. The red line is the standard responses of the domestic systemic risk and the black line is the SGIRFs when we mute the spillover effect. The differences between the two indicate the impact of the direct contagion effect amongst euro area economies. The lag selection is based on the Akaike information criterion (AIC). The shaded area represents the 68% confidence level, which is based on 200 bootstrap iterations.

To examine the relationship between the stress in financial markets and economic activity, we analyse the responses of output following an unexpected increase in the aggregate level of systemic risk in the Eurozone. In the first row of Figure 4, we present the response of output for the euro area and the two euro-regions. Our empirical findings indicate that increases in systemic risk result in a persistent slowdown in economic activity. At the country level, we observe low

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[39] Similar evidence is provided by Holló et al. (2012) and Evgenidis & Tsagkanos (2017), who support that in periods of high stress, the impact of a stress shock on industrial production is significantly stronger.

variation across both regions and homogeneous responses. Greece and Ireland which both needed bailout programs to stabilize their economies, suffer the most severe drop in GDP following a union-wide systemic risk shock. In addition, we present the responses when there is no direct spillover effect amongst countries to examine the significance of financial contagion on output responses.[40] In the majority of the countries, the spillover effect plays an important role and results in deeper recessions. It is worth noticing that in some core economies, namely the Netherlands, Belgium and Austria, when we mute the foreign variables from the country equation, the impact of systemic risk shocks on output is insignificant or even positive. On the other hand, Italy, Greece and Ireland present a more significant drop if we don't take into consideration the spillover effect, which indicates that domestic factors drive the responses. The findings are in line with the previous empirical evidence which indicates that core economies are exposed to systemic risk spillovers from the Periphery, whereas the latter is more affected by the domestic macro-financial environment. The sizeable adverse effect on the economic activity highlights the need for close monitoring of systemic risk at the country level but also the financial contagion across the union members.

In summary, we provide evidence of significant systemic risk transmission across the euro area economies. This degree of financial contagion is a strong mechanism through which domestic shocks are propagated to other economies. However, as noted by Allen et al. (2011), spillovers should not undermine the rationale of financial integration in the euro area since the gains from diversification and risk sharing outweight potential costs. In addition, they support that some of the costs arisen from the contagion effects can be attributed to the lack of policy coordination and they can be avoided. In the next section, we examine how central banks can use different tools to mitigate systemic risk and also the role of the spillovers in the effectiveness of monetary policy.

5 Monetary Policy and Systemic Risk

Central banks have a pivotal role in supervising and supporting financial stability. An extensive amount of literature has focused on the linkage between monetary policy and financial stress, however in the period of the ZLB the empirical evidence is mixed. In this section, we examine if this relationship is homogeneous across countries but also across time. Borio & Zhu (2012) is one of the first papers to introduce the concept of the risk-taking channel by analysing the impact of monetary policy on agents' risk perception. They support that accommodative monetary policy encourages more risk-taking behavior of financial institutions. Similar findings are presented by Neuenkirch & Nöckel (2018) who argue that euro area expansionary monetary policy shocks lead to a decrease in the banks' lending standards and consequently to an increase in systemic risk. More recently, Faia & Karau (2019) find evidence of the risk-taking channel in the US, whereas in the euro area there is evidence of the price puzzle and the systemic risk responses are insignificant.[41]

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[40] See the black line with the dotted confidence interval in Figure 4.

[41] They apply a Panel VAR to analyse the effect of monetary policy shocks and they use both Wu & Xia (2016) and Krippner's (2013) shadow rate to capture unconventional policies.

On the other hand, another strand of the literature argues that expansionary unconventional monetary policy supported the financial system during the crisis (see Gambacorta et al., 2014 and Boeckx et al., 2017).[42] Kapinos (2020) finds that expansionary news shocks result in lower systemic risk during the zero lower bound period. In light of these results, we proceed by dividing the sample period into two sub-periods with the cutting point being the month that the shadow rate becomes negative.[43] For the first sample period, our results below are in line with the risk-taking channel, therefore a monetary expansion leads to greater systemic risk. However, when we focus on the period of the ZLB and of the unconventional monetary policies, the relationship is being reversed and expansionary policy shocks lead to systemic risk reduction.

5.1 Identification of Monetary Policy Shocks

5.1.1 *Cholesky decomposition and shadow rate*

To capture changes in the monetary policy stance, we use the shadow rate by Wu & Xia (2016), which is being modeled as a common (global) variable.[44] The domestic variables include the GDP, prices and systemic risk[45] which is estimated at a country level. Figure 5 illustrates the euro area aggregate responses following an unexpected one standard error decrease in the shadow rate. When we focus on the first sub-period, we find evidence of a price puzzle with an expansionary monetary policy shock to result in lower prices and in a drop in economic activity. In the second sub-period, the price puzzle disappears and an expansionary monetary policy leads to inflationary pressure and a boost in economic activity.

As far as the systemic risk is concerned, in the first period the evidence supports the risk-taking channel of monetary policy. Interestingly, the relationship changes over time and becomes positive in the second period, when the adoption of expansionary policies at the ZLB, led to a considerable reduction of the euro area systemic stress. According to our findings, the response peaks five periods after the shock occurs. We also observe significant heterogeneity amongst the countries' responses in line with the literature on the Euro area monetary policy shocks (see Burriel & Galesi, 2018). The impact is stronger for core countries that drive the response of the union-wide variables.[46] On the other hand, the responses of the peripheral countries are negative but insignificant, which indicates that the region has not benefited by the UMPs in terms of financial stability.[47] This could explain our previous findings that periphery is a considerable source of risk for the rest of the union. In Section 5.3 we will discuss in detail the heterogeneity of regional responses following a monetary policy shock.

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[42] Gambacorta et al. (2014) and Boeckx et al. (2017) use the assets of the ECB balance sheet as an instrument of monetary policy and they argue that these policies do not increase the volatility of the financial system (VIX) or systemic stress (CISS) respectively.

[43] The specific sub-samples are being selected so we can analyse the impact of the monetary policy before and after the period of the Zero Lower Bound.

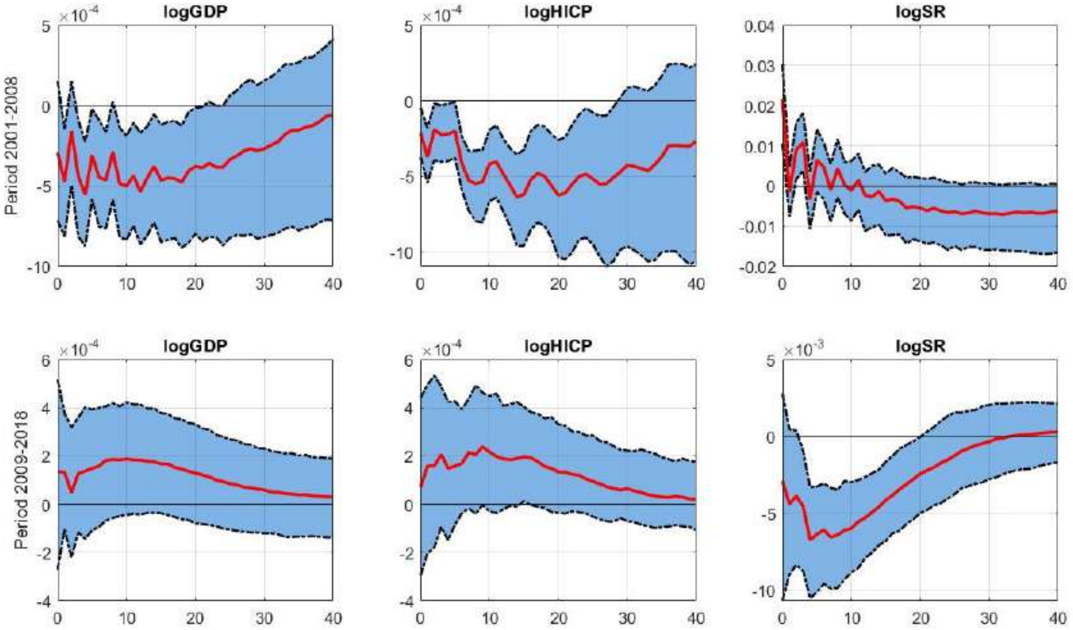
[44] IMF (2016) and Colabella (2019) also use shadow rates and Cholesky decomposition to identify monetary policy shocks in a GVAR model.

[45] All the data series have been transformed using the logarithms.

[46] See Appendix, Figure A1 for the regional responses.

[47] The results are based on the Akaike lag selection criterion. For robustness purposes, we also include the responses based on SBC. The main responses are presented in the sensitivity analysis Table A5.

Figure 5: Monetary Policy Shocks: Shadow Rate



Notes: The figure reports the SGIRFs following an expansionary monetary policy shock. The monetary policy shock is defined as one s.e. decrease in the shadow rate and the identification strategy is based on the Cholesky decomposition. The response variables which are being presented are the euro area aggregate GDP, price level and systemic risk in rows one to three respectively. The first row refers to the sub-period before 2009 and the other to the second sub-period until 2018. The lag selection is based on the Akaike information criterion (AIC). The shaded area represents the 68% confidence level, which is based on 200 bootstrap iterations.

5.1.2 *High-Frequency Monetary Surprises*

The presence of the price puzzle indicates that the identification of a monetary policy shock through the Cholesky decomposition is problematic (see Sims, 1992). To address this issue we follow the new strand of the literature that uses the central bank's announcements to identify monetary policy shocks. For that purpose, we use data from Altavilla et al. (2019) who construct a Euro Area event-study database of monetary surprises (EA-MPD) by measuring the asset price changes following a policy announcement window. By looking at the press release window and the very short-end of the yield curve, they identify the 'target' surprises following the work of Gurkaynak et al. (2004).

The estimation is based on a factor model where M is a matrix that includes changes in yields of risk-free rates at different maturities[48] and F stands for the latent factors which are being estimated by principal component analysis.

$$M^j = F^j \Lambda^j + e^j \tag{10}$$

where j = {press release or conference release}

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[48] More specifically, they include the changes in 1, 3, and 6-month and 1, 2, 5, and 10-year yields. For maturities longer than 2 years, the German sovereign yields are being used as a proxy for the euro due to lack of data at this time period.

The main advantage of this methodology is that it identifies more precisely monetary surprises by capturing new policy tools, such as Forward Guidance and Quantitative Easing (QE).[49] This is one of the first papers that incorporates high-frequency shocks into the GVAR model.[50] For that purpose, we follow Plagborg-Møller & Wolf (2019) who show that the structural estimation of a proxy SVAR model could be carried out by using the monetary policy shock series ordered first in a standard recursive VAR model. Therefore, we include the externally identified shock in the model as an exogenous variable that has a contemporaneous effect on the macroeconomic variables and systemic risk. Similar analysis has been carried by Miranda-Agrippino (2016) and Jarociński & Karadi (2020) who also incorporate high-frequency surprises ordered first in a VAR model. Since all the variables in the model are also expressed in levels and not in differences, in line with Coibion (2012), we use the cumulative shock series to identify the policy shocks. Similarly to Barakchian & Crowe (2013), we let the series to take values equal to zero for months with no announcements.[51]

Figure 6 presents the responses following an expansionary monetary policy shock for the two sub-periods we have split the sample into. By incorporating the high-frequency shocks into the model the price puzzle disappears. For the first period, an accommodative policy shock results to an increase in GDP and prices. In accordance with the results shown above, the regional and country responses are not homogeneous. The impact is stronger in core countries, whereas the peripheral economies present insignificant responses. The consequence of the monetary expansion is the increase in systemic risk in both regions, which is line with the "risk-taking channel".

Regarding the second period, the findings are similar to those obtained using the shadow rate shocks as shown in the previous section. In both cases, output and price level increase following a monetary expansion, with only the results for core economies being statistically significant. With respects to systemic risk, the empirical evidence provide novel policy implications. A negative shock in the policy instrument decreases significantly following the shock. In terms of regional responses, peripheral economies benefit less from the policy changes than core countries. The main difference in the responses between the two different identifications of the monetary policy shock in the second sub-period, is the timing of the responses. The high-frequency instrument analysis leads to an immediate decrease of systemic risk, whereas in the case of the shadow rate shocks the lowest point was reached after 5 periods. However, this was expected due to the construction of the 'target' surprises which affect asset prices only in the short term. The results are robust to alternative measures of systemic risk such as the CISS (see Appendix, Figure A3).

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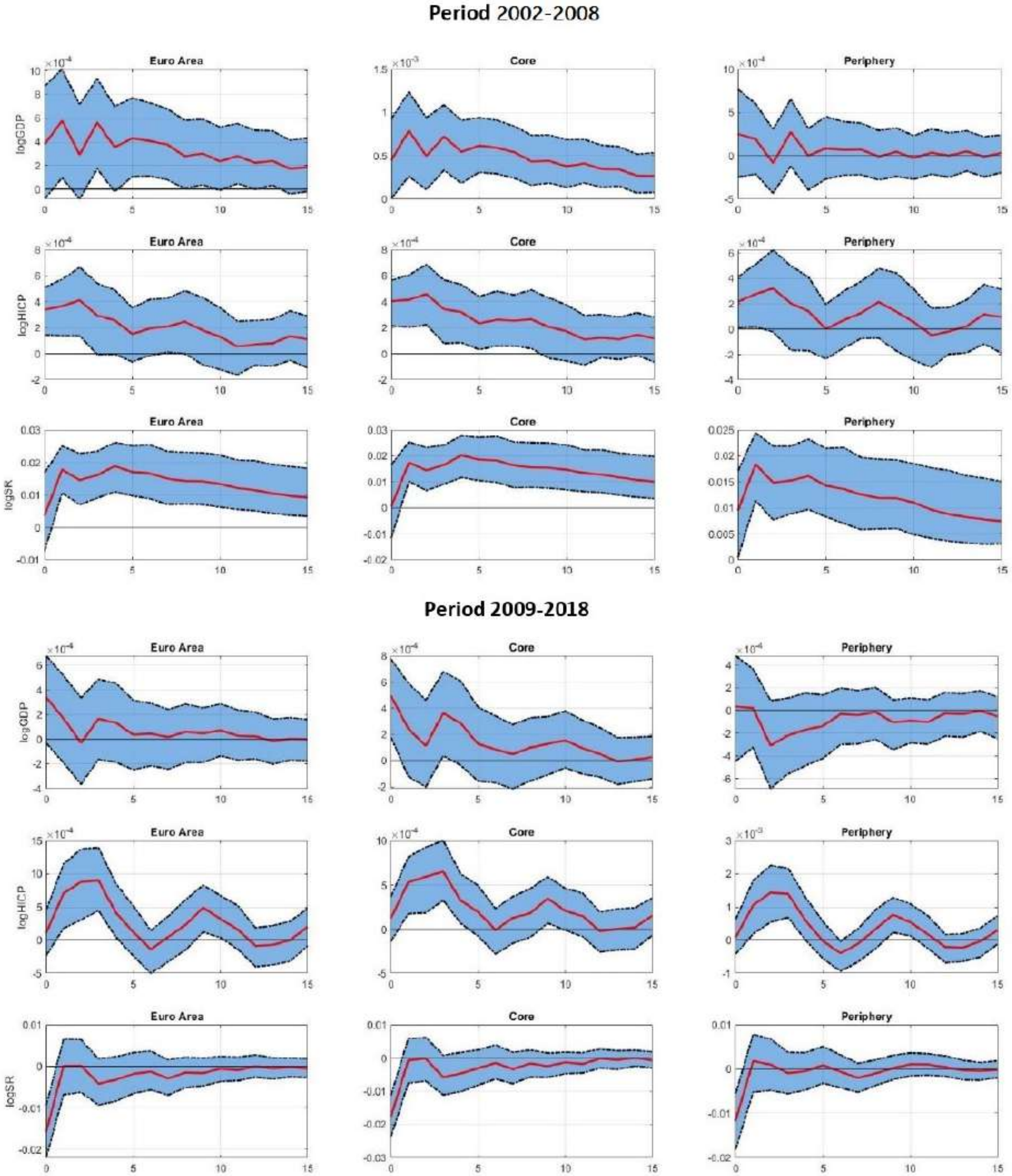
[49] Goodhead (2021) uses the EA-MPD surprises in a Proxy SVAR to study the effect of forward guidance and yield curve compression surprises on Euro Area macro-financial variables.

[50] In a similar context, Alzuabi et al. (2020) use monetary policy shocks series constructed based on the shocks series by Romer & Romer (2004) for the US economy in the GVAR framework.

[51] They also use the cumulative shock series ordered both first and last and they present similar results for both specifications. As a robustness check, we run the model with the shock series and the 3 month euro area government bond as the monetary policy tool and we obtain similar results.

Figure 6: Monetary Policy shock: High-Frequency Identification



Notes: The figure reports the SGIRFs of systemic risk following an expansionary monetary policy shock. The shock is defined as one s.e. decrease in the exogenous cumulative target surprises series provided by Altavilla et al. (2019) and the identification strategy is based on the Cholesky decomposition. The first three rows present the responses of the sub-period 2002-2008 and the last three of the second sub-period until 2018. The responses include the aggregate euro area and two regions; core and periphery and three variables are logGDP, logHICP and systemic risk. The lag selection is based on the Akaike information criterion (AIC). The shaded area represents the 68% confidence level, which is based on 200 bootstrap iterations.

5.2 Transmission channels of monetary policy

By employing a high-frequency identification strategy we can decompose the effect of (unconventional) monetary policy into different transmission channels. For that reason, we use data from Altavilla et al. (2019) who extract the surprises from the ECB's press conference window. The first two factors are 'timing' and 'forward guidance', which capture the signalling channel in the short run and medium run respectively. They also isolate the 'QE surpises' by using the method of Swanson (2017) in the post-2014 period. Following their work, we incorporate one instrument at a time[52] to extrapolate each component separately and to examine how they impact systemic risk and the macroeconomic environment. The process is identical to the 'target' surprises as the cumulative shock series are modelled as exogenous variables in the GVAR model structure. In line with Altavilla et al. (2019), we focus on the period 2008m1-2018m8 for the 'timing' and 'forward guidance' shocks and the period 2014m1-2018m8 for the 'QE' shock.

The results have interesting policy implications. The impact of the conference window shocks on systemic risk changes over time. In the first part of the period there was only the expectations channel, but since 2014, QE dominates the press conference window surprises. Our results indicate that the expectation channel has a positive relationship with systemic risk for the entire period.[53] In other words, expansionary monetary policy announcements lead to a systemic risk reduction. The effect of the 'timing' shock, that refers to the short-term expectations, is stronger in the first periods and it results to an increase in output and a decrease in systemic risk, but also causes inflationary pressures. The 'forward guidance' factor presents similar results leading to a decline in systemic risk a year after the shock. However, the results on output and price level are insignificant and in some cases negative in the short-run. It's worth noticing though that in both channels we observe considerable heterogeneity across regions. The euro area systemic risk response is predominately driven by core economies, whereas peripheral countries experience in some cases higher systemic risk, inflationary pressures and weak growth.[54]

On the period after 2014 and the initiation of QE, the results are significantly different. If we estimate the impact of the target surprises and shadow rate shocks for the 2014m1-2018m12 period, we observe that the decrease in systemic risk is considerably lower. The findings from the 'QE' shocks indicate the asset purchases program led to an increase in the aggregate systemic risk. The last row in Figure 7 presents the responses following a 'QE' shock. In terms of output, the shock results to a positive but statistically insignificant effect in most of the countries. Systemic risk is increasing across the euro area with the highest responses observed in core economies providing evidence of the risk-taking channel similarly to expansionary shocks in normal times. It is worth mentioning that at the same time period expansionary forward guidance decreases systemic risk but the effect is partially cancelled out by the impact generated by the asset purchases program.

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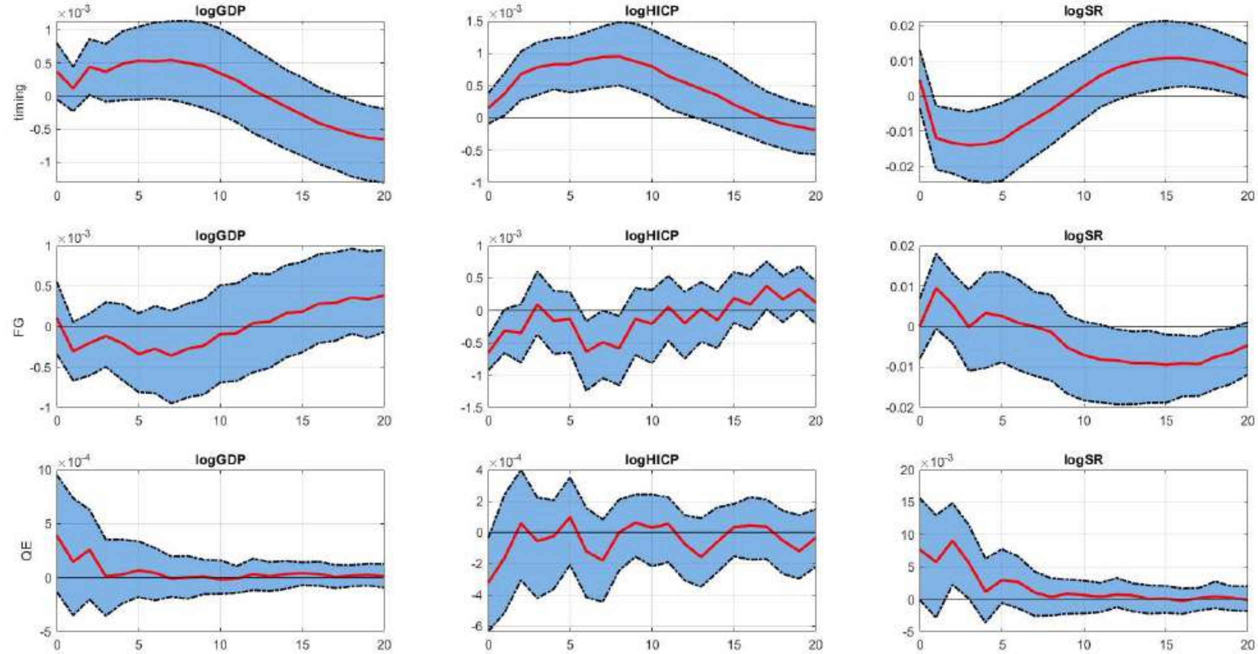
[52] The results for the timing and the QE factor are similar if you include all the instruments in the same model, whereas the responses of the Forward Guidance shocks change but they statistically insignificant for most of the cases.

[53] The results are similar for the sub-periods 2001m1-2007m12 and 2014m1-2018m8.

[54] See Appendix, Figure A2 for the regional responses and Section 5.3 for the analysis of the asymmetry of responses following a monetary policy shock.

Figure 7: Monetary Policy shocks: Transmission Channels



Notes: The figure reports the SGIRFs of systemic risk following a monetary policy shock defined as one s.e. decrease in the exogenous cumulative timing, Forward Guidance and QE surprises series provided by Altavilla et al. (2019). The identification strategy is based on the Cholesky decomposition. The examined period is 2008m1-2018m12 for the first two shock series and 2014m1-2018m8 for the latter. The lag selection is based on the Akaike information criterion (AIC) . The shaded area represents the 68% confidence level, which is based on 200 bootstrap iterations.

Our findings indicate that the initiation of the QE program creates a trade-off for the ECB between economic growth and financial stability. In 2016, Mario Draghi, the then president of the ECB, recognized this adverse effect and he clarified that is not the goal of the ECB to ensure the profitability of any particular institutions. More specifically, QE programs can reduce the profitability of financial institutions such as insurance companies which are exposed to the decline in interest rates. In our sample insurance companies account for 26% of the firms' Market Capitalization, therefore we expect that the asset purchase program will result to a deterioration of the financial sector index.[55]

Part of the literature also emphasizes the negative impact of QE on financial stability. Gern et al. (2015) and Claeys & Leandro (2016) support that prolonged expansionary monetary policies encourage risk-taking beyond the socially desirable. Additionally, it may result in asset prices disconnecting from the fundamentals and fueling asset price bubbles, which can trigger a banking crisis in the medium or long term. In conclusion, the different channels of unconventional forms of monetary policy present mixed results regarding their impact on systemic risk. Despite the increase in systemic risk caused by the adoption of the QE program, expansionary UMP shocks (signalling and target/policy rate surpises) appear to be an important tool for mitigating systemic risk.[56]

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[55] In Appendix, Table A2 presents the composition of the portfolio of financial firms that are being used for the systemic risk index.

[56] Similarly to Claeys & Darvas (2015) who support that the overall benefits of the UMP outweight the potential risks.

5.3 Heterogeneity of Responses to Monetary Policy Shocks

The findings of the analysis so far suggest that the impact of monetary policy changes is not homogeneous amongst regions and countries. As depicted in Figure 6, core euro area countries benefit the most from monetary policy changes in terms of economic growth and financial stability. A negative shock results to a sizeable boost in economic activity in core economies in both sub-periods. On the other hand, peripheral countries present positive but insignificant responses. This is not the first paper that focuses on the monetary policy's transmission asymmetries. Georgiadis (2015) apply a GVAR model for the euro area to analyse the impact of monetary policy on output and inflation. He finds significant heterogeneity amongst countries driven by structural characteristics such as the industry structure[57] and more specifically the percentage of output associated with sectors sensitive to interest rate but also labor market variables.[58] In addition, Burriel & Galesi (2018), in a euro-area GVAR model, find union-wide significant asymmetries in the transmission of monetary policy with countries with less fragile banking system to benefit the most.[59] Other characteristics such as the ease of doing business or the low level of GDP per capita result in higher output gains.

However the literature is limited regarding the potential asymmetries of ECB's monetary policy on the financial variables. Table 2 illustrates the peak systemic risk country responses following an expansionary monetary policy shock to the shadow rate and the cumulative target surprises for both sub-periods. In the first period, the results are similar across the euro area with both regions experiencing higher systemic risk after an unexpected decrease in the policy rate. However, as discussed in the previous sections, the benefits in terms of economic growth of the expansion were observed mostly in the core countries. Regarding the period after 2009, there is significant heterogeneity amongst the Eurozone. Core countries such as France, Austria and Germany present a considerable decrease in systemic risk, whereas peripheral economies such as Greece and Ireland experienced a small drop followed by a strong increase in risk level. The empirical evidence underlines the asymmetric transmission of monetary policy across the monetary union, not only in terms of output, but also with regards to financial stability. Similar pattern is being observed in the conference window shocks, where timing and Forward Guidance result in mitigating systemic risk primarily in core economies.[60] Finally, QE shocks results in an increase in systemic risk in all the countries, with only core economies to present statistically significant responses.[61]

Overall, the results support that monetary policy, especially in the period of the ZLB, affect primarily the Core region. According to the aforementioned literature, the reasons that could explain the heterogeneity of responses is the structure of the financial system and the domestic macroeconomic environment, since core economies were not affected

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[57] Galesi & Rachedi (2019) construct a New-Keynesian model and they also attributed heterogeneity of responses on the industry structure.

[58] Tillmann & Hafemann (2020) provide evidence of significant heterogeneity in the response of unemployment and stock market across the Euro Area following an aggregate shock.

[59] Ciccarelli et al. (2013) suggest that the monetary transmission mechanism depends on the financial fragility of the sovereigns, banks, firms and households. They also support that the effect of common monetary shock on GDP growth is heterogeneous across countries and changes over time.

[60] Fendel et al. (2020) document that ECB communication affects the economies differently. Most specifically, economies with a low solvency rating are affected across different maturities, whereas the impact for countries with a high solvency rating is significant only in short term.

[61] See Appendix, Figure A2 for regional responses.

Table 2: Monetary Policy Shocks: Regional and Country Responses

	Systemic Risk SGIRFs ($\times 10^{-2}$)			
Period:	Period A (2001-2008)		Period B (2009-2018)	
Instrument:	HFI	Shadow rate	HFI	Shadow rate
Regions				
Euro Area	1.882**	2.158**	-1.571**	-0.672**
Core	2.027**	2.942**	-1.772**	-0.926**
Periphery	1.838**	0.702*	-1.171**	-1.949
Countries				
GER	2.004**	3.897**	-1.653**	-0.966**
FRA	2.107**	2.184**	-2.310**	-0.826**
NDL	2.510**	2.295**	-1.281**	-1.064**
BEL	2.312**	1.650**	-1.595**	-1.647**
AUS	1.958**	3.885**	-2.084**	-0.922**
FIN	0.593*	1.101**	1.660**	-0.966*
ITA	2.275**	1.187**	-1.321**	-0.704**
ESP	1.827**	1.175**	-1.595**	-0.019**
GRE	1.251*	3.315**	-0.582	-0.708*
POR	2.165**	-2.096**	-0.808**	0.414*
IRE	1.917**	1.306**	1.028**	1.604**

Notes: The table illustrates the peak systemic risk SGIRF responses following an expansionary monetary policy shock for the two euro area regions; core and periphery. We divide the sampling period into two sub-periods to examine the effect during conventional times and the zero lower bound. For the identification of the shock we apply the Cholesky decomposition and as a policy instrument we use the cumulative target surpises by Altavilla et al. (2019) and the shadow rate by Wu & Xia (2016). Notation of ** and * indicate statistically significant results at 90% and 68% respectively.

considerably by the sovereign debt crisis. Moreover, regarding the QE shocks, based on the data provided by ECB on the Public Sector Purchase Program (PSPP), 63.7% of the conducted purchases were focused on core economies and the remaining 36.3% on peripheral countries, which could explain the weaker impact on the latter.

5.4 Direct and Indirect Effect of Monetary Policy

In the previous sections we showed that there are considerable financial spillovers across the monetary union. Contagion and interconnectedness amongst financial institutions play an important role in the transmission of the monetary policy (see Kabundi & De Simone, 2020). For that reason, we re-run the model when muting the systemic risk spillovers across countries to decompose the effect of monetary policy into the direct and the indirect component.[62] Overall, in line with the literature, the impact of monetary policy is stronger in terms of the euro area GDP and inflation when we take into consideration the spillover channel.[63] With regards to systemic risk and the period before 2009, the contagion

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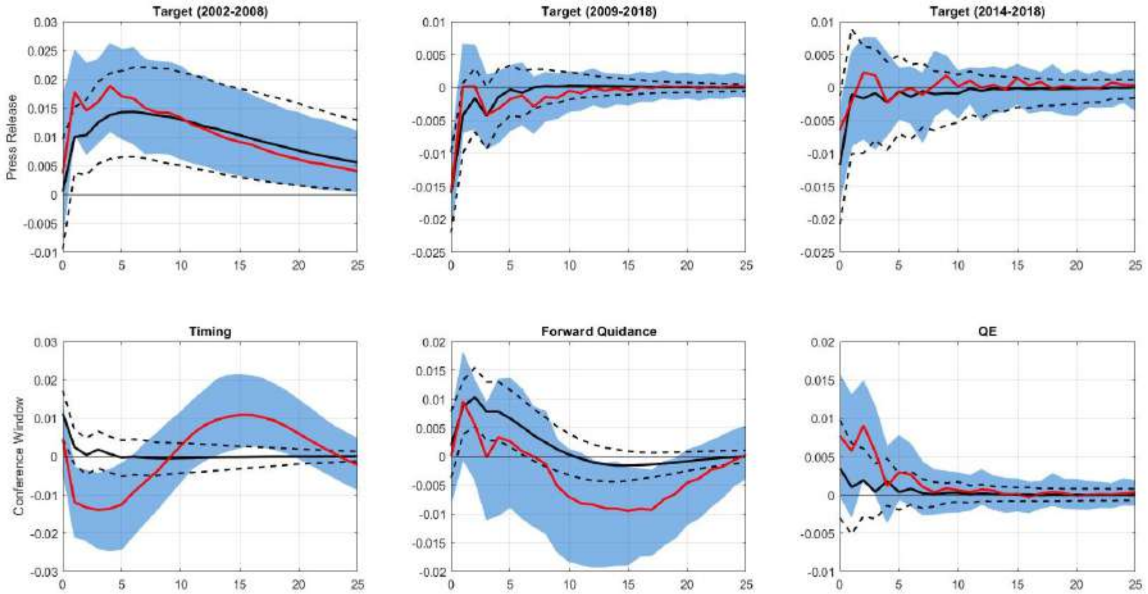
[62] Similarly, Burriel & Galesi (2018) attribute a considerable fraction of the monetary shocks' impact on the spillovers amongst countries, which amplifies the aggregate effect.

[63] Detailed results available upon request.

amongst euro area economies results in higher systemic risk as a consequence of the adoption of expansionary policies. As presented in Figure 8, one standard error decrease in the cumulative target shock series leads to 1.8% increase in the euro area systemic risk, but when we isolate the direct effect of the policy change, the impact is lower at 1.4%.

Figure 8: Monetary Policy shocks: Direct vs. Indirect Effect



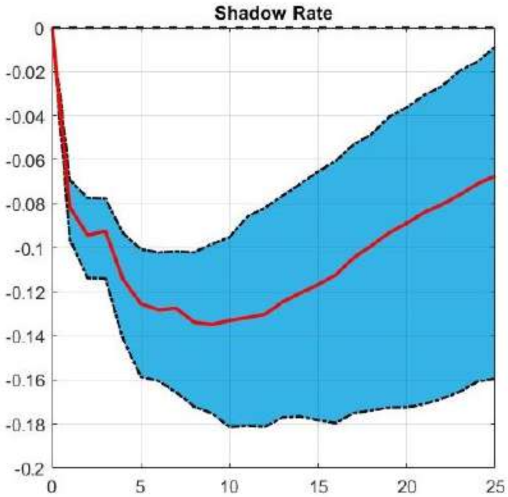
Notes: The figure reports the SGIRFs of systemic risk following an expansionary monetary policy shock. The red line represents the standard SGIRFs and the black line stands for the responses when we mute the spillover effect. The shock is defined as one s.e. decrease in the exogenous cumulative target (first row), timing, Forward Guidance and QE (second row) surprises series provided by Altavilla et al. (2019). The lag selection is based on the Akaike information criterion (AIC). The shaded area represents the 68% confidence level, which is based on 200 bootstrap iterations.

In the second period, the results are mixed and on aggregate the initial systemic risk responses following a target shock are slightly stronger when we include the spillover effect. However by focusing on the period after 2014, the indirect channel reduces the effectiveness of the policy shocks and expansionary target shocks still decrease systemic risk with the response to be significantly weaker in the presence of spillovers. To shed light on this result, we look into the responses following the conference window shocks. The findings so far suggest that expansionary signalling shocks (timing and forward guidance) reduce systemic risk. The results presented in Figure 8 allows us to examine the direct and indirect effect of the conference windows shocks. The empirical evidence highlights the important role that contagion plays on the transmission of the signalling shocks. In both cases of timing and forward guidance, if we do not take into consideration the spillover effect the systemic risk responses become insignificant. The opposite effect is being observed in the period after 2014, when spillovers enhance the effect of QE and result in higher systemic risk. As we observe in the last figure, when the contagion effect is muted, the results become insignificant. Therefore, cross-country spillovers play a crucial role for the transmission of monetary policy shocks. Regarding the policy rate and QE surprises, financial contagion contributes significantly on the increase of systemic risk, whereas in the case of the signalling channel, spillovers across economies are proved to be beneficial in terms of financial stability.

5.5 Do policymakers react to systemic risk shocks?

The recent financial crisis created a trade-off for central banks between price and financial stability. Bekaert et al. (2013) support that monetary policy may lead to risk aversion but policymakers also react to a nervous and uncertain market place by loosening monetary policy. Gilchrist & Zakrajšek (2012) construct a new credit spread index ("*GZ credit spread*") derived by the decomposition of corporate credit spreads. They find that financial stress shocks result in a decline in economic activity and monetary policy easing. In the euro area, Kremer (2016) finds that CISS is a key driver of macroeconomic policies in Eurozone and that ECB reacted to changes in stress conditions.

Figure 9: ECB response to systemic risk shocks



Notes: The figure reports the shadow rate's SGIRF following a euro area systemic risk shock during the period of negative shadow rates (2009m1-2018m12). To capture the response of ECB, we employ different monetary policy instruments; the shadow rates by Wu & Xia (2016) (both current and lag values), the cumulative target surprises and the (logarithm of the) assets of the ECB'balance sheet. The results are similar across specifications. Both figures show that systemic risk shocks lead to an monetary policy expansion. The lag selection is based on the Akaike information criterion (AIC). The shaded area represents the 68% confidence level, which is based on 200 bootstrap iterations.

The structure of the GVAR model allows the central bank to respond to changes in GDP, prices and also systemic risk. Figure 9 illustrates the shadow rate's response following a euro area systemic risk shock. Similarly to the previous section, the analysis is focusing on the period 2008-2018. One standard error increase in the union aggregate systemic risk results to a 0.13% decrease in the policy rate.[64] In addition, we use alternative instruments of monetary policy such as the log assets of ECB's balance sheet, the lag of the shadow rate and the cumulative target surprises.[65] The findings are similar, with a systemic risk shock leading to a policy expansion. The empirical findings indicate that the ECB reacted consistently to changes in systemic risk by using accommodative monetary policy to mitigate the risk level in periods of higher volatility.

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[64] For the analysis we use the shadow rates, so a decrease in the rate could be an actual decrease in the policy rate or asset purchasing programs (QE).

[65] In this case the high-frequency target surprises are included as an endogenous variable in the model.

6 Conclusions

Since the financial crisis, systemic risk has become a major concern for regulators and policymakers. According to the ECB report (2009), the analysis of systemic risk should consider both endogenous and exogenous sources of risk. In this paper we quantify the financial exposure of euro area economies to other union members. To capture financial stress, we present a new index of country-level systemic risk based on micro-data and the $\Delta CoVaR$ methodology by Adrian & Brunnermeier (2016). We then incorporate the index into a GVAR model to examine the spillovers across euro area economies. The empirical evidence suggests that there are considerable systemic risk spillovers across the union and that they play an important role in the transmission of monetary policy. The results are robust to alternative measures of systemic risk. More specifically, we observe high degree of financial contagion amongst core countries, which is not spreading out to the Periphery. On the other hand, our findings suggest that peripheral countries have a disproportionate importance in spreading systemic risk. A systemic risk shock originated in the region affect all the union members. By focusing at the country level, systemic risk shocks in small economies, such as Ireland and Portugal have a sizeable effect on the other member countries, which highlights the need for monitoring financial risk not only at the aggregate level. Additionally, we study the impact of systemic risk on economic activity. Our findings suggest that a euro area systemic risk shock results in a significant drop in GDP across the union and that the responses are mostly driven by the spillover channel. Greece and Ireland, which have both received financial rescue packages, appear to be the more exposed economies.

Furthermore, we investigate the relationship between monetary policy and systemic risk by incorporating high-frequency monetary policy surprises into the GVAR framework. In line with the literature, we find that in normal times a monetary contraction reduces systemic risk. However, if we focus on the period of the ZLB when the unconventional forms of policy were introduced, the relationship is reversed and expansionary monetary shocks lead to a decrease in the risk level. We then decompose the monetary policy shocks into the signalling and the QE components to analyse the transmission channels. Based on our results the QE program provides evidence of the risk-taking channel similarly to expansionary shocks in normal times. Therefore, the reversed relationship between systemic risk and monetary policy at the ZLB is predominately caused by the signalling channel; expansionary announcements lead to systemic risk reduction. Finally, monetary policy shocks affect primarily the core economies and a significant proportion of the response can be attributed to the spillover channel.

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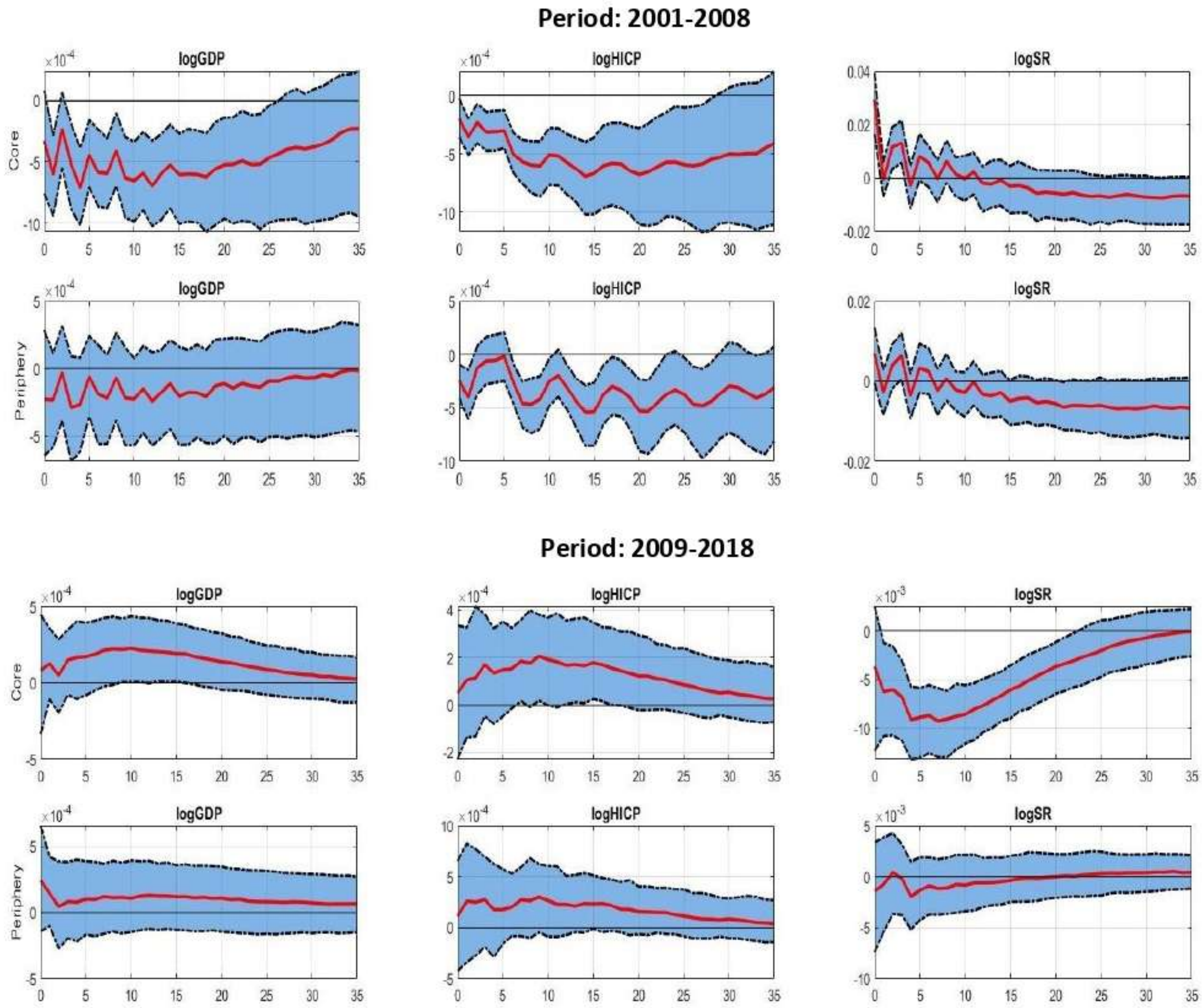
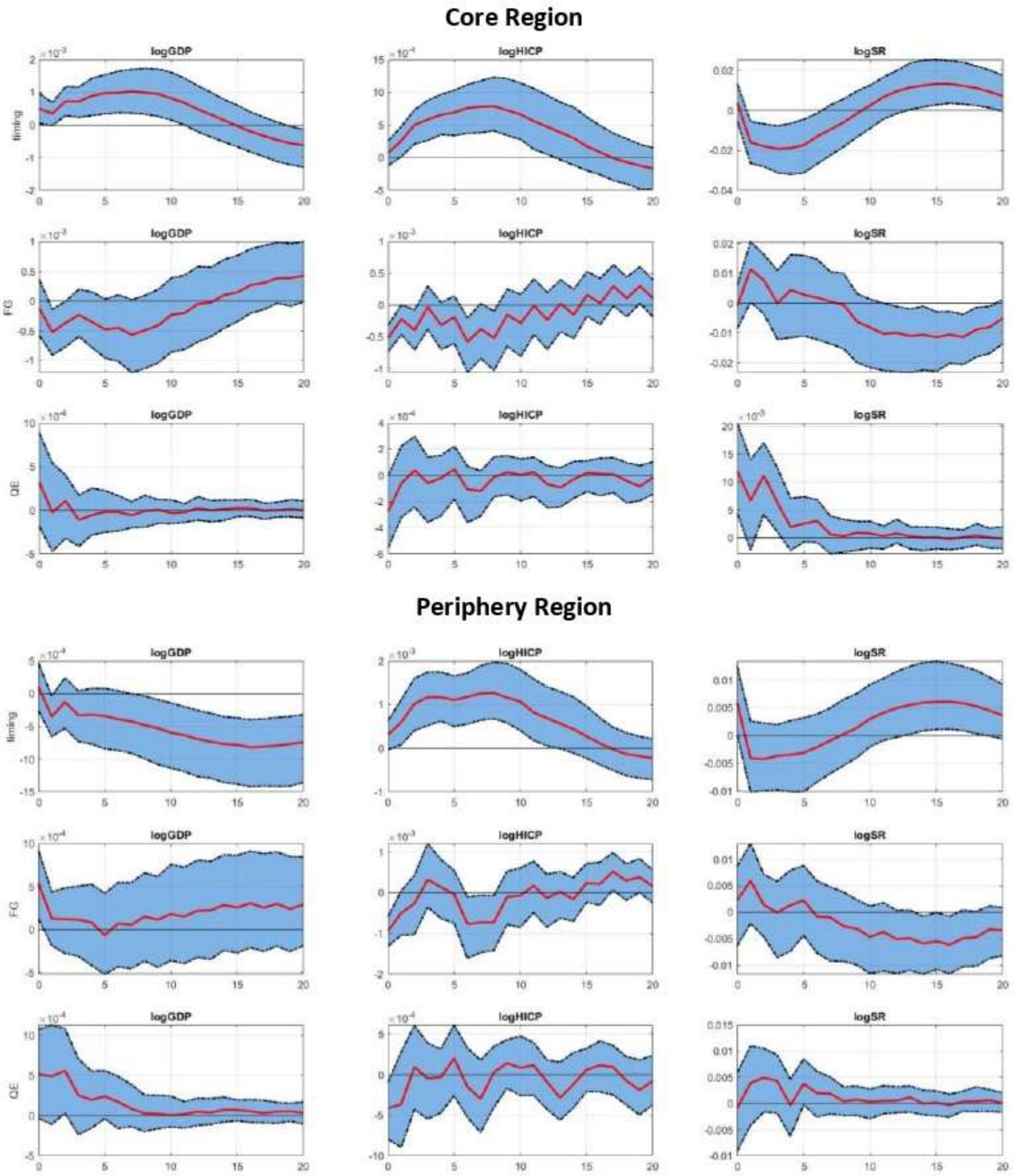
Appendix

Figure A1: Shadow Rate Monetary Policy Shocks: Regional Responses



Notes: The figure reports the SGIRF following an expansionary monetary policy shock. We present the results for two regions; core and periphery and two sub-periods; 2001-2008 and 2009-2018. The monetary policy shock is defined as one s.e. decrease in the shadow rate by Wu & Xia (2016) and the identification strategy is based on Cholesky decomposition. The response variables which are being presented are the euro area aggregate GDP, price level and systemic risk in columns one to three respectively. The lag selection is based on the Akaike information criterion (AIC). The shaded area represents the 68% confidence level, which is based on 200 bootstrap iterations.

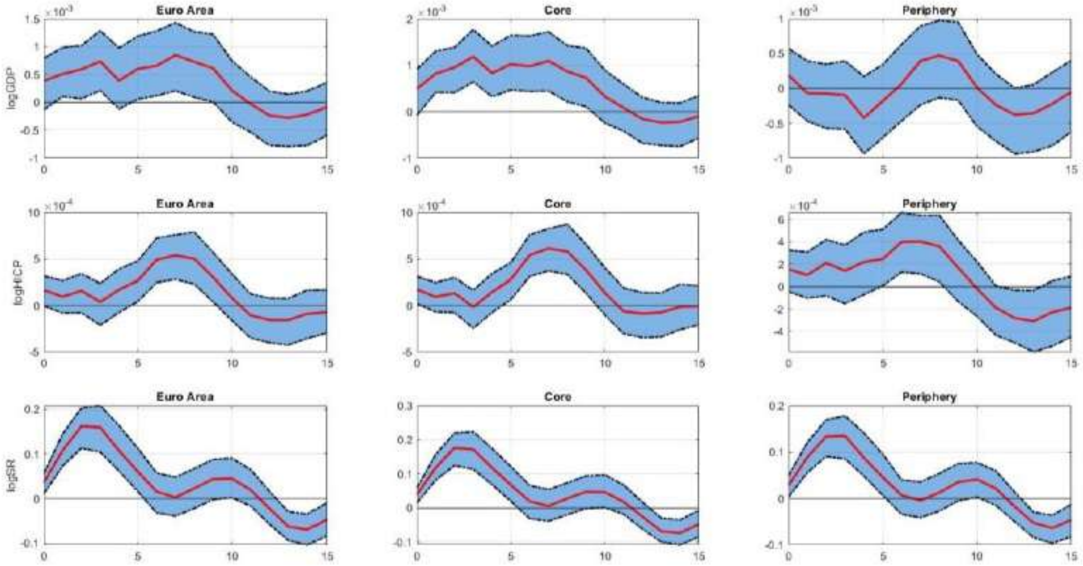
Figure A2: Conference Window Shocks: Regional Responses



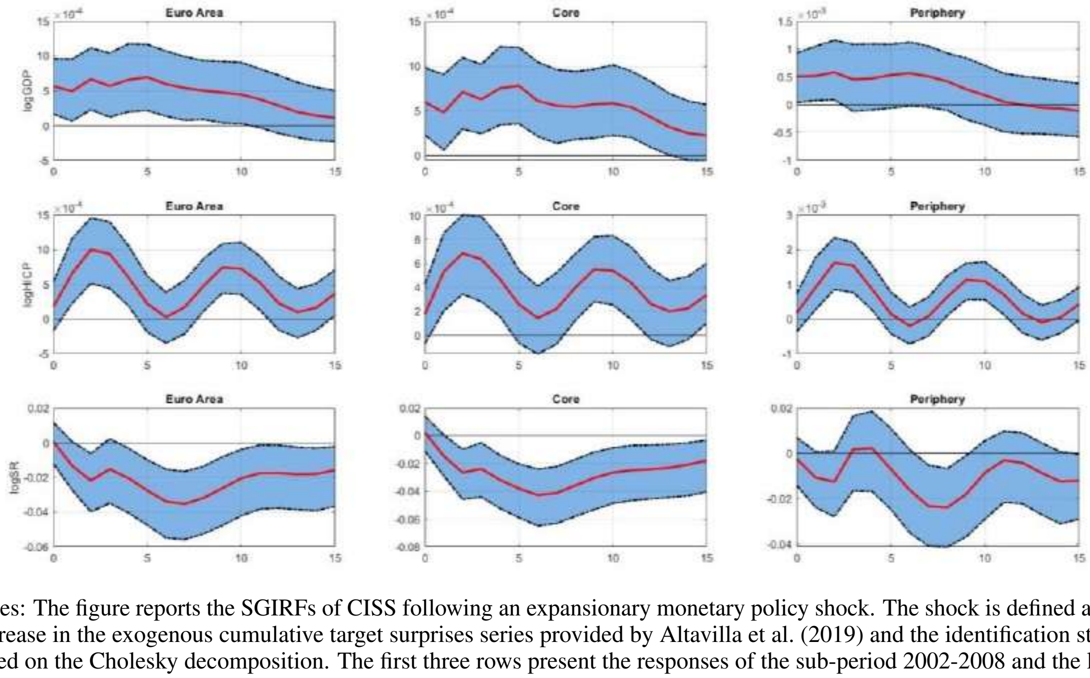
Notes: The figure reports the SGIRFs of systemic risk following an expansionary monetary policy shock for the two euro area regions; core and periphery. The shock is defined as one s.e. decrease in the cumulative timing, Forward Guidance and QE surprises series provided by Altavilla et al. (2019) and the identification strategy is based on the Cholesky decomposition. The examined period is 2008m1-2018m12 for the first two shock series and 2014m1-2018m8 for the latter. The lag selection is based on the Akaike information criterion (AIC). The shaded area represents the 68% confidence level, which is based on 200 bootstrap iterations.

Figure A3: Monetary Policy shock: Alternative Systemic Risk Measure (CISS)

Period 2002-2008



Period 2009-2018



Notes: The figure reports the SGIRFs of CISS following an expansionary monetary policy shock. The shock is defined as one s.e. decrease in the exogenous cumulative target surprises series provided by Altavilla et al. (2019) and the identification strategy is based on the Cholesky decomposition. The first three rows present the responses of the sub-period 2002-2008 and the last three of the second sub-period until 2018. The responses include the aggregate euro area and two regions; core and periphery and three variables are logGDP, logHICP and systemic risk. The lag selection is based on the Akaike information criterion (AIC). The shaded area represents the 68% confidence level, which is based on 200 bootstrap iterations.

Table A1: Data Description

Variable series	Frequency	Source
Gross Domestic Product (GDP)	Quarterly	Eurostat
Industrial Production	Monthly	FED of St. Louis (FRED)
Harmonised Consumer Price Index (HCIP)	Monthly	Eurostat
Shadow Rate	Monthly	Wu & Xia (2016)
High-Frequency Monetary Surprises	Monthly	Altavilla et al. (2019)
ECB Assets	Monthly	Eurostat
Composite Systemic Stress Index (CISS)	Monthly	Eurostat
ΔCoVaR and MES data	Monthly	Datastream
State Variables		
3 month Goverment Bond	Monthly	FRED, Datastream, IMF
10 year Goverment Bond	Monthly	FRED
EURIBOR	Monthly	FRED
Stock Market Index	Monthly	Datastream

Notes: The table illustrates the sources of the economic and financial series used in the GVAR model estimation. We also report the state variables sources used for the systemic risk index estimation. For countries where the 3 month govermnent bond is not available, we use alternatively the Datastream series: TR EURO GVT 3MO.

Table A2: ΔCoVaR Estimation: Data

Financial Sectors					
	no.	MV(%)		no.	MV(%)
Banks	55	44.65%	Financial Services	81	13.52%
Insurance	25	26.05%	Real Estate	100	15.79%
Countries					
Core	no.	MV(%)	Periphery	no.	MV(%)
GER	49	22.21%	ITA	29	12.62%
FRA	48	22.86%	ESP	25	14.33%
NDL	31	11.00%	GRE	13	0.58%
BEL	32	6.62%	POR	7	0.32%
AUS	13	3.28%	IRE	9	1.64%
FIN	5	4.62%	Total	261	1

Notes: The table reports the data used to estimate the ΔCoVaR index. For that purpose, we collect Price and Market Capitalization data from Datastream for 261 active Euro Area financial firms. Data for ‘dead’ companies are not available, leading potentially to a survivorship bias. The sectoral division is based on Datastream reports. We observe that banks account for almost 45% of the Market Capitalization of the Euro Area financial system. We include firms that consists the (country) DS Financial sector as presented by the data source. The estimation period is 2001m1-2018m12.

Table A3: GVAR weights

	GER	FRA	ITA	ESP	NDL	BEL	AUS	FIN	GRE	POR	IRE
GER		0.36	0.35	0.32	0.31	0. 30	0.30	0.29	0.29	0.29	0.29
FRA	0.30		0.26	0.24	0. 23	0. 22	0. 22	0.22	0.22	0.22	0.22
ITA	0.24	0.22		0.19	0.18	0.18	0.18	0.17	0.17	0.17	0.17
ESP	0.15	0.14	0.13		0.12	0.11	0.11	0.11	0.11	0.11	0.11
NDL	0.09	0.09	0.08	0.08		0.07	0.07	0.07	0.07	0.07	0.07
BEL	0.05	0.05	0.05	0.04	0.04		0.04	0.04	0.04	0.04	0.04
AUS	0.05	0.04	0.04	0.04	0.03	0.03		0.03	0.03	0.03	0.03
FIN	0.03	0.03	0.02	0.02	0.02	0.02	0.02		0.02	0.02	0.02
GRE	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.2		0.02	0.02
POR	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.2	0.02		0.02
IRE	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.2	0.02	0.02	

Notes: The table illustrates the weights for the GVAR model.
The estimation is based on the average quarterly GDP data provided by Eurostat for the period 2001-2018.

Table A4: Lag order selection

	Full Period	Period A	Period B	Foreign var.
GER	3	3	3	1
FRA	2	1	2	1
ITA	3	2	2	1
ESP	4	4	2	1
NDL	4	4	2	1
BEL	4	4	3	1
AUS	1	1	1	1
FIN	2	4	1	1
GRE	4	4	3	1
POR	3	3	2	1
IRE	2	2	1	1

Notes: The table reports the optimal lag selection for the GVAR model based on the Akaike information criterion (AIC) for the full time period (first column) and two sub-periods (second and third column). The last column stands for the lag of the foreign variables, which is set to be equal to 1 by construction in line with the GVAR literature.

Table A5: Sensitivity Analysis Results: Systemic Risk SGIRFs

Regions:	Euro Area	Core	Periphery
Benchmark Model ($\Delta CoVaR$)			
Core SR Shock	2.92**	●	0.66**
Periphery SR Shock	2.99**	2.70**	●
CMP Shock	1.88**	2.03**	1.84**
UMP Shock	-1.57**	-1.77**	-1.17**
Alternative Measures of Systemic Risk			
CISS			
Core SR Shock	7.75**	●	4.28**
Periphery SR Shock	8.18**	7.31**	●
CMP Shock	16.20**	17.71**	13.55**
UMP Shock	-3.52**	-4.28**	-2.39*
Alternative Lag Selection Method (SBC)			
Core SR Shock	6.07**	●	4.48**
Periphery SR Shock	6.41**	6.41**	●
CMP Shock	1.54**	1.50**	1.61**
UMP Shock	-1.40**	-1.52**	-1.16**
Alternative Weights: Trade (based on data from Burriel & Galesi, 2018)			
Core SR Shock	3.68**	●	1.07**
Periphery SR Shock	2.00**	3.21**	●
CMP Shock*	1.58**	1.50**	1.72**
UMP Shock*	-1.58**	-1.72**	-1.25**

Notes: The table illustrates the peak regional SGIRF for systemic risk following one s.e. increase in the systemic risk at regional level and an expansionary monetary policy shock for both sub-periods. For robustness purposes, we employ two different measures of systemic risk; $\Delta CoVaR$ and $CISS$. Across all specifications, periphery is more systemically important than core economies. Regarding the monetary policy shocks, all the robust checks are in line with the heterogeneous effects across periods of the benchmark model. Notation of ** and * indicate statistically significant results at 90% and 68% respectively.

* To secure structural stability in same cases, we select the optimal lags based on the SBC.

** All the values are expressed in $\times 10^{-2}$