E Pluribus Unum?

Essays in European macroeconomics

By

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ABSTRACT OF THE DISSERTATION

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This dissertation develops empirical models aimed at analysing some relevant macroeconomic trends and policies in the euro area, with a focus on post-crisis dynamics.

Chapter 1 focuses on the decoupling between productivity and compensation growth, which has become more evident in the euro area after the 1990s. By using static and time-varying econometric techniques, it assesses how extensively this phenomenon has affected the different economies in the euro zone. Results suggest that both the aggregate euro area and its four biggest economies have experienced a significant decrease in the pass-through of productivity on to compensation, such decoupling being a rather long-lasting phenomenon with a certain degree of cross-country heterogeneity in terms of magnitude and timing.

Chapter 2 aims at assessing the macroeconomic impact of unconventional monetary policies (UMPs) that the ECB has put in place in the euro area after 2007. With this purpose, it first documents how the relative importance of the main transmission channels of such measures has changed over time, with the portfolio rebalancing being generally more impactful than the signalling channel after the "Whatever it takes" speech in July 2012. However, it also provides evidence of a great degree of heterogeneity across core and peripheral economies, as well as over time. A time-varying Structural Vector Autoregression (SVAR) model with stochastic volatility is then constructed to account for such heterogeneity, with UMP shocks identified by means of "dynamic" sign restrictions. Finally, a counterfactual experiment based on the outcome of the model estimation shows that a more aggressive loosening on the part of the ECB could have helped support the economic performance of peripheral euro area economies.

Chapter 3 tackles the question as to what extent the process of (re-)shaping the

architecture of the European Economic and Monetary Union (EMU) has repercussions outside of the continent. This is done by quantifying the economic effects that shocks to EMU cohesion can have on the rest of the world. Notably, the chapter proposes an identification strategy to isolate economic stress shocks to the euro area which is based on the imposition of sign, magnitude and narrative restrictions on a daily SVAR model with financial variables. The effects of euro area stress shocks on the rest of the world are then further investigated by means of panel local projections for a set of advanced and emerging economies. Shocks to EMU cohesion are found to have a significant impact on the rest of the world.

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Dedication

To my beloved parents, Francesco and Anna Maria

To the love of my life, Massimo

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Introduction

In January 2020, the euro has reached its 20th birthday. Ever since the creation of the European Economic and Monetary Union (EMU), the Eurozone bloc has become one of the biggest economic powers, whose currency is now the second most important in the international monetary system after the US dollar. The journey towards these remarkable achievements, however, has not been an easy one. The Global Financial Crisis in 2008-2009 and the ensuing euro area sovereign debt crisis have indeed presented the Member States with unprecedented challenges and have also unveiled some inherent frailties in the Union. This has led to an increasing divergence between the so-called "core" euro area economies and the "peripheral" countries, with the latter being hit the most by the economic downturn.

The dynamics triggered by the crisis have also ignited the nowadays long-lived debate on the viability of the Eurozone as such. In particular, discussions in academia and policy circles have tried to address three main questions:

i) Is the heterogeneity across Eurozone members structural or state-contingent?

ii) Are the Union-wide policy tools suitable to address the divergence across Member States?

iii) Would a speeding in EMU completion help fix these problems?

This dissertation contributes to these three aspects, by deploying time-series techniques, as well as devising and improving novel identification strategies, to capture the salient features of the euro area economies in the post-crisis period by means of Structural Vector Autoregression (SVAR) models.

The first aspect considered is the apparent decoupling between productivity and compensation growth which has emerged in the euro area after the 1990s, i.e. around the period where the Maastricht Treaty entered into force. Such a coincidence has induced some to identify the adoption of the common currency as one of the main drivers of the de-linkage between productivity and compensation, mainly due to a loss in competitiveness on the part of peripheral members vis-à-vis core economies. Chapter 1: *"The Compensation-Productivity Divide in the euro area"* sheds light on this issue by using static and time-varying econometric techniques to assess possible discrepancies across different economies in the euro zone. Results suggest that both the aggregate euro area and its four biggest economies have experienced a significant decrease in the pass-through of productivity on to compensation, with the decoupling being a long-term phenomenon and presenting a certain degree of cross-country heterogeneity in terms of magnitude and timing. However, there is also evidence of a significant time variation in the productivity-compensation relationship, as the gap has been closing up in more recent times in economies like France, Italy and Spain.

As to to point ii), this dissertation takes into consideration one of the most powerful tools at disposal of the euro area institutions: the single monetary policy. In particular, Chapter 2: *"Does one (unconventional) size fit all?"* aims at assessing the macroeconomic impact of unconventional monetary policies (UMPs) that the ECB has put in place in the euro area after the 2007 crisis. With this purpose, the analysis takes into consideration the two main subcomponents of the interest rate transmission channel: i) the portfolio rebalancing channel; ii) the signalling channel. This is done by decomposing the yield curve of euro area economies via arbitrage-free affine term structure models. The chapter then documents how the relative importance of these channels has changed over time, with the portfolio rebalancing being generally more impactful than the signalling channel after the "Whatever it takes" speech in July 2012. However, results also underline the presence of a great degree of heterogeneity across core and peripheral economies as well as over time. Such heterogeneity is accounted for by means of a time-varying Structural Vector Autoregression (SVAR) model with stochastic volatility, where the identification of UMP shocks is attained via "dynamic" sign restrictions. Differently from the existing literature on the use of zero and sign restrictions in VARs (e.g., Arias et al. (2018)), these novel restrictions are time-contingent, as they change depending on the time period considered in the estimation. Finally, a counterfactual experiment based on the model estimates provides evidence of how a more aggressive lossening on in the ECB's monetary policy stance could have helped support the economic performance of peripheral euro area economies over the period 2011-2012.

Finally, Chapter 3: *"The International Dimension of EMU deepening"* relates to point iii) by tackling the question as to what extent the process of (re-)shaping the architecture of the EMU has repercussions outside of the continent. This dimension has been indeed largely neglected in the debate over EMU completion. The chapter then aims at quantifying the economic effects that shocks to EMU cohesion can have on the rest of the world. With this purpose, the first step of the exercise consists of proposing an identification strategy to isolate stress shocks to the euro area, which is based on the implementation of sign, magnitude and narrative restrictions in a daily SVAR model with financial variables. The series of shocks thus identified are well disentangled from global risk aversion shocks. The effects of euro area stress shocks on the rest of the world are then further investigated by means of panel local projections for a set of advanced and emerging economies. It is found that shocks to EMU cohesion can exert a real impact not only on the euro area members but also on the rest of the world.

The whole set of results discussed in Chapters 1 to 3 provides insights to be used in the current policy debate, especially in the context of the ongoing reform initiatives[1].

[1]See for instance the launch of the ECB's monetary policy strategy review: https://www.ecb.europa.eu/press/pr/date/2020/html/ecb.pr200123~3b8d9fc08d.en.html

Chapter 1

The Compensation-Productivity Divide in the euro area: a time-varying approach [1]

1.1 Introduction

> *(...) we have acknowledged the progress on the growth front, on the recovery front. We are pretty confident that, as this will proceed, this slack will close, the labour market conditions will improve. We'll start seeing [that] wage growth, which is the lynchpin of a self-sustained increase in inflation. That is the key variable that we should look at* (Draghi (2017)).

Productivity is considered to be the most relevant driver of real wage growth over the medium to long run. The alignment between productivity and real wages is important, as it speaks to the extent to which the income produced by firms at the macro level is enjoyed by individuals at the household level (Atkinson (2009)). Besides this, the interaction between the growth in real wages and labour productivity has implications for external competitiveness and overall macroeconomic stability (Mihaljek et al. (2010)). For these reasons, the link between the two has always received attention in academia and policy circles, and even more so in the context of the marked slowdown in wage growth after the Great Recession[2]. The latter, indeed, has been widely considered as the most relevant driver of the increase in inequality observed in the last decades (IMF (2017), Szörfi and Tóth (2018)).

According to standard economic theory, productivity gains should translate into

[1]This chapter is based on a paper co-authored by Elena Bobeica (European Central Bank) and Elisa Liz (European Central Bank)

[2]As an example, in September 2016 the European Council invited all European Union Member States sharing the euro to set up a National Productivity Board (NPB), whose objective is to offer a diagnosis and analysis that "spans a comprehensive notion of productivity and competitiveness" according to the Council Recommendation (European Council 2016).

real wage gains for workers, thus leading to constant real unit labor costs and, hence, a constant labor share of income (Kaldor (1957)). This seems to have been the case also in the euro area from the early 1970s to the 1990s (see Figure 2.2.2). Since then, however, the distribution of income has substantially changed, leading to a decline in the labor share (Karabarbounis and Neiman (2014)), as also confirmed by the widening divergence between productivity and compensation growth, with the former being faster than the latter (see Figure 1.1.2) [3].

In this regard, the relevant literature provides mixed evidence as to whether an effective decoupling between labor productivity and compensation has taken place[4]. Feldstein (2008) shows that there is no evidence of decoupling in the US in the first half century, once non-wage benefits are taken into account, something that is also supported by Lawrence (2016), who also underlines how the historic divergence in the US is due to the depreciation of labor productivity. Bivens and Mishel (2015), on the other hand, document the presence of a wedge in the US starting from the 1970s and they show this is mostly due to rising inequality, which is also in line with the findings in Schwellnus et al. (2017) and OECD (2018). The latter, however, also provides evidence that decoupling in advanced economies has been mainly driven by global developments like technological progress and the expansion of global value chains.

These contrasting results are partially due to the use of different measures of compensation and productivity. Some papers, indeed, study the divergence between productivity and the typical worker's compensation[5], while others prefer to focus on the discrepancy between productivity and average compensation, which is conceptually equivalent to the decline in labor share[6]. Finally, Stansbury and Summers (2017) find substantial evidence of linkage between productivity and compensation by studying the evolution

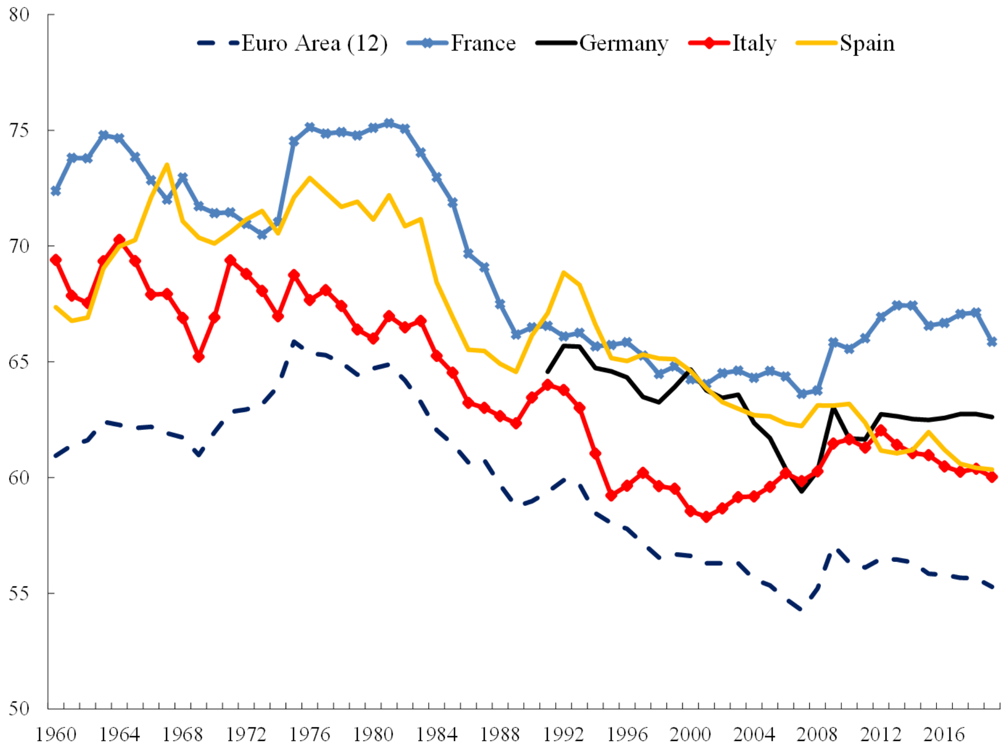
[3] In our analysis, we define productivity as the amount of GDP per hour worked and compensation as the ratio between total compensation and total hours worked. The two measures are then deflated using the GDP deflator and the CPI respectively.

[4] As reported by Stansbury and Summers (2017), "Using compensation rather than wages is important. The share of compensation provided in non-wage benefits such as health insurance significantly rose over the postwar period, particularly during the 1960s and 1970s, meaning that comparing productivity against wages alone would imply a larger divergence between productivity and workersâ pay than has actually occurred."

[5] See, for instance, Bivens and Mishel (2015), where compensation is quantified by using median compensation and average production/non supervisory worker compensations, both deflated by consumer price deflators.

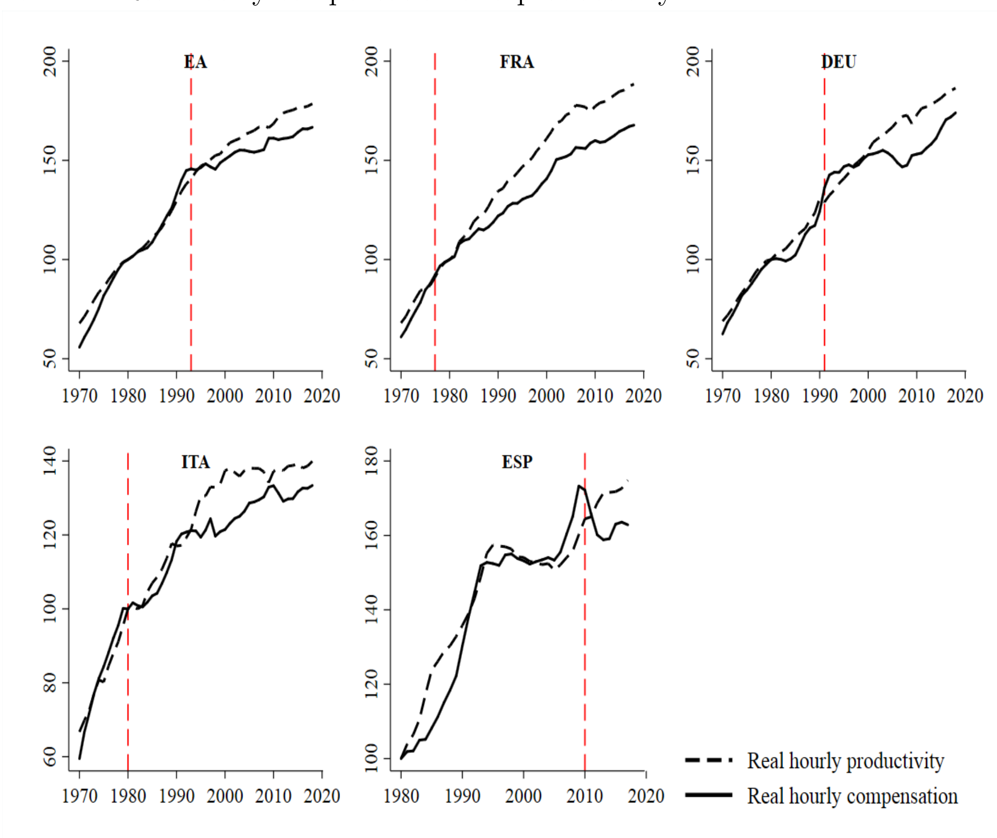
[6] For example, Feldstein (2008) compares labor productivity in the nonfarm business sector to average nonfarm business sector compensation, deflated by the producer price deflator.

Figure 1.1.1: Adjusted wage share for euro area and selected European economies.



Source: AMECO

Figure 1.1.2: Real hourly compensation and productivity.



Notes: 1980 = 100. Red dashed lines correspond to break years. Compensation is deflated using the consumer price index, while productivity is deflated using the GDP deflator.
Sources: National authorities, Eurostat and authors' calculations.

of both average, median and production/non supervisory compensation. However, their estimates also provide a less-than-one elasticity of compensation to productivity, which implies the presence of other orthogonal factors that have been dampening the increase in compensation in spite of the acceleration in productivity. These factors however do not include technological progress[7]. In addition to what already mentioned, literature finds it also difficult to quantify the precise magnitude of the drop in the labor share of income, as well as to pinpoint the starting date of the decline[8].

As to the rationale behind the phenomenon, several alternative explanations have been provided. Some researchers agree with the so-called "accumulation view" (Rognlie (2015)), whereby the fall in the labor share is mainly attributable to shocks that have led to higher capital accumulation. Piketty (2014), for instance, argues that aggregate savings have risen globally relative to national incomes and this has led to an increase in the capital-output ratios. Karabarbounis and Neiman (2014), instead, maintain that a drop in the price of investment goods relative to consumer goods has determined an increase in the capital share of income due to a rise in capital accumulation. However, such mechanism would assume an elasticity of substitution between capital and labor superior to one, something that has been deemed unrealistic (see Lawrence (2015) and Grossman et al. (2017))[9].

Meanwhile, a more recent strand of literature has related the decline in the labor share of income to a decrease in the accumulation of human capital. Jones (2016), for instance, provides evidence of a slowdown in educational attainment in the US whose timing is compatible with the productivity-compensation decoupling. Grossman et al. (2017), on the other hand, incorporate optimal schooling choice in a neoclassical growth model so that productivity slowdowns can contribute to the decrease in the labor share of income via a deceleration in human capital accumulation.

As an alternative to these views, Karabarbounis and Neiman (2018) show that the decline in payments to labor in the US is only partially explained by the rise in payments

[7]A less than one-to-one relation is also documented by Pasimeni (2016), who analyses the increasing gap between productivity and compensation for a sample of 34 countries over the past half century. In particular, cyclical conditions and labor market structures are considered as the main factors affecting the link.

[8]See Karabarbounis and Neiman (2014), Piketty and Zucman (2014), and Dao et al. (2017) among others.

[9]Other possible explanations include: a shift in the bias of technology in favour of capital (Oberfield and Raval (2014)); the automation of tasks previously performed by labor (Autor and Dorn (2013), Acemoglu and Restrepo (2016, 2019)).

to capital and they find that a growing share of the value added is imputable to residual payments, the so-called "factorless income".

Finally, part of the literature detects in labor markets imperfections the main rationale for the divergence between wage and productivity rates. Notably, imperfect competition on labor markets leads to the materialisation of rents to the employment relationship for both workers and employers. As both parties might face search costs, they might also want to close employment agreements at wage rates divergent from productivity rates, in order to divide the total rent according to the relative bargaining positions (Pissarides (1985), Manning (2011))[10].

Against this backdrop, an assessment of the evolution in the relationship between compensation and productivity becomes important to understand whether the observed stylised facts are due to an effective decoupling of compensation vis-à-vis productivity or to a change in the relationship between the two. In this chapter a time-varying VAR with stochastic volatility is developed to analyze the time variation in the productivity-compensation link, as this methodological approach seems also supported by the preliminary empirical analysis in Section 1.2. Conceptually, the proposed framework builds on three strands of research: i) empirical studies of the co-movements of productivity and compensation (e.g. Bivens and Mishel (2015), Stansbury and Summers (2017), Pasimeni (2016)); ii) analyses of the decline in the labor share of income (e.g. Karabarbounis and Neiman (2014, 2018), Lawrence (2015) and Bergholt et al. (2019)); iii) models of the inflation-unemployment link (e.g. Galí (2011), Gordon (2013), Galí and Gambetti (2019)).

From a methodological standpoint, the chapter relates to the literature studying significant time variations in the joint dynamics of output, labor compensation and employment. In this respect, the closest works are Galí and Gambetti (2009), Benati and Lubik (2014) and Guglielminetti and Pouraghdam (2018). That being said, this chapter provides a contribution to the existing literature along the following dimensions: i) it shows that a time-varying setup is better-suited to analyze the patterns of interest (e.g., the break in the one-to-one relationship evidenced by data and tests in Section 1.2 below); ii) it investigates the relationship between productivity and compensation, while

[10] This strand of research also highlights the structural relationship between goods and labor markets structure, as shown in Blanchard and Giavazzi (2003).

also controlling for the dynamics of unemployment; iii) it provides a deeper understanding of whether and how the relationship between productivity and compensation would react to unemployment shocks.

The results underline the presence of a significant wedge between compensation and productivity growth, both at the aggregate euro area level and in the four biggest economy. Such a gap, however, has evolved over time following a smooth transition from a strong coupling to a de-linkage between compensation and output growth. However, the transition cannot be captured with discrete-time models and becomes evident only when switching to time-varying frameworks. Moreover, the decoupling is a phenomenon that affects the long-run relationship between compensation and productivity, though at different pace across the four countries. Notably, in France the decoupling is driven by an evident slowdown in productivity, whereas in Germany the wedge is a consequence of the boom in productivity after the reunification. In Italy, on the other hand, the long-run relationship between productivity and compensation features a marked decoupling over the period 1980-2007, but there is thereafter evidence of a closing in such gap partly due to a decrease in productivity[11]. Finally, there is no strong evidence of a de-linkage in Spain, with the exception of the period 2009-2010 that roughly corresponds to the height of the sovereign euro area debt crisis.

The remainder of the chapter is structured as follows: Section 1.2 presents some preliminary empirical analysis; Section 1.3 describes the methodological framework and discusses the results; Section 2.5 concludes.

1.2 Preliminary empirical evidence

This section presents some hypothesis testing in support to the stylized facts exposed in Section 1.1 above. First, some break tests on y-o-y growth rates of compensation and productivity are performed. Results show that there is a significant break in the link between the two variables, both at the aggregate euro area level and in the four biggest economies, though at different dates. Moreover, Levene's tests detect a change in volatility for both productivity and compensation growth in the whole euro area, as well as in France, Germany, Italy and Spain, with breaks ranging from 1977Q3 (France)

[11] As to the Italian case, empirical findings are particularly mixed. Torrini (2016), for instance, finds no evidence in support of an effective decoupling.

to 2010Q2 (Spain) (see Table 1.2.1).

Given this and following Stansbury and Summers (2017), a single-equation model with quarterly data is estimated for each economy and the euro area aggregate separately[12]. The bounds testing procedure proposed by Pesaran et al. (2001) is then used to check for the presence of a long-run relationship between compensation and productivity growth, regardless of whether the variables considered are either integrated of order zero/one ($I(0)/I(1)$ respectively) or cointegrated.

Table 1.2.1: Break test and test of equality of variances across subsamples.

Break Test*				
	Date	**Statistic**	**P-value**	
Euro area	1993q3	121.57	0.00	
France	1977q3	122.67	0.00	
Germany	1991q2	68.25	0.00	
Italy	1980q1	87.40	0.00	
Spain	2010q2	44.37	0.00	
Changes in volatility **				
	Pre	**Post**	**Ratio**	**P-value**
Productivity				
Euro area	0.01	0.01	1.59	0.00
France	0.02	0.01	1.44	0.00
Germany	0.02	0.01	1.25	0.03
Italy	0.02	0.02	1.35	0.01
Spain	0.06	0.01	6.17	0.00
Compensation				
Euro area	0.01	0.01	1.59	0.00
France	0.02	0.01	1.44	0.00
Germany	0.02	0.01	1.25	0.03
Italy	0.02	0.02	1.35	0.01
Spain	0.06	0.01	6.17	0.00

* Supremum Wald test on the coefficients of the regression: $comp_t = \alpha_0 + \alpha_1 prod_t + \varepsilon_t$, where $comp_t$ and $prod_t$ are the y-o-y log-differences of hourly compensation and productivity respectively; ** Levene's test based on break dates found by Wald test; H_0: variances are equal across subperiods.

Specifically, the following autoregressive distributed lag (ARDL) model is set up:

$$comp_t = \alpha + \sum_{i=1}^{p} \phi_i comp_{t-i} + \sum_{i=0}^{q} \beta_i prod_{t-i} + \gamma unemp_{t-1} + \varepsilon_t \tag{1.1}$$

where $comp_t$ and $prod_t$ are the y-o-y growth rates of hourly compensation and productivity respectively, while $unemp_{t-1}$ is the lagged unemployment rate and is treated as

[12]See Appendix A.1 for a description of data and sources.

exogenous. Equation (1.1) can then be reparametrized in conditional Error Correction (EC) form:

$$\begin{aligned}\Delta comp_t = \alpha - \delta(comp_{t-1} - \theta prod_{t-1}) + \sum_{i=1}^{p-1} \psi_i \Delta comp_{t-i} + \omega \Delta prod_t \\ + \sum_{i=1}^{q-1} \zeta_i \Delta prod_{t-i} + \gamma \Delta unemp_{t-1} + \varepsilon_t\end{aligned} \tag{1.2}$$

where $\delta = 1 - \sum_{i=1}^{p} \phi_i$ is the speed of adjustment, while $\theta = \frac{\sum_{i=0}^{q} \beta_i}{\delta}$ is the long-run coefficient. The optimal lag lengths, p and q, are chosen via the Schwartz Information Criterion (SIC)[13] and the model in Equation (1.2) is estimated via OLS. Then an F-test is conducted for the joint null hypothesis: $H_0^F : (\delta = 0) \cap (\sum_{i=0}^{q} \beta_i = 0)$. If H_0^F is rejected, a t-statistic is computed to test for the null $H_0^t : \delta = 0$. The existence of a (conditional) long-run relationship is confirmed if both H_0^F and H_0^t are rejected, on the basis of the lower and upper bounds for the asymptotic critical values provided by Pesaran et al. (2001). Results, reported in Table 1.2.2 below, show that both the null hypotheses can be rejected in most cases at the conventional significance levels, thus supporting the presence of a long-run relationship between compensation and productivity growth. Estimates for Italy in the period 1980Q2-2018Q1 are less conclusive, as the p-value level for the t-test on I(0) variables ($< 10\%$) does not allow to accept the null hypothesis. Moreover, the test rejects the presence of a long-run relationship for Spain in the overall 1980Q1-2018Q1 period, while it fails to do so in the two subsamples.

Table 1.2.3 reports the estimates of Equation (1.2) for aggregate euro area[14]. Results indicate that the long-run coefficient of productivity growth has decreased over time, with a drop from 1 (*strong linkage*) to 0 (*strong delinkage*) before and after 1993Q3[15]. In addition, the coefficient for the overall period is 0.878 and is not statistically significant from 1, thus implying a full pass-through from productivity to compensation. The estimates of both the adjustment and the short-run coefficients also suggest that compensation growth follows a process which has become more and more persistent and slow-moving over time. These results provide interesting insights, in particular given

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[13] The maximum number of lags is set as $p_{max} = [12 \times (\frac{T}{100})^{1/4}]$ (see Schwert (1989)).

[14] Tests and estimation are performed using the Stata `ardl` module of Kripfganz and Schneider (2018).

[15] For estimates that exceed 1, an F-test is run to check whether they are statistically different from 1. In all instances, the F-test fails to reject the null hypothesis ($H_0 : \hat{\theta} = 1$).

the fact that the detected break date (1993Q3) coincides with the entry into force of the Maastricht Treaty establishing the convergence criteria for the European Economic and Monetary Union (EMU) and, hence, the adoption of the single currency.

Table 1.2.2: Tests for existence of long-run relationship.

	F - test	**t -test**	**F - test**	**t -test**	**F - test**	**t -test**
France	1960q1-2018q1		1960q1-1977q2		1977q4-2018q1	
Statistic	12.76	-4.92	6.41	-3.53	31.04	-7.87
P-values:						
I(0)	[0.000]	[0.000]	[0.019]	[0.010]	[0.000]	[0.000]
I(1)	[0.000]	[0.000]	[0.037]	[0.026]	[0.000]	[0.000]
Germany	1970q1-2018q1		1970q1-1991q1		1991q3-2018q1	
Statistic	17.70	-5.13	8.96	-3.11	24.24	-6.93
P-values:						
I(0)	[0.000]	[0.000]	[0.003]	[0.029]	[0.000]	[0.000]
I(1)	[0.000]	[0.000]	[0.006]	[0.070]	[0.000]	[0.000]
Italy	1970q1-2018q1		1970q1-1979q4		1980q2-2018q1	
Statistic	3.09	-2.45	3.19	-1.99	3.94	-2.76
P-values:						
I(0)	[0.198]	[0.123]	[0.189]	[0.246]	[0.105]	[0.062]
I(1)	[0.303]	[0.220]	[0.289]	[0.365]	[0.177]	[0.128]
Spain	1980q1-2018q1		1980q1-2010q1		2010q3-2018q1*	
Statistic	3.38	-2.52	6.27	-3.37	6.40	-3.55
P-values:						
I(0)	[0.159]	[0.104]	[0.019]	[0.013]	[< 0.025]	[< 0.01]
I(1)	[0.253]	[0.192]	[0.037]	[0.037]	[< 0.05]	[< 0.025]
Euro area	1970q1-2018q1		1970q1-1993q2		1993q4-2018q1	
Statistic	11.25	-4.67	6.33	-3.42	8.84	-3.97
P-values:						
I(0)	[0.000]	[0.000]	[0.019]	[0.012]	[0.003]	[0.002]
I(1)	[0.001]	[0.001]	[0.036]	[0.034]	[0.006]	[0.007]

Notes: [1] P-value in brackets, based on the bounds of asymptotic critical values in Pesaran et al. (2001). [2] (H_0: no long-run relationship) is rejected at ($\alpha \times 100$)% significance level if both the p-values for I(1) variables are less than α; (H_0: no long-run relationship) cannot be rejected at ($\alpha \times 100$)% significance level if both the p-values for I(0) variables are above α. [*] The number of lags included in the equation for Spain after 2010Q3 is above the number of observations, thus allowing to compute only thresholds for the p-values.

That being said, aggregation across euro area countries might anyways conceal important country-specific dynamics, as also partially indicated by Figure 1.1.2. Therefore, Equation (1.2) is estimated separately for the four biggest euro area economies: France, Germany, Italy and Spain. Results, displayed in Tables 1.2.4 and 1.2.5, show a significant decrease in the long-run coefficient for Germany, Italy and, to a lesser extent, France.

Table 1.2.3: Regression results - **Euro area**

$\Delta comp_t$	(1) ARDL(5,0) 1970q1-2018q1	(2) ARDL(1,0) 1970q1-1993q2	(3) ARDL(5,0) 1993q4-2018q1
$prod_{t-1}$	**0.878*** **	**1.353*** **	0.190
	(0.232)	(0.403)	(0.275)
$comp_{t-1}$	**-0.197*** **	**-0.225*** **	**-0.288*** **
	(0.042)	(0.066)	(0.073)
$\Delta comp_{t-1}$	0.090		**0.222*** **
	(0.069)		(0.083)
$\Delta comp_{t-2}$	**0.265*** **		**0.263*** **
	(0.069)		(0.088)
$\Delta comp_{t-3}$	**0.281*** **		**0.298*** **
	(0.069)		(0.087)
$\Delta comp_{t-4}$	**-0.223*** **		**-0.196** **
	(0.072)		(0.094)
U_{t-1}	**-0.077** **	-0.033	-0.063
	(0.032)	(0.048)	(0.043)
Constant	**0.710** **	0.119	**0.741* **
	(0.332)	(0.483)	(0.434)
Observations	176	79	98
R^2	0.285	0.152	0.365
F-test - H_0: long-run coefficient equal to 1			
Test statistic	0.28	0.77	8.66
P-value	0.60	0.38	0.00

Notes: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard error in parentheses. Break dates are detected via a Supremum Wald test on the coefficients of the regression $comp_t = \alpha_0 + \alpha_1 prod_t + \varepsilon_t$. Lag lengths of the model are selected using the Schwartz information criterion (SIC).

This seems to be in line with a generalized weakening in the productivity-compensation link over time (Karabarbounis and Neiman (2014)), although the full-sample coefficient for Germany is not statistically different from 1. On the other hand, the long-run coefficients are not significant for Spain. This heterogeneity in the magnitude, the significance and the timing of the estimates might be due to different levels of cyclical adjustment as well as market flexibility (Kügler et al. (2018)). Moreover, cross-country differences can also be determined by both firm-level dynamics and discrepancies in public policies and institutional settings (OECD (2018)). In this regard, the adoption of the euro might have entailed a structural change in the relationship of interest at the euro area level, thus seemingly confirming the generalized opinion that the single currency, or rather the process leading to its introduction, might have generated a compression of compensation due to a loss in external competitiveness (Micossi (2015)). However, country-level results do not support this interpretation in that the detected breaks are placed on dates that are not compatible with the monetary union timeline. In addition, existing literature has provided evidence that the interplay between external competitiveness and labor costs in the euro area does not always follow a clear-cut direction (Gabrisch and Staehr (2014)).

Table 1.2.4: Regression results - **France and Germany**.

	France			Germany		
	ARDL(7,6)	ARDL(2,2)	ARDL(4,1)	ARDL(6,2)	ARDL(1,0)	ARDL(2,7)
$\Delta comp_t$	1970q1-2018q1	1970q1-1977q2	1977q4-2018q1	1970q1-2018q1	1970q1-1991q1	1991q3-2018q1
$prod_{t-1}$	**0.382****	**0.576****	**0.436*****	**0.962*****	**1.595*****	0.331
	(0.164)	(0.279)	(0.088)	(0.293)	(0.582)	(0.366)
$\Delta prod_t$	**0.288*****	0.126	**0.321*****	0.015		-0.163
	(0.065)	(0.105)	(0.076)	(0.079)		(0.117)
$\Delta prod_{t-1}$	**-0.432*****	**-0.561*****		**-0.300*****		**-0.305*****
	(0.0678)	(0.101)		(0.0764)		(0.112)
$\Delta prod_{t-2}$	0.023					-0.075
	(0.060)					(0.108)
$\Delta prod_{t-3}$	**0.143****					-0.016
	(0.063)					(0.083)
$\Delta prod_{t-4}$	**0.175*****					**-0.405*****
	(0.066)					(0.080)
$\Delta prod_{t-5}$	**-0.229*****					0.056
	(0.068)					(0.086)
$\Delta prod_{t-6}$	**0.118****					**-0.335*****
	(0.067)					(0.081)
$comp_{t-1}$	**-0.268*****	**-0.306*****	**-0.383*****	**-0.248*****	**-0.231*****	**-0.321*****
	(0.054)	(0.087)	(0.049)	(0.048)	(0.074)	(0.046)
$\Delta comp_{t-1}$	**0.437*****	**0.533*****	**0.169*****	**0.191****		**0.269*****
	(0.077)	(0.116)	(0.063)	(0.077)		(0.085)
$\Delta comp_{t-2}$	**0.256*****		**0.265*****	0.074		
	(0.075)		(0.063)	(0.073)		
$\Delta comp_{t-3}$	0.066		**0.276*****	**0.130***		
	(0.068)		(0.065)	(0.069)		
$\Delta comp_{t-4}$	**-0.365*****			-0.061		
	(0.069)			(0.070)		
$\Delta comp_{t-5}$	**0.203*****			**0.334*****		
	(0.068)			(0.068)		
$\Delta comp_{t-6}$	**0.118****					
	(0.052)					
U_{t-1}	**-0.133*****	0.150	**-0.108*****	**-0.0878****	0.024	**-0.172*****
	(0.035)	(0.209)	(0.031)	(0.043)	(0.074)	(0.053)
Constant	**1.393*****	0.735	**1.206*****	0.665	-0.492	**1.631*****
	(0.372)	(0.783)	(0.319)	(0.419)	(0.625)	(0.465)
Observations	215	56	162	176	71	107
R^2	0.634	0.694	0.521	0.353	0.219	0.614
F-test - H_0: long-run coefficient equal to 1						
Test statistic	14.22	2.31	40.69	0.02	1.05	3.35
P-value	0.00	0.14	0.00	0.90	0.31	0.07

Notes: Standard errors in parentheses, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Break dates are detected via a Supremum Wald test on the coefficients of the regression $comp_t = \alpha_0 + \alpha_1 prod_t + \varepsilon_t$. Lag lengths of the model are selected using the Schwartz information criterion (SIC).

The possible presence of time variation in the estimates as well as of a long-run relationship between productivity and compensation call for the adoption of a framework accounting for both issues. The choice of the model, however, depends on whether the time variation is continuous or discrete. It becomes then necessary to test for the presence of continuous time variation in the compensation-productivity link. This is done by using the time-varying paramenter median unbiased estimator (TVP-MUB)

Table 1.2.5: Regression results - **Italy and Spain**.

	Italy			Spain†		
	ARDL(9,1)	ARDL(5,0)	ARDL(9,1)	ARDL(5,5)	ARDL(1,1)	ARDL(8,9)
$\Delta comp_t$	1970q1-2018q1	1970q1-1979q4	1980q2-2018q1	1980q1-2018q1	1970q1-2010q1	2010q3-2018q1
$prod_t$	0.084	**0.753****	-0.0341	0.550	0.348	-0.412
	(0.265)	(0.317)	(0.223)	(0.451)	(0.341)	(0.683)
$\Delta prod_t$	**0.210****		**0.242*****	**0.564*****	**0.517*****	**1.002***
	(0.083)		(0.084)	(0.110)	(0.097)	(0.502)
$\Delta prod_{t-1}$				-0.096		-0.681
				(0.108)		(0.531)
$\Delta prod_{t-2}$				**-0.398*****		-0.492
				(0.108)		(0.440)
$\Delta prod_{t-3}$				-0.165		-0.619
				(0.114)		(0.443)
$\Delta prod_{t-4}$				**0.257****		0.498
				(0.111)		(0.331)
$comp_{t-1}$	**-0.181****	**-0.493***	**-0.238*****	**-0.189*****	**-0.206*****	**-0.352****
	(0.074)	(0.248)	(0.086)	(0.049)	(0.057)	(0.145)
$\Delta comp_{t-1}$	-0.102	**0.348****	-0.051	-0.080		**0.515****
	(0.087)	(0.163)	(0.094)	(0.085)		(0.214)
$\Delta comp_{t-2}$	0.042	**-0.497*****	**0.232****	**0.184****		**0.543****
	(0.087)	(0.163)	(0.095)	(0.085)		(0.216)
$\Delta comp_{t-3}$	**0.170****	**0.295****	**0.207****	**0.155***		**0.720****
	(0.086)	(0.126)	(0.096)	(0.083)		(0.247)
$\Delta comp_{t-4}$	**-0.557*****	**-0.656*****	**-0.543*****	**-0.329*****		-0.064
	(0.083)	(0.142)	(0.091)	(0.082)		(0.171)
$\Delta comp_{t-5}$	**-0.166****		-0.122			**0.417****
	(0.071)		(0.077)			(0.164)
$\Delta comp_{t-6}$	0.040		0.109			0.256
	(0.071)		(0.077)			(0.191)
$\Delta comp_{t-7}$	**0.170****		**0.184****			**0.465****
	(0.070)		(0.077)			(0.179)
$\Delta comp_{t-8}$	**-0.272*****		**-0.211*****			
	(0.070)		(0.074)			
U_{t-1}	-0.008	-0.002	0.014	-0.034	-0.027	-0.300
	(0.054)	(0.605)	(0.051)	(0.026)	(0.039)	(0.165)
Constant	0.214	0.790	0.049	0.612	0.645	**6.655***
	(0.543)	(3.429)	(0.503)	(0.414)	(0.539)	(3.354)
Observations	176	28	152	136	106	30
R^2	0.539	0.805	0.543	0.517	0.388	0.916
F-test - H_0: long-run coefficient equal to 1						
Test statistic	11.92	0.61	21.43	1.00	3.66	4.28
P-value	0.00	0.45	0.00	0.320	0.059	0.066

Notes: Standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Break dates are detected via a Supremum Wald test on the coefficients of the regression $comp_t = \alpha_0 + \alpha_1 prod_t + \varepsilon_t$. Lag lengths of the model are selected using the Schwartz information criterion (SIC).
† For the sake of brevity, coefficient estimates for $\Delta prod_{t-i}, i = 5, \ldots, 7$ in the Spain regression are omitted as they are not significant.

approach proposed in Stock and Watson (1998), Benati (2007) and Benati and Lubik (2014)[16]. Results, reported in Table 1.2.6, provide strong evidence of random walk time variation in the equation for compensation both for the aggregate euro area and for France, Germany, Italy and Spain.

1.3 Time-varying VAR with stochastic volatility

As explained in Section 1.1 and further supported by the empirical evidence discussed in Section 1.2, the type of patterns detected in the productivity-compensation link in the euro area and its biggest economies require a modelling approach that accounts for some

[16] See Appendix A.2 for details.

Table 1.2.6: Test results based on Stock and Watson TVP-MUB methodology.

	euro area		*France*		*Germany*	
	EW	SW	EW	SW	EW	SW
Statistic	16.22	40.07	53.52	116.78	13.65	35.77
P-value	(0.0001)	(0.0001)	(0.00)	(0.00)	(0.0002)	(0.0001)
$\hat{\lambda}$	0.047	0.049	0.036	0.036	0.058	0.063
	Italy		*Spain*			
	EW	SW	EW	SW		
Statistic	60.52	129.79	7.29	22.00		
P-value	(0.00)	(0.00)	(0.014)	(0.009)		
$\hat{\lambda}$	0.034	0.034	0.039	0.043		

Notes: Statistics - EW: *exp*-Wald test; SW: *sup*-Wald test; H_0: no random walk time variation in the sum of coefficients; p-values in parentheses. Standard errors are computed using the Newey-West HAC covariance estimator.

important non-linearities in such relationship. Moreover, the outcome of the TVP-MUB test has shown that these non-linearities can be best captured in a continuous time framework, rather than via discrete changes[17].

For these reasons, and following Galí and Gambetti (2009), Benati and Lubik (2014) and Guglielminetti and Pouraghdam (2018), the ensuing analysis will be based on the estimation of a time-varying parameter Vector Autoregressive model with stochastic volatility (TVP-VAR-SV) à la Primiceri (2005) and Del Negro and Primiceri (2015). Specifically, the framework is based on the following reduced-form model:

$$Y_t = B_{0,t} + B_{1,t}Y_{t-1} + \cdots + B_{k,t}Y_{t-k} + \nu_t \equiv X_t'\theta_t + \nu_t \tag{1.3a}$$

$$X_t' = I_N \otimes [1, Y_{t-1}', \ldots, Y_{t-k}'] \tag{1.3b}$$

$$\theta_t = [B_{0,t}, B_{1,t}, \ldots, B_{k,t}] \tag{1.3c}$$

where Y_t is a $T \times N$ vector of endogenous variables, $B_{0,t}$ is a vector of time-varying intercepts, $B_{i,t}, i = 1, \ldots, k$ are matrices of time-varying coefficients and ν_t is a $T \times 3$ vector of unconditionally heteroskedastic disturbance terms with time-varying covariance matrix Σ_t. Equation (1.3b) and Equation (1.3c) provide the state-space representation of the model. The variables included are real hourly productivity growth, $prod_t$, real hourly compensation growth, $comp_t$, and the log-unemployment rate, u_t. Following Primiceri (2005) and Del Negro and Primiceri (2015), all the time-varying coefficients are modeled

[17]This finding is also supported by some evidence from labor studies at the micro level, in particular in regard to the "composition effect" over wage distribution (Fernandez-Val et al. (2018)).

as random walks with independent innovations. Moreover, the reduced-form innovations ν_t are assumed to be a time-varying linear transformation of the underlying structural shocks, ε_t:

$$\nu_t \equiv Q_t \varepsilon_t$$

which implies that $Q_t Q_t' = \Sigma_t$. As in Peneva and Rudd (2017), the relevant structural shocks are identified via a Choleski factorization of Σ_t, with the endogenous variables ordered as presented above. In addition, the lag-length k is set equal to 4. The model is then estimated by means of a Bayesian MCMC algorithm[18].

1.3.1 Results

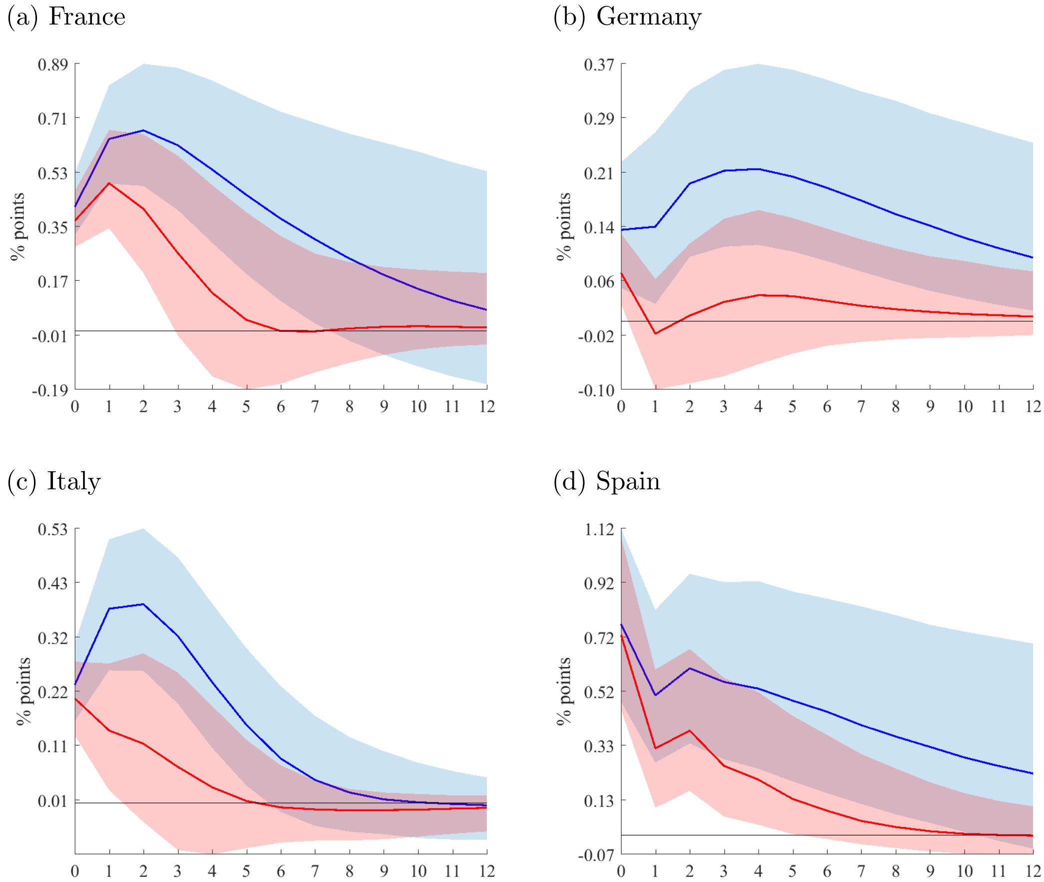
In the context of the TVP-VAR-SV, time-varying impulse response functions (IRFs) of compensation to a shock in productivity growth can provide a good indication as to whether the compensation-productivity relationship has significantly changed over the period considered. Figures 1.3.1 and 1.3.2 display the evolution in these IRFs from the 1970s to today. Generally speaking, the effect has become less and less significant over time, though at different pace in the four economies. This heterogeneity is more evident when considering the 4-quarter-ahead impact of productivity shock over compensation (Figure 1.3.3).

For France and Italy, indeed, the delinkage looks to have taken place between the 1970s and the 1980s, with an average decrease in the median cumulative response of around 0.7 pps (40%) and 1.4 pps (55%), even though for France there is also evidence of a slight inversion of this trend after the end of 1990s. In Germany, on the other hand, the turning point seems to be placed at the beginning of the 1990s, with an average decrease in the median 4-quarter-ahead impact of 0.64 pps (70%). Moreover, and differently from the other three cases, the estimates are not statistically different from 0 from 1991Q3 on. Finally, in Spain the response has dropped on average by 0.13 pps (6%) before and after 2010Q2, which is far lower than the decrease estimated for the other countries and also not statistically significant.

Additional insights in this regard are provided by the historical decomposition of hourly compensation growth (Figure 1.3.4). Compared to the beginning of the sam-

[18] See Appendix A.3 for additional technical details.

Figure 1.3.1: IRFs of hourly compensation growth to a 1 p.p. increase in productivity growth at beginning (blue) and end of sample (red).

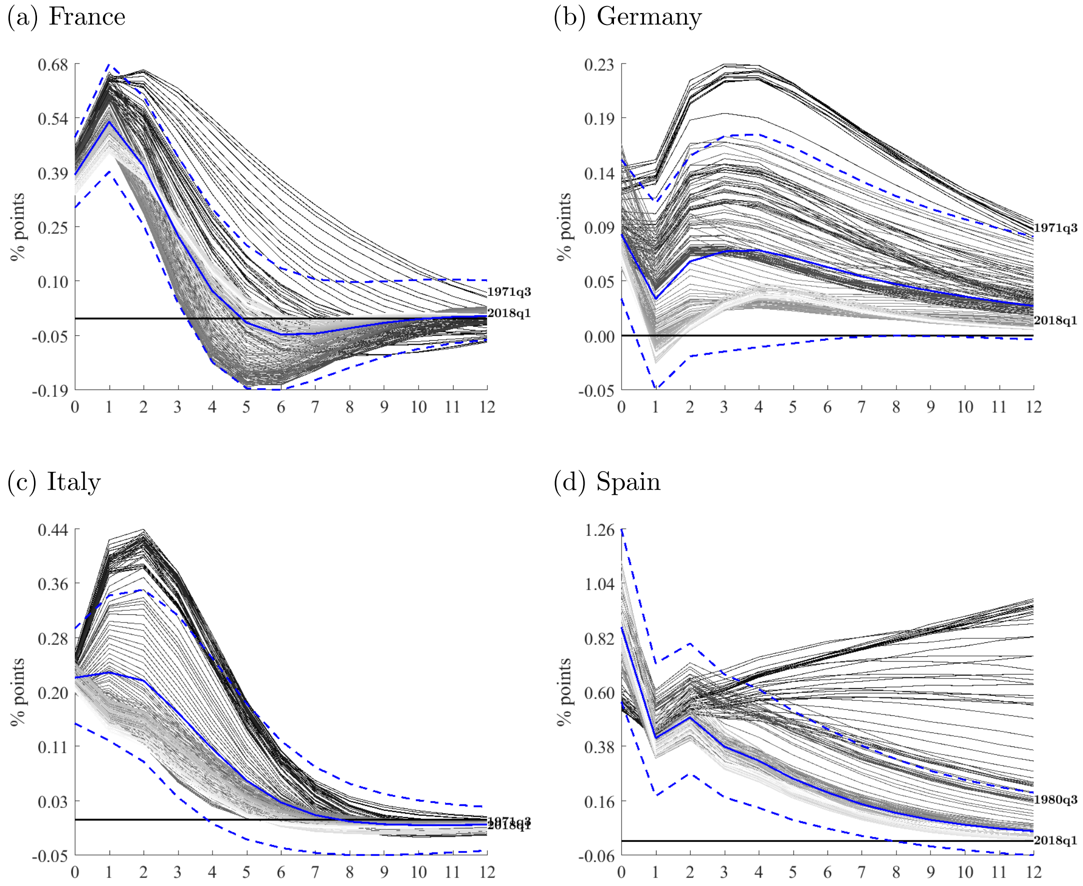


Notes: Shaded areas are 68% confidence bands.

ple, the contribution of productivity shocks to compensation has generally decreased over time, with the notable exception of Italy. The picture also reveals another important fact, i.e. that compensation and productivity contributions have become less synchronized domestically, which is in line with the results of the univariate estimations in Section 1.2 and is also compatible with the gradual decrease in the conditional correlation between productivity and compensation (Figure 1.3.5). However, there are some evident cross-country co-movements during the period 2009-2013 which roughly corresponds to the euro area sovereign debt crisis, especially for France, Germany and Italy.

This latter aspect is further explored by tracking the evolution of the productivity-compensation dynamic multiplier, which is computed on the basis of the cumulative

Figure 1.3.2: Evolution of median IRFs of hourly compensation growth to a 1 p.p. increase in productivity growth from beginning (blue) to end of sample (red).



Notes: Blue lines are the time-invariant mean IRFs (solid) with 68% confidence bands (dashed).

impulse responses generated by the TVP-VAR as follows[19]:

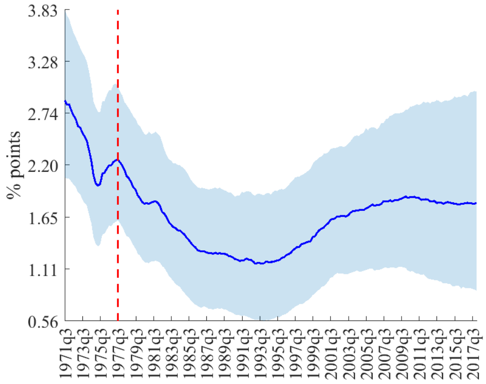
$$\Phi_t^i(k) \equiv \left| \frac{\sum_{k=0}^{K} \frac{\partial prod_{t+k}}{\partial \varepsilon_t^u}}{\sum_{k=0}^{K} \frac{\partial comp_{t+k}}{\partial \varepsilon_t^u}} \right| \tag{1.4}$$

where $K = 0, 1, \dots, 8$ and ε_t^u is the structural unemployment shock. These statistics are more suitable to analyse the relationship across these variables, in that they abstract from any *ex ante* assumption around the functional form of the link and thus allow to control for possibly disregarded additional relations between compensation and productivity. Results, shown in Figure 1.3.6, unveil some interesting differences across countries. In Germany (Figure 1.3.6b) multiplier estimates are consistently above one on impact and increasing across horizons, thus implying that productivity is much more reactive than compensation to a change in unemployment rate. The maximum value of

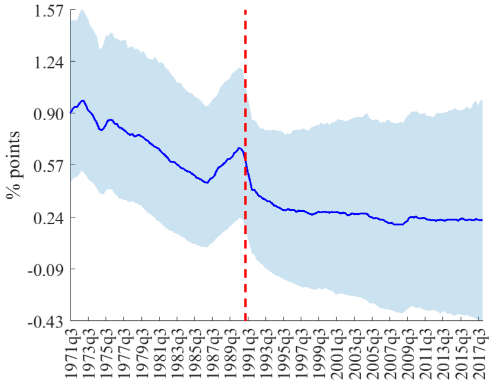
[19] Galí and Gambetti (2019) use this approach to estimate the wage inflation-unemployment multiplier in a TVP-VAR setting. See also Barnichon and Mesters (2019).

Figure 1.3.3: 4-quarter-ahead cumulative impact of a 1 p.p. shock in productivity growth on compensation growth.

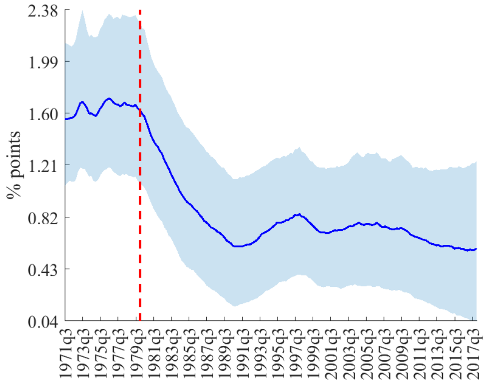
(a) France



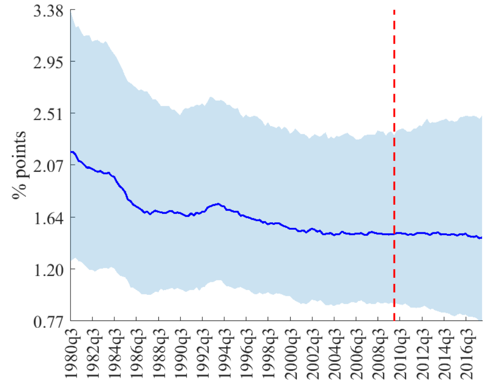
(b) Germany



(c) Italy



(d) Spain



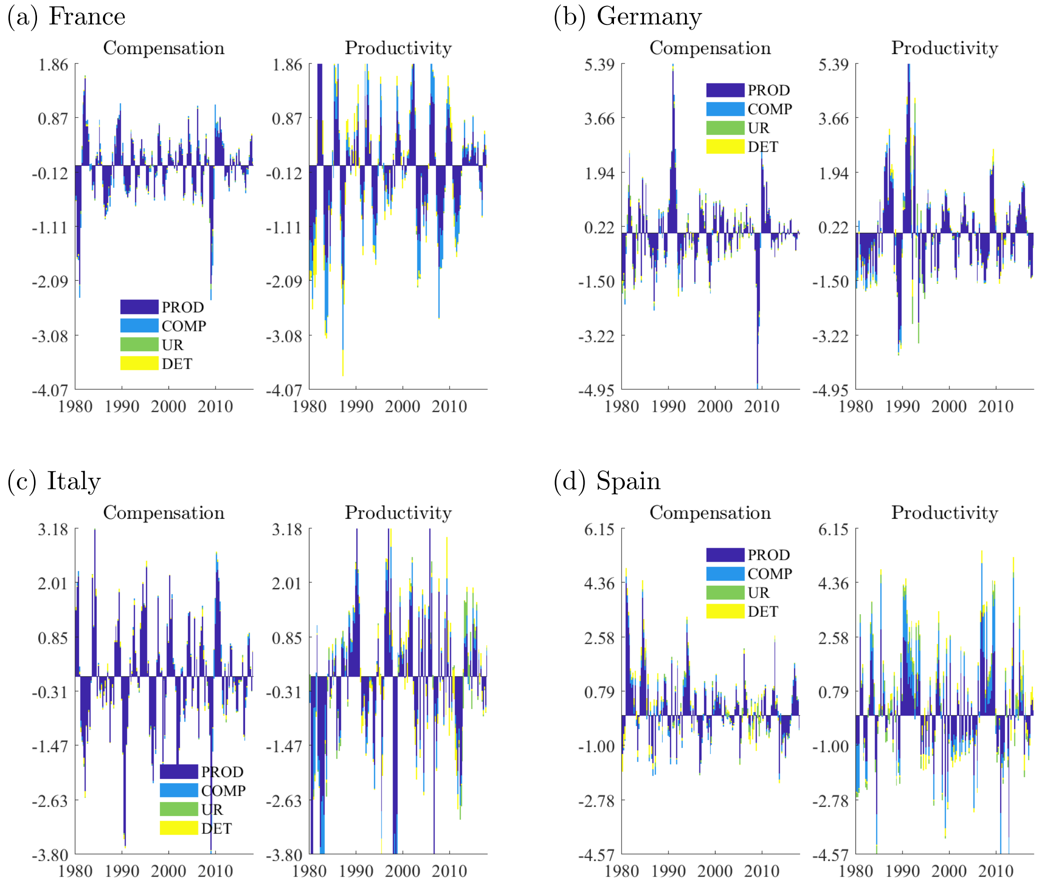
Notes: Shaded areas are 68% confidence bands. Red dashed lines indicate the break in the data.

the multiplier, around 4, is registered at quarter eight, in the mid 2000s. After then, however, the curve at later horizons (quarters 6, 7 and 8) is much flatter, as estimated values are always below 3.

Estimates for France (Figure 1.3.6a), on the other hand, are on average 1 on impact and then show a certain degree of time variation in the longer-run. At the beginning of the sample and until the mid 1990s, indeed, the curve presents a downward slope which indicates a delayed catch-up of compensation with productivity. However, starting from the end of 1990s, the slope gets positive, in particular from quarter four on, with a peak of 2 at quarter eight around the beginning of 2010s. Therefore, while in earlier periods (1970s and 1980s) productivity and compensation have been able to adjust to the same extent to unemployment shocks, with the latter eventually surpassing the former, this has not been the case after the mid 1990s as indicated by the higher estimates of the multiplier.

Results in the cases of Italy and Spain (Figures 1.3.6c and 1.3.6d) depict a somewhat

Figure 1.3.4: Historical decomposition of hourly compensation growth.

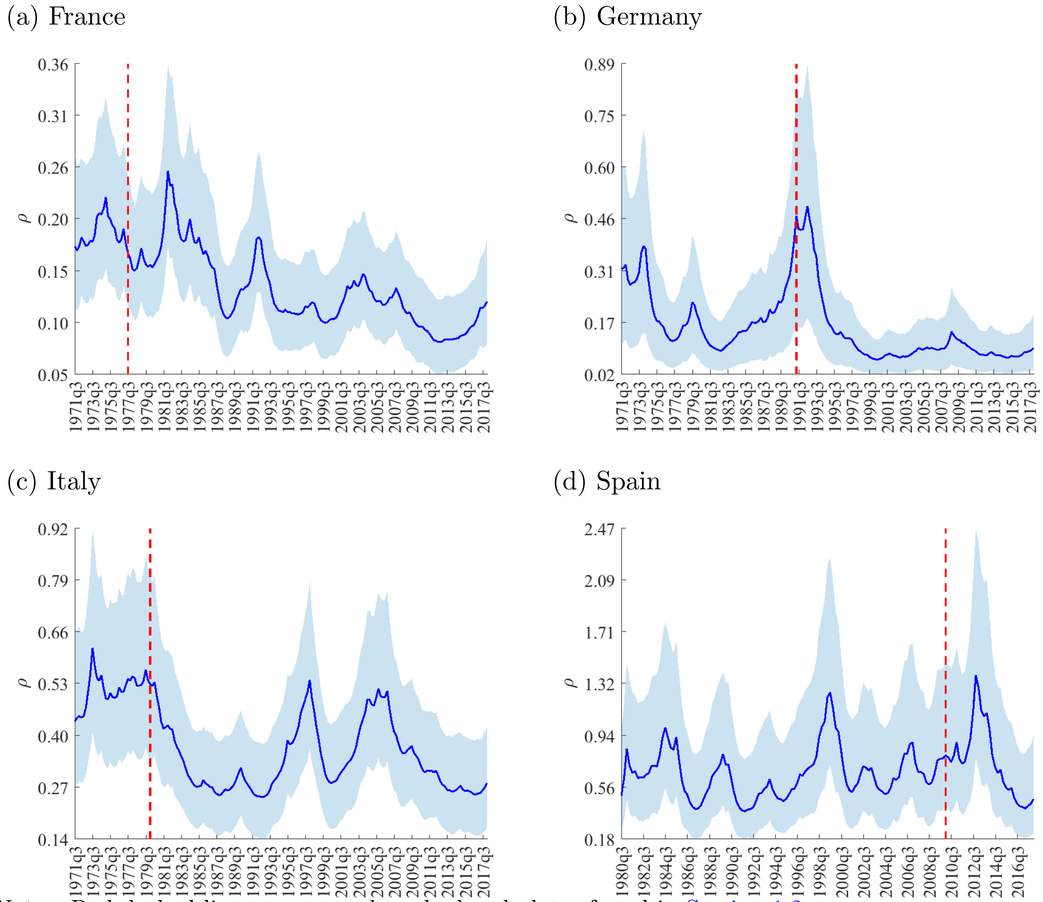


Notes: Contributions of: 1.productivity growth (blue); 2.compensation growth (light blue); 3.unemployment (green); 4.deterministic component (yellow).

different picture. For Italy, the multiplier is consistently below unity, which seems to suggest that compensation reacts to macroeconomic shocks on average more than productivity. In addition, estimates show a downward trend moving towards the longer-run, thus implying that the adjustment is mainly driven by changes in compensation rather than productivity. However, the degree of transmission has evolved over time, in that the decrease of the multiplier in the is more marked during the 1990s. Similarly, for Spain the multiplier has a downward slope, but estimates are on average above 1 and display a high degree of time variation at longer horizons. This result suggests a more pronounced effect on productivity rather than compensation.

All in all, then, dynamic multipliers show two evident dimensions of heterogeneity: 1) cross-country, with some countries experiencing more down- and upward compensation stickiness than others as in the cases of France and Germany; 2) over time, with the channels of transmission of macroeconomic shocks changing across different periods and horizons.

Figure 1.3.5: Time-varying conditional correlation coefficient between productivity and compensation growth.



Notes: Red dashed lines correspond to the break dates found in Section 1.2.

Against these results, it needs to be assessed whether the productivity-compensation link displays a comparable degree of time-variation also in the long-run, as the results of the ARDL model in Section 1.2 seem to suggest. This is done by computing the time-varying unconditional means of productivity and compensation growth. Notably, Equation (1.3a) above can be rewritten in companion form as:

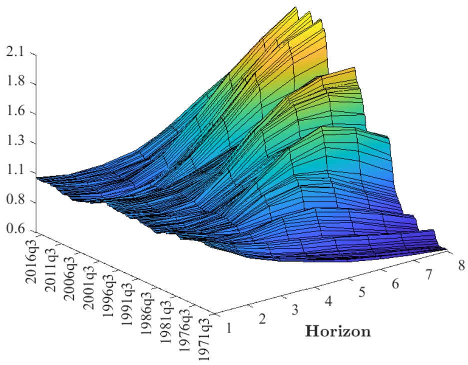
$$\mathbf{Y}_t = \mu_t + \mathbf{C}_t \mathbf{Y}_{t-1} + \epsilon_t \tag{1.5}$$

where $\mathbf{Y}_t' = [Y_t', \ldots, Y_{t-k+1}']$, $\epsilon_t = [\nu_t', 0, \ldots, 0]$ and:

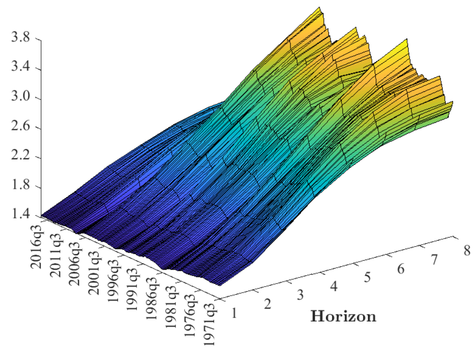
$$\mathbf{C}_t = \begin{bmatrix} B_{1,t} & B_{2,t} & \ldots & B_{k-1,t} & B_{k,t} \\ I_N & 0 & \ldots & 0 & 0 \\ 0 & I_N & \ldots & 0 & 0 \\ \vdots & & \ddots & & \vdots \\ 0 & \ldots & \ldots & I_N & 0 \end{bmatrix}, \qquad \mu_t = \begin{bmatrix} B_{0,t} \\ 0 \\ \vdots \\ 0 \end{bmatrix}.$$

Figure 1.3.6: Productivity/compensation dynamic multipliers for a 1% increase in unemployment rate.

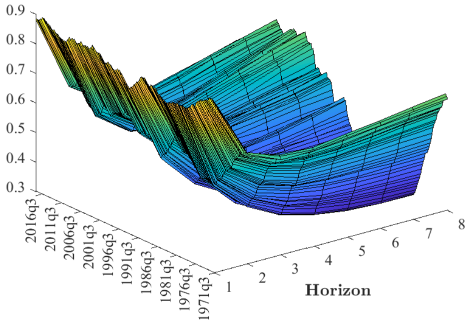
(a) France



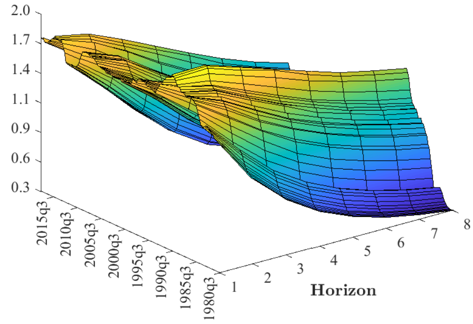
(b) Germany



(c) Italy



(d) Spain



The unconditional long-run mean of the vector $\mathbf{Y}_t$ at time t is then given by $E_t(\mathbf{Y}_t) = (I_N - \mathbf{C}_t)^{-1}\mu_t$. As shown in Figure 1.3.7, the median long-run means mirror some country-specific dynamics that are partially in line with the ARDL estimates[20]. Notably, there are instances of a less-than-one pass-through from productivity to compensation in Germany and Italy (Figures 1.3.7b and 1.3.7c). However, in Germany the wedge between the two growth rates has soared after 1991Q3 due to a jump in productivity and has remained more or less constant since 2005Q3; in Italy, on the other hand, the discrepancy between the two means is particularly pronounced between 1980Q1 and 2009Q3, but it closes in the second half of the sample where compensation growth slightly outperforms productivity.

As to Spain (Figure 1.3.7d), compensation growth is actually higher than productivity until 2000Q3, though at an evident decreasing rate. After then, the two means are very correlated, with productivity growing slightly more than compensation during the

[20] Galí and Gambetti (2019) show that the key qualitative findings provided by unconditional reduced form regressions can also emerge in the conditional (structural) estimation.

crisis period (2008-2010) and, conversely, compensation growing more than productivity after 2010Q3.

Finally, for France (Figure 1.3.7a) the increasing wedge between compensation and productivity after 1977Q3 is characterized by a marked downward trend in both variables, with compensation growth being consistently higher than productivity growth, a finding which is unique to this country. In this case, it is not possible to talk about a proper decoupling but rather of a strong decrease in both productivity and compensation. These particular dynamics could not be captured by a discrete time model.

The results so far discussed well fit the timing of some important country-specific events, as well as their narrative. In Italy, for instance, the difference between productivity and compensation growth rates peaks in 1993Q3, which broadly corresponds to the heat-up of the Italian debt crisis. This crisis derived from a speculative attack on the Italian lira which led to the suspension of the Exchange Rate Mechanism (ERM) and a devaluation of around 22% against the Deutsche Mark between 1992 and 1996. Such speculative attack, which also targeted other members of the European Monetary System (EMS) like UK, Denmark, Sweden and Finland, had also originated from the decision of the Bundesbank to raise its key interest rate to countervail inflationary pressures stemming from the post-reunification boom (1991Q3).

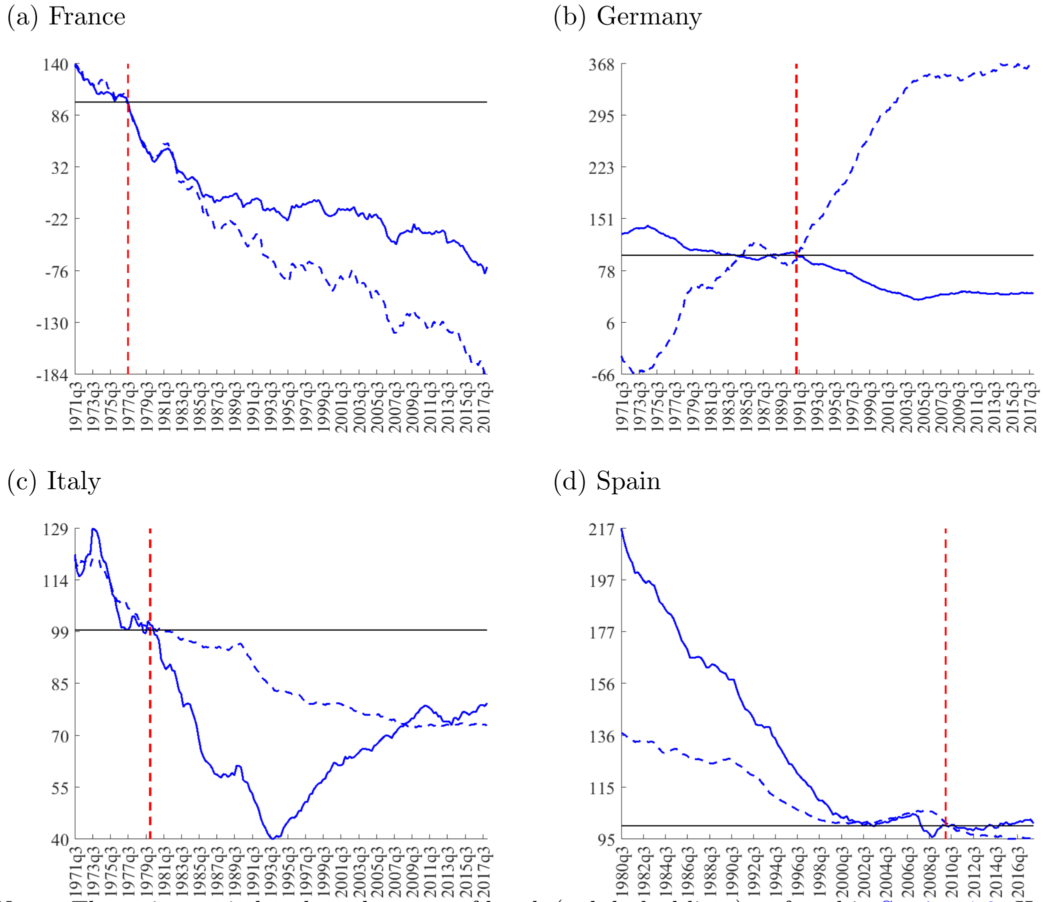
Relatedly, 1991Q3 also marks the break in the compensation-productivity link for Germany, where the increase in the gap between compensation and productivity growth highlighted in Figure 1.3.7b comes to a stop in the mid 2000s, a period that roughly corresponds to the implementation of a set of extensive labor market reforms, known as the Hartz reforms, aimed at increasing job market efficiency[21].

1.4 Concluding remarks

The productivity-compensation delinkage is a widespread phenomenon across advanced economies. The extent to which changes in productivity are transmitted to movements in wages is crucial for determining how income produced at the macroeconomic level is distributed across households, thus determining the level of income inequality. For this reason, the decoupling between wages and productivity has attracted more and more

[21] See Fahr and Sunde, Klinger and Rothe (2012), Hertweck and Sigrist (2013) and Klinger and Weber (2016).

Figure 1.3.7: Long-run means of productivity (dashed) and compensation (solid) growth.



Notes: The series are indexed on the years of break (red dashed lines) as found in Section 1.2. Hence for France: 1977 = 100; for Germany: 1991 = 100; for Italy: 1980 = 100; for Spain: 2010 = 100.

attention on the part of the policymakers. Against this backdrop, the euro area case has become particularly relevant in light of the apparent effects stemming from the adoption of the single currency.

This chapter contributes to the ongoing debate by providing some new evidence on the dynamics of the productivity-compensation relationship in the euro area. Notably, it shows not only that there is a wedge between compensation and productivity, but also that the extent of this delinkage has changed over time, with a structural break in the long-run relationship between compensation and productivity growth taking place around the end of 1993, when the Maastricht Treaty entered into force. In addition, some empirical evidence is provided on the existence of significant cross-country heterogeneity by analysing the four biggest euro area economies separately. Specifically, in France the long-run gap between compensation and productivity has been more or less constant over time due to a persistent decrease in both variables, but the short-run dynamics also show signs of a re-linkage in more recent times. In Germany, on the other hand, the de-linkage observed in the data seems to have been rather driven by an upward jump in productivity after the reunification which has not been matched by a likewise increase in compensation; in addition, the compensation-productivity wedge appears to be constant since the mid 2000s. In Italy, compensation growth has dropped far below productivity growth over the period 1980-2007, whereas in Spain compensation has generally grown more than productivity for most of the sample, with a temporary reverse in this trend during the 2007-2009 crisis. However, the analysis also highlights how the long-run gap between productivity and compensation has been closing up in both Italy and Spain.

This evidence can be used as a well grounded starting point for delving deeper into the study of the main drivers underlying these different dynamics. The model adopted in this chapter provides a framework which is flexible enough to expand the analysis in this sense and this is a venue for future research.

Chapter 2

Does one (unconventional) size fit all? Effects of the ECB's unconventional monetary policies on the euro area economies

2.1 Introduction

> *Within our mandate, the ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough* (Draghi (2012)).

In the wake of the global financial market turmoil in 2007-2009 (GFC henceforth), all major central banks loosened their monetary policies by aggressively cutting the policy rates to historically low levels and, after reaching the zero lower bound on short-term interest rates, by also embarking on a series of unconventional monetary policy measures (UMPs) aimed at containing the risks to economic and financial stability. These measures can be classified along three dimensions: (i) the immediate impact on the central bank balance sheet; (ii) the choice of the counterparties for the non-standard central bank transactions; (iii) the intent of either re-establishing conventional channels of monetary transmission or of exploiting typically neglected ones.

The first dimension characterizes the large-scale asset purchases (LSAP) conducted after 2008 by several central banks, including the Federal Reserve (FED) and the European Central Bank (ECB). These interventions are referred to as "Quantitative Easing" (QE) and expanded the central banks balance sheet by withdrawing large quantities of longer-term sovereign securities from the private sector. Over the same period, however, central banks also undertook policies commonly named "Qualitative Easing" (QualE), that changed the *composition* of their balance sheets by replacing 'conventional' assets with 'unconventional' ones[1]. In this context, central bank balance sheets have increasingly become the most important monetary policy instrument, thus replacing interest rates (Gambacorta et al. (2014)).

Against this backdrop, it becomes important to assess whether and how UMPs, also known as "balance sheet policies", have impacted the real economy[2].

While there is an extensive literature that investigates the impact of traditional interest rate movements on real activity and inflation, quantifying UMPs impact has posed new challenges to both empirical and theoretical frameworks, the major difficulty being that there is no well-defined instrument providing an encompassing evaluation of a central bank's unconventional policy stance. The existing empirical literature can be then classified according to the choice of the policy instrument used to measure UMPs.

Part of the literature makes use of high-frequency data to quantify the impact of Federal Reserve's (FED's) QE surprises on financial variables[3], the main finding being that a QE announcement is typically followed by a decrease in domestic interest rates and a depreciation of the US dollar against the other major currencies. More recent similar studies focusing on the euro area find that monetary policy surprises can be decomposed into a number of factors, each affecting a different portion of the yield curve (Altavilla et al. (2019)). Their effects are complemented by positive shocks stemming from the information that the central bank provides on the economic outlook (Jarociński and Karadi (forthcoming)). These latter papers, however, do not disentangle between conventional and unconventional monetary policy measures, thus implicitly assuming that their effect on the economy is similar in nature and that the only difference observed is given by the magnitude of shocks as measured with high-frequency data.

Another strand of the literature analyses the composition and size of the central balance sheet to assess the broader macroeconomic effects of UMPs. Peersman (2011), for instance, provides empirical evidence that shifts in the monetary base and the balance sheet of the Eurosystem due to UMP shocks have a significant impact on both output and inflation. Similarly, Gambacorta et al. (2014) find that expansionary UMPs

[1] See Buiter (2008, 2010).

[2] Section 2.2 below provides an overview of all the different UMPs implemented by the major central banks as a response to the GFC.

[3] See, among others, Joyce et al. (2011), Krishnamurthy and Vissing-Jorgensen (2011), Gagnon et al. (2011), Hamilton and Wu (2012), D'Amico et al. (2012), D'Amico and King (2013).

lead to a significant, yet temporary, increase in output and prices in the US, the euro area and Japan, with effects that are comparable to those deriving from movements in the policy rate (i.e. conventional monetary policy). Boeckx et al. (2017) show that an expansionary balance sheet shock stimulates euro area aggregate bank lending, reduces interest rate spreads, leads to a depreciation of the euro, and has a positive impact on economic activity and inflation, these effects being substantial in the aftermath of the crisis. Burriel and Galesi (2018), on the other hand, demonstrate that benefits coming from ECB's UMPs are heterogeneous across euro area members, and the effects on real economic activity are substantially dampened in countries with more fragile banking systems. Moreover, and similarly to Gambacorta et al. (2014), they document that UMP shocks entail smaller and less persistent effects than those arising from conventional interest rate surprises.

Finally, a third strand of the literature proxies the policy stance by analysing the developments of either the long-term interest rates or the long-short term spreads. Among others, Lenza et al. (2010) find that in the euro area the compression of the interest spreads exerts a sizable effect on loans and interest rates and has a delayed impact on the real economy, while the reaction of broad money is rather modest. Kapetanios et al. (2012) show that the Bank of England's (BoE's) QE has been effective in avoiding a deeper recession and deflation, while Churm et al. (2018) find that the BoE's second QE round has also had a a positive effect on economic activity, though smaller than the first. In the same vein, Baumeister and Benati (2013) provide evidence that the FED's and the BoE's UMPs have avoided a large, Depression-like output collapse[4]. Chen et al. (2016) use a global vector error-correction model to show that the FED's QE impact is more pronounced when UMP shocks are measured via the US corporate spread. Meinusch and Tillmann (2016) provide an interesting contribution to the empirical literature by computing the FED's latent propensity to implement QE in a Qual Vector Autoregression model (VAR) that integrates QE announcements in a standard monetary policy

[4]These results are also in line with the findings provided by theoretical models. Among others, Gertler and Karadi (2011) show that the welfare benefits from UMPs are substantial when the relative efficiency costs of central bank intermediation are modest in a dynamic stochastic general equilibrium (DSGE) setting. Cahn et al. (2017) obtain comparable results for the euro area. Chung et al. (2012) find that the expansion of the FED's balance sheet has prevented the unemployment rate to rise to levels that would have prevailed absent the QE and has likely averted a deflationary spiral in the US economy. Chen et al. (2012) and Del Negro et al. (2017) present similar findings using medium-sized DSGE models.

VAR. Differently from the authors mentioned above, they show that QE has had modest effects on real economic activity, inflation, interest rates and stock prices and that it accounts for a small fraction of the dynamics in stock prices and interest rates since 2008.

As to the modalities of transmission of UMPs to financial and economic activity, the literature has mainly focused on the interest rate channel, which, in turn, can be broken down in two main components: 1) *portfolio rebalancing*, which operates through changes in the term premia of target assets; 2) *signalling*, that relates to the ability of the central bank to shape expectations about the future path of interest rates. These mechanisms are extensively discussed in Section 2.2 below.

The present chapter provides three contributions to the existing literature: i) it documents the relative importance of the portfolio rebalancing and signalling channels and assessing whether it has changed over time in the euro area (EA heceforth); ii) it produces evidence of the strong heterogeneity between core and peripheral euro area economies in terms of economic impact as well as underlying mechanisms of transmission; iii) it shows that a more aggressive monetary policy stance on the part of the ECB would have sustained the economic performance of peripheral economies.

The analysis builds on and complements several studies that have dealt with similar research questions. Some of them make use of static methodologies (Gambacorta et al. (2014), Elbourne et al. (2018), Burriel and Galesi (2018)), others adopt time-varying approaches without isolating the transmission channels (Baumeister and Benati (2013), Feldkircher and Huber (2018), Filardo and Nakajima (2018)), others consider the transmission channels, but neglect cross-country heterogeneity, which is relevant in the euro area economy (Boeckx et al. (2017)).

The remainder of the chapter is structured as follows. Section 2.2 provides a taxonomy of central bank measures, summarises what central banks around the world have done since the onset of the GFC and discusses the transmission channels.

Section 2.3 introduces the approach to isolate such channels, which is based on the use of a range of arbitrage-free affine term structure models to decompose the sovereign yields of core and peripheral euro area members in two main subcomponents: i) a term premium, which is a proxy for portfolio rebalancing; ii) a risk-neutral or expectation component, which is used as an indicator for the signalling channel. Results of an event study around ECB's main UMP announcements from 2008 onward show that term premia and risk-neutral yields have reacted in a different manner across the two groupings, with the signalling channel being much stronger in the peripheral economies compared to the core countries. However, the speech held by President Draghi in July 2012 (the famous "Whatever it takes") and the implementation of the negative deposit rate in June 2014 have marked two important turning points in the behaviour of yields both in peripheral and core euro area. Specifically, hitting the effective zero lower bound (ELB) has led market participants to revise their expectations on the future path of interest rates, with investors pricing an increase of the policy rate in core euro area sovereign yields, while zeroing out any expectation for further changes in the case of peripheral sovereign bonds.

Section 2.4 leverages on these stylized facts to identify UMP shocks in a structural Vector Autoregressive model with time-varying parameters and stochastic volatility (TVP-SVAR-SV). Notably, the structural identification is based on zero and sign restrictions which are at once group and time-contingent ("dynamic"), in that they depend on both the country grouping and the time period, with different identification schemes imposed for core and peripheral countries before and after June 2014. Results delivered by the model show a significant reduction in the macroeconomic impact of the ECB's unconventional monetary policy measures, above all in core economies. Moreover, the same measures are found to exert a more meaningful impact on the output of peripheral members, with a peak cumulative increase of ~12.6 percentage points in January 2012. Meanwhile, the economic performance of core members is affected only through inflation, with a peak cumulative increase of 4.2 percentage points in December 2010. These findings also highlight the presence of the so-called "missing inflation puzzle" in the peripheral euro area, whereby a more accommodative monetary stance leads to a counter-intuitive decrease in inflation, with a peak cumulative drop of ~0.6 percentage points in January 2016. Furthermore, while the signalling channel appears to be a key avenue of transmission to the macroeconomic aggregates in the peripheral euro area economies, its relevance has greatly decreased after the ELB kicked in.

In light of these results, Section 2.4.2.1 assesses whether a different pace in the decrease of the policy rate to the ELB would have entailed a significantly different economic performance on the part of the euro area economies. The question is addressed by setting up a counterfactual experiment around the much debated interest rate hikes implemented by the ECB in April and July 2011. Conditional on the estimated parameters of the TVP-SVAR-SV, the exercise consists of reverting the direction of the signalling channel by exerting a counter shock on the risk-neutral spreads which offsets any increase stemming from the changes in the policy rate. Both output and inflation are then simulated using the modified shock series. Differences between the historical and simulated series show that a looser monetary policy stance would not have significantly affected the economic performance of core countries, while it would have helped peripheral economies contain the economic slowdown.

Finally, Section 2.5 concludes.

2.2 UMPs: classification and channels

2.2.1 Taxonomy

A central bank's monetary policy consists of two main building blocks: i) the *interest rate policy*, which influences financial conditions by setting or closely controlling a short-term interest rate (often overnight) and by steering expectations about its future path ("interest rate forward guidance"); ii) the *balance sheet policy*, which allows the central bank to influence financial conditions by adjusting either the size or the composition of its balance sheet (or both). These policies can be implemented independently, as a central bank can set the short-term interest rate regardless of the size of its balance sheet and, conversely, can engage in balance sheet policies at any level of the short-term rate. This is due to the so-called "decoupling principle", whereby the same amount of bank reserves can coexist with different levels of the policy rate and, similarly, a given level of the policy rate is compatible with different amounts of reserves[5]. Table 2.2.1 provides a taxonomy of monetary policy measures.

Balance sheet policies can be classified in four subcategories:

1) *exchange rate policy*: through operations in the foreign exchange market, the central bank alters the net exposure of the private sector to foreign currencies;
2) *quasi-debt management policy*: through these operations, the central bank targets the market for public sector debt, by altering the composition of claims held by

[5]See Borio and Disyatat (2010).

Table 2.2.1: A taxonomy of monetary policy implementation measures.

Policy	Description	Examples
Interest rate policy	Setting the policy rate and influencing expectations about its future path	
Forward guidance on interest rates	Communication about the future policy rate path	The central bank "expect[s] [the key interest rates] to remain at their present levels for an extended period of time." [1]
Negative interest rates	Setting the policy rate below zero	Negative deposit interest rate at the ECB and at the BOJ. [2,3]
Balance sheet policies	Adjusting the size/composition of the central bank balance sheet and influencing expectations about its future path to influence financial conditions beyond the policy rate	
Exchange rate policy	Interventions in the foreign exchange market	
Quasi-debt management policy	Operations that target the market for public sector debt	The central bank has decided "to conduct interventions in the euro area public [. . .] debt securities markets (Securities Markets Programme) to ensure depth and liquidity in those market segments which are dysfunctional."[4]
Credit Policy	Operations that target private debt and securities markets	Modifying the discount window facility
		Adjusting the maturity/collateral/counterparties for central bank operations: the central bank "has decided that the European Investment Bank will become an eligible counterparty in the Eurosystem's monetary policy operations."[5]
		Commercial paper, ABS and corporate bond funding/purchase: "over the next few quarters the [central bank] will purchase large quantities of agency debt and mortgage-backed securities to provide support to the mortgage and housing markets" [6]
Bank reserves policy	Operations that target bank reserves	The central bank conducts "money market operations so that the monetary base will increase at an annual pace of about 60-70 trillion yen." [7]
Forward guidance on the balance sheet	Communication about the future balance sheet path (composition/size)	"The [BOJ] will purchase JGBs so that their amount outstanding will increase at an annual pace of about 50 trillion yen... as long as it is necessary for maintaining [the 2% price stability] target in a stable manner." [8]

[1] ECB, 25 January 2018: https://www.ecb.europa.eu/press/pressconf/2018/html/ecb.is180125.en.html;
[2] ECB, starting from 11 June 2014: https://www.ecb.europa.eu/press/pr/date/2014/html/pr140605_3.en.html;
[3] BOJ, 29 January 2016: http://www.boj.or.jp/en/announcements/release_2016/k160129a.pdf;
[4] ECB, 10 May 2010: http://www.ecb.europa.eu/press/pr/date/2010/html/pr100510.en.html;
[5] ECB, 07 May 2009: https://www.ecb.europa.eu/press/pressconf/2009/html/is090507.en.html;
[6] FED, 16 December 2008: https://www.federalreserve.gov/newsevents/pressreleases/monetary20081216b.htm;
[7] BOJ, 4 April 2013: http://www.boj.or.jp/en/announcements/release_2013/k130404a.pdf; [8] BOJ, ibid.

the private sector;

3) *credit policy*: the central bank targets segments of the private debt market by altering its exposure to them. This can be achieved by modifying collateral, maturity and counterparty terms of monetary operations, by providing loans or by acquiring private sector assets;

4) *bank reserves policy*: the central bank sets a specific target for bank reserves regardless of how this is mirrored on the asset side of its balance sheet. Therefore, the ultimate impact on private sector depends on the asset counterpart to the

reserves expansion.

The expression "Quantitative Easing" usually refers to *domestic* balance sheet policies, i.e. those that exclude foreign exchange interventions (e.g. LSAP). Moreover, the term "credit easing" encompasses those domestic balance sheet policies that target the asset side of the balance sheet and disregard what happens on the liability side.

2.2.2 International comparison of UMPs after the GFC

After the GFC, all the major central banks adopted a broad set of measures, as categorized in Table 2.2.2. This section provides an overview of the course of action undertaken by four central banks: the FED, the BoE, the ECB and the Bank of Japan (BOJ)[6].

All these central banks actively engaged in credit policies, quasi-debt management

Table 2.2.2: Selected policies by central banks since the GFC.

	Central Banks			
Policy	**FED**	**BOE**	**ECB**	**BOJ**
Balance sheet policies				
Credit Policy	✓	✓	✓	✓
Quasi-debt management policy	✓	✓	✓	✓
Bank reserves policy			✓	✓
Forward guidance on interest rates				
Time-contingent (Delphic)				
Qualitative	✓[1]		✓[2]	
Quantitative	✓[3]		✓[4]	
State-contingent (Odyssean)				
Qualitative	✓	✓[5]	✓	✓[6]
Quantitative	✓[7]	✓[8]		✓[9]
Forward guidance on balance sheet	✓		✓	✓

[1] In March 2009 the FED expected low rates for "an extended period." [2] In January 2018 the ECB expected policy rates "to remain at their present levels for an extended period of time." [3] In August 2011 the FED expected low rates "at least through mid-2013." [4] In July 2019, the ECB expected the key interest rates "to remain at their present or lower levels at least through the first half of 2020." [5] In February 2014 the BOE stated that unemployment needed to fall further before the policy rate would be increased. [6] In January 2013 the BOJ expected to keep rates at zero "for as long as it judge[d] appropriate given its inflation objective." [7] In December 2012 the FED expected low rates to be appropriate while unemployment was above 6.5% and inflation was forecast below 2.5%. [8] In August 2013 the BOE expected not to raise the policy rate at least until unemployment fell below 7%. [9] In February 2012 the BOJ expected to maintain its virtually zero interest rate policy until a yearly 2% CPI inflation goal was "in sight."

policy and forward guidance. Among them, BOJ was the only one to specifically target bank reserves, while the ECB introduced a two-tier system for remunerating excess reserves in September 2019. Moreover, the ECB and BOJ were the first ones to push their deposit rates into negative territory.

However, the type of policies put in place evolved as the crisis unravelled. During the first phase of the GFC, central banks relied on balance sheet policies to stabilise the

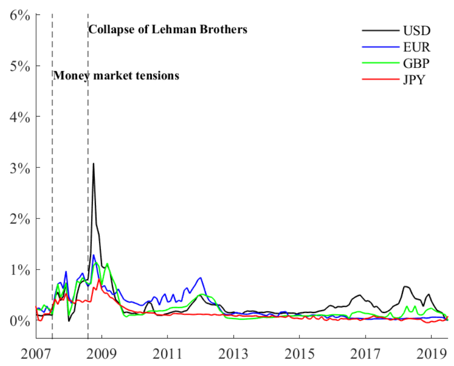
[6] The summary is based on Fawley and Neely (2013) and Borio and Zabai (2018). For more detailed accounts, refer also to Micossi (2015) (ECB) and Haldane et al. (2016) (BoE).

financial system, whereas, later on, as the attention shifted towards more traditional macroeconomic objectives, central banks have started to rely more on forward guidance. In summer 2007, the response to the interbank market freeze (Figure 2.2.1a) was to undertake operations that would provide more ample liquidity and to activate inter-central bank FX swap lines as dollars became increasingly scarce (Lenza et al. (2010), Joyce et al. (2012)). After the collapse of Lehman Brothers in September 2008, with short-term interest rates close to zero (Figure 2.2.1), central banks expanded their set of measures to address market dislocations (e.g. back-up liquidity facilities for non-bank intermediaries, purchases of private sector assets). The ECB, for instance, adopted a *fixed interest rate with full allotment* (FRFA) policy whereby banks have gained unlimited access to liquidity at a pre-specified interest rate against the provision of adequate collateral.

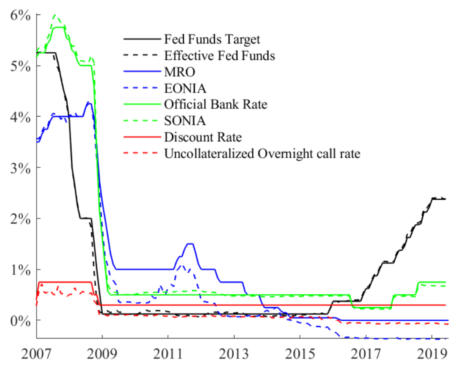
When the euro area was hit by a sovereign debt crisis in 2009, the ECB started to purchase government debt outright in order to promote financial stability in the countries under strain. As financial conditions began to normalise, asset purchases and lending schemes were deployed to boost the economic recovery. This process also entailed a shift from credit policies to quasi-debt management policies that were mainly aimed at lowering government bond yields.

Figure 2.2.1: Interbank and policy rates

(a) 3-month LIBOR-O/N spread



(b) Policy and Short-term Interest Rates



Notes: The Euro spread (EUR) is the difference between the 3-month EURIBOR fixing and the EONIA rate. For the US dollar (USD) and British pound (GBP), the interbank deposit rate used is the 3-month LIBOR fixing, while the overnight rates are, respectively, the Effective Fed Funds Rate (EFFR) and the SONIA rate. For Japanese Yen (JPY), the spread is computed as the difference between the 3-month LIBOR fixing and the Uncollateralized Overnight Call Rate. The main policy rates for the Fed, ECB, BOE and BOJ are, respectively, the Fed Funds Target Rate, the main refinancing operations (MRO) rate, the Official Bank rate and the Discount Rate. The short-term interest rates of reference are the EFFR, the EONIA, the SONIA and the Uncollateralized Overnight Call Rate.

Besides these broader common trends across central banks, balance sheet policies adopted after the GFC also present some idiosyncratic features that are related to the peculiar structure of the financial system that each central bank had to cope with. Hence, in capital market-based systems like the US LSAPs played a dominant role. In bank-based systems like the euro area, on the other hand, liquidity provision through the banks was initially the main type of operations[7].

These measures have changed the size and structure of central bank balance sheets, with an increase by a factor of two in the Eurosystem and by a factor of four for the other central banks. Figure 2.2.2 displays the balance sheets for the FED, the ECB, the BoE and the BOJ together with a timeline of the main unconventional measures implemented after the GFC. Balance sheet sizes at the end of 2018 range between ~20% (BoE) and ~70% (BOJ) of GDP. In terms of composition, the increase in the assets held by the FED, BoE and BOJ has been mainly due to a surge in securities, while in the Eurosystem loans have played a prominent role until 2015. On the liability side, bank reserves have soared in the case of the FED, BoE and BOJ.

2.2.2.1 UMPs in the Euro Area

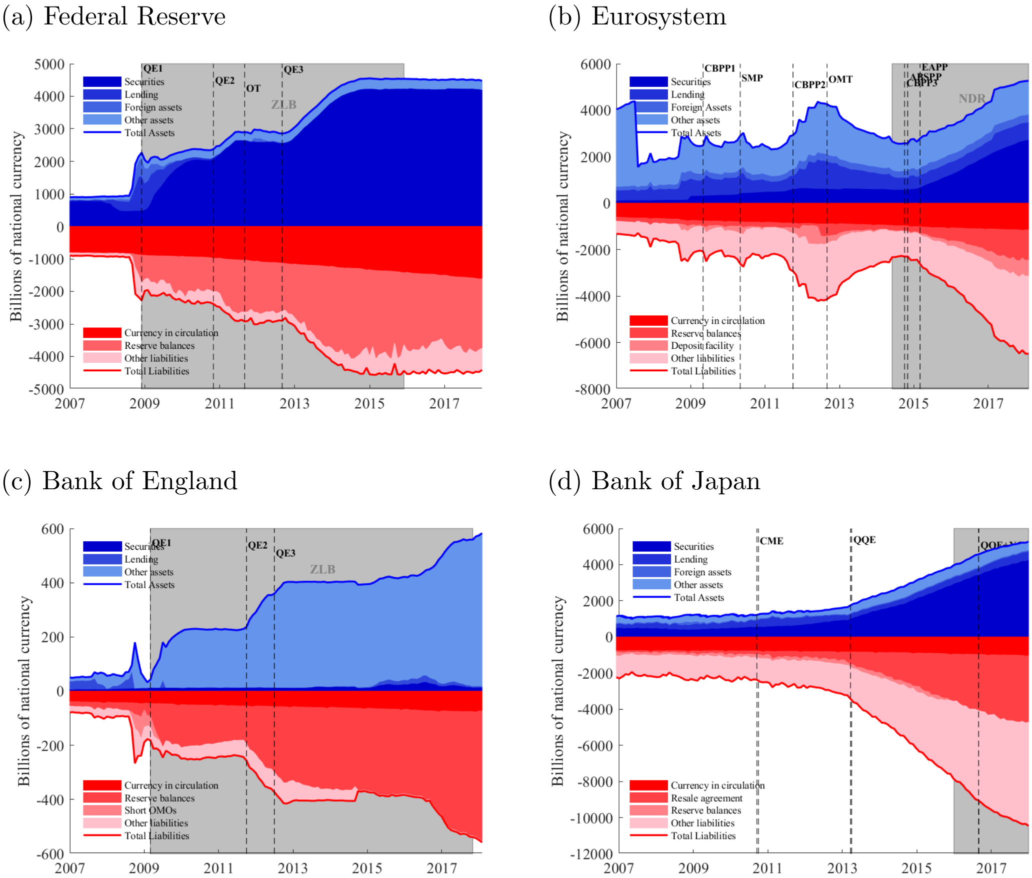
The strategy adopted by the ECB in the aftermath of the GFC can be divided into three main phases[8]:

> **September 2008-end of 2009**: in this phase the ECB was mainly acting as a lender of last resort by increasing the credit available to financial intermediaries. In particular, ECB's strategy focused on fixing the plunge in inter-bank trading by reducing credit and counterparty risks. The policy reaction entailed an expansion of the main liquidity operations and the implementation of several rounds of Longer-Term Refinancing Operations (LTROs). Inter-bank market activity was eventually replaced by intermediation through the central bank (Gonzáléz-Paramo (2011)). Other measures included the use of foreign-currency swap lines (especially with the FED), an expansion in the range of assets eligible for refinancing operations and the launch of the Covered Bond Purchase Program (CBPP).

[7] Peersman (2011) notices that "borrowing and lending in the euro area predominantly take place through the intermediation of the banking sector. The non-standard policy measures taken by the Eurosystem as a response to the crisis were also primarily aimed at fuelling the banking system. Even the limited outright purchases of covered bonds were intended to improve bank funding conditions." In this regard, see also European Central Bank (2011, 2018).

[8] This summary is based on Dell'Ariccia et al. (2018).

Figure 2.2.2: Balance sheet decomposition at major central banks



Notes: For definitions, refer to Borio and Zabai (2018).
Source: FED, ECB, BoE, BoJ, author's calculations.
Acronyms: **FED** QE: Quantitative Easing; OT: Operation Twist; ZLB: Zero Lower Bound. **ECB** CBPP: Covered Bonds Purchase Programme; SMP: Securities Market Programme; OMT: Outright Monetary Transactions; ABSPP: Asset-Backed Securities Purchase Programme; EAPP: Expanded Asset Purchase Programme; NDR: Negative Deposit Rate. **BoE**: QE: Quantitative Easing; ZLB: Zero Lower Bound. **BOJ** CME: Comprehensive Monetary Easing; QQE: Quantitative and Qualitative Easing; QQE+YC: Quantitative and Qualitative Easing with Yield Control; NDR: Negative Deposit Rate.

Early 2010-late 2012: this is the period when financial distress started to be compounded by potential fiscal and sovereign-debt crisis, due a confidence shock stemming from the announcement, in November 2009, that the Greek fiscal deficit would skyrocket to 12.7% of GDP. This led to a jump in governments' borrowing costs not only in Greece, but also in other economies featuring high debt-to-GDP levels, both public (Italy and Portugal) and private (Ireland and Spain). The situation escalated to the point that Greece needed to require an EU-IMF financial assistance program.

In this context, the ECB changed its strategy by resorting more extensively to LSAPs. Specifically, on 10 May 2010 the central bank launched the Securities Market Program (SMP), which consist of purchasing government debt issued by Greece, Ireland and Portugal in the secondary market[9]. Later on, the ECB an-

[9]The requirement to act on the secondary market has avoided to consider SMP as breaching Article

nounced the purchase of Italian and Spanish bonds as well, totalling EUR 218 billion purchases of Greek, Irish, Italian, Portuguese and Spanish bonds as of end-2012. In spite of the SMP, sovereign debt markets in the EA kept on being distressed and this led Ireland and Portugal to request EU-IMF programs, which were signed in December 2010 and May 2011 respectively. Peripheral EA economies entered a double-dip recession, with real GDP declining further. Against the backdrop of self-fulfilling dynamics whereby countries with higher deficits would be penalized with higher borrowing costs on the markets feeding into higher default risks (the so-called "re-denomination risk"), the ECB reiterated its commitment to implement further QE by announcing the Outright Monetary Transactions (OMT) program, which would entail purchases of government bonds for Member States requesting its activation and accepting close monitoring on the part of the ECB. This announcement followed a well-known speech held by former President Mario Draghi in London at the end of July 2012. Such speech plus the announcement *alone* were able to calm the markets down and to reverse the negative spiral[10].

Mid-2013-current: as of 2013, the ECB has used UMPs mainly to improve credit conditions and provide monetary stimulus, in an attempt to boost the ailing economic performance and increase inflation rate to the target. First of all, it started to make systematic use of forward guidance. Secondly, in June 2014 the ECB cut its deposit rate to -0.1 percent, thus hitting the zero lower bound (ZLB). At the same time, a new round of credit measures was launched, the Targeted Longer-Term Refinancing Operations (TLTROs), which granted more favourable financing conditions to banks lending to households and firms . After that, in September 2014, the ECB announced the introduction of the Extended Asset Purchase Program (EAPP), the first LSAP. Since then, the central bank has purchased securities, covered bonds, corporate sector bonds, and government bonds, reaching a total amount of holdings of about EUR 2.4 trillion in May 2018.

Latest developments: after announcing the phasing-out of the EAPP as of September 2018, the ECB implemented a new round of monetary stimulus in September 2019 and introduced a two-tier system for remunerating excess liquidity

123 of the Treaty on the Functioning of the European Union (TFEU), which prohibits monetary financing of governments.

[10]As a matter of fact, to date no Member State has made a formal request for OMT.

holdings.

2.2.3 Channels of transmission

UMPs can affect financial and real economic activity via several channels. Among them, the literature has mostly focused on the interest rate channel. By adopting quasi-management debt and credit policies, indeed, the central bank can increase asset prices and reduce the interest rates for investors. This can in turn boost the real economy, through, *inter alia*, a reduction in the borrowing costs and positive wealth effects.

As mentioned in Section 2.1, the interest rate channel can be decomposed in portfolio rebalancing and signalling. The relation between these two components and real activity directly derives from the standard New Keynesian model, where the output gap and inflation both depend on expectations as well as on the difference between the policy rate and the natural rate of interest[11]. These can then be interpreted as the two above mentioned channels. Notably, the non-policy bloc of the model is given by:

$$\pi_t = \beta \mathbb{E}_t\{\pi_{t+1}\} + \kappa \tilde{y}_t \tag{2.1a}$$

$$\tilde{y}_t = -\frac{1}{\sigma}(i_t - \mathbb{E}_t\{\pi_{t+1}\} - r_t^n) + \mathbb{E}_t\{\tilde{y}_{t+1}\}, \tag{2.1b}$$

where π_t is inflation, $\tilde{y}_t$ is the output gap, r_t^n is the natural rate of interest and $\mathbb{E}_t$ is the expectation operator at time t. Equation (2.1a), known as the (forward-looking) New Keynesian Phillips Curve, and Equation (2.1b), the (forward-looking) Dynamic IS Curve, are then complemented with a monetary policy rule that closes the model[12].

This interpretation is in line with what observed ever since the onset of the GFC. Notably, before the crisis the common tenet was that a central bank would only control the policy rate to guarantee price stability, while letting the markets form expectations about the future outlook of the economy as well as the path of interest rates. However, after the crisis it has been noticed how market participants can extrapolate relevant information out of the central bank's announcements, which can then have a direct impact on $\mathbb{E}_t\{\pi_{t+1}\}$, $\mathbb{E}_t\{\tilde{y}_{t+1}\}$ (Jarociński and Karadi (forthcoming)) and also the natural rate of interest, r_t^n. This is even more so in the case of UMP announcements (Nakamura and

[11] The natural interest rate is here defined as the level of real interest rate whereby aggregate demand would equal the level of output featured by an economy with full price flexibility (Woodford (2003)).

[12] Refer to Galí (2015) for details.

Steinsson (2018)).

It is possible to map the theoretical setting into empirical data via the decomposition of long-term interest rates into a risk-neutral expected future short-term interest rate and a term premium:

$$y_{L,t} = \frac{1}{L}\mathbb{E}_t \sum_{l=0}^{L-1} y_{1,t+l} + tp_{L,t}, \tag{2.2}$$

where $y_{L,t}$ is the L-period government bond yield at time t, $y_{1,t}$ is the one-period net interest rate and tp_t is the L-period term premium. Along this reasoning and following the literature, the term premium will be used as a proxy for portfolio rebalancing, while the risk-neutral component will be linked to the signalling channel[13].

2.2.3.1 Portfolio rebalancing

The portfolio balance channel is linked to the impact that purchases of long-term government debt can have on term premia. Such measures, indeed, increase the private sectors' holdings of short-term reserves. For investors with a preferred habitat for a given asset and/or maturity in the government bond market and facing limits to arbitrage, the price of longer-term assets has to increase and the yield to fall for them to willingly accept the change[14]. To the the extent that the short-term interest rate does not move, such change has to take place through the term premia on longer-term assets. With lower long-term asset returns, investors will start searching for higher yields by demanding other longer-term assets, thus rebalancing their portfolios. This demand-driven rebalancing will then increase prices and reduce term premia for a range of long-term assets; the compression in long-term yields can transmit to the real economy via a reduction in borrowing costs and an increase in wealth for the private sector. That said, portfolio rebalancing can be triggered also by forward guidance, as it can induce changes in term premia deriving from a change in the compensation for interest rate risk. Indeed, if a central bank's announcement lowers the investors' uncertainty around the future path of short-term interest rates, term premia will decrease. Similarly, forward guidance on future balance sheet policies can impact term premia and, hence, provoke portfolio changes on announcement days (Akkaya et al. (2015)).

Based on Krugman et al. (1998) and Eggertsson and Woodford (2003), where the case

[13] See Lloyd (2017).

[14] See, for instance, Vayanos and Vila (2009).

is made explicitly, Woodford (2012) argues that the portfolio balance view is invalid, and, if central bank asset purchases are to be effective, their effectiveness must rely on their ability to alter the public's expectations of future central bank policies[15]. D'Amico and King (2013), on the other hand, provide evidence of a decline in term premia for several long-term asset as a consequence of the Fed's LSAPs. Similarly, Weale and Wieladek (2016) investigate the relative importance of this channel in the US, by means of a Bayesian SVAR with alternative identification restrictions. They show that US asset purchases mainly influence yields on medium and long-term government debt, which suggests a major role for portfolio rebalancing. Building on this approach, Wieladek and García Pascual (2016) find that, in absence of the first round of ECB QE, euro area real GDP and core CPI would have been 1.3% and 0.9% lower, respectively, with Spanish real GDP benefiting the most and Italian the least. They also isolate four main channels of transmission, namely portfolio rebalancing, signalling, credit easing and exchange rate. Among these channels, Varghese and Zhang (2018) provide evidence on the prominent role played by the rebalancing channel in the euro area after 2014.

2.2.3.2 Signalling

The signalling mechanism, originally suggested by Eggertsson and Woodford (2003), is based on the idea that central bank asset purchases can lower the investors' expectations about future short-term interest rates and, consequently, impact the long-term rates as well. In presence of imperfect information, indeed, such operations might be interpreted as an indication that the policy interest rate will remain at its effective lower bound for longer. While Bernanke et al. (2004) and Gagnon et al. (2011) find little evidence in support of this mechanism, Christensen and Rudebusch (2012) and Bauer and Rudebusch (2014) show exactly the opposite, namely that the signalling channel has dominated in the US. Moreover, asset purchases can also help manage expectations about future inflation and real GDP growth and, hence, reduce economic uncertainty, which in turn reshapes expectations about future short-term interest rates[16]. Uncertainty around both monetary policy and economic performance is indeed particularly relevant as regards the effective transmission of UMPs, as highlighted by Husted et al.

[15] For a discussion, refer also to Peersman (2014).

[16] See Woodford (2003).

(2017). Similarly, Lloyd (2017) finds that the macroeconomic effects of the FED QE announcements between November 2008 and April 2013 are largely attributable to the signalling channel (~60%)[17].

2.2.3.3 Additional channels

There are some additional channels though which UMPs can affect the real economy. One of them is the credit channel, whereby unconventional monetary policy can transmit to output and inflation independently of long-term interest rates (Joyce et al. (2012)). The central bank can indeed purchase assets from non-bank financial institutions, which, in turn, may increase their deposits with banks. When the deposits exceed the banks' demand for liquidity, banks may be either more willing to extend credit through new lending or less willing to contract new lending if they suffer losses from other sources. This channel is the most relevant when bank intermediation and funding are disfunctional, as it was after the 2007-2008 crisis. In the euro area case, Altavilla et al. (2015) show that targeting assets at long maturity and spanning the investment-grade space have supported the duration and the credit channels, thus successfully lowering longer-term yields even in times of low financial stress, as it was the case for the ECB's asset purchase programme announced in January 2015.

Another mechanism of transmission is the exchange rate channel. If UMPs reduce interest rates and expected future rates, international investors might decide to seek for higher returns abroad. *Ceteris paribus*, this should lead to a depreciation of the domestic currency, an increase in the competitiveness of export prices and, hence, a boost to output[18]. However, as this mechanism ultimately depends on interest rate differentials, it can be considered as a function of the portfolio balance and signalling channels (Bauer and Neely (2014)). Finally, Krishnamurthy and Vissing-Jorgensen (2013) provide evidence of a new channel, the scarcity channel, which has been dominant for the Fed's purchases of Mortgage-Based Securities (MBS).

[17] For additional evidence on the signalling channel, see also Bhattarai et al. (2015) and Engen et al. (2015).

[18] On the international spillovers of UMPs, see Feldkircher and Huber (2016), Neely (2015) and Fratzscher et al. (2018).

2.3 Preliminary evidence on UMPs in the EA

This section presents an event study aimed at assessing the impact that the announcements of some UMPs in the EA have exerted on interest rates. This will provide a first indication as to which of the transmission channels have prevailed in these cases.

In order to account for the inherent cross-country heterogeneity characterizing the Eurozone, euro area economies are sorted into two groups of countries: core EA and peripheral EA members. Aggregate yield curves are then constructed accordingly[19].

2.3.1 Decomposition of the yield curve

On the basis of Equation (2.2), the yield curve is decomposed into risk-neutral yields and term premia. Following the relevant literature (Gagnon et al. (2011), Bauer and Rudebusch (2014), Lloyd (2017)), the portfolio rebalancing and the signalling effects are associated to the term premium and the risk-neutral components respectively.

The decomposition is carried out by comparing the following arbitrage-free affine term structure models (TSMs):

1) the Dynamic Nelson-Siegel model (DNS) à la Diebold and Li (2006);
2) the Dynamic Svensson-Söderlind (DSS), which is the 4-factor model in Diebold and Li (2006);
3) the Short-Rate Based 3 and 4-factor models (SRB3-SRB4) as in Nyholm (2018).

Models are estimated for the government bond yields of core and peripheral EA economies at maturities from 1 to 10 years. Figure 2.3.1 displays the actual and fitted yields (top panel), the term premium (mid panel) and the risk-neutral yield (bottom panel) for the 10-year maturity. The four frameworks deliver very similar results for core EA, while there are slight differences in the case of peripheral EA, especially w.r.t. the risk-neutral yield. As expected, both term premia and risk-neutral yields are higher for peripheral EA compared to core countries. Moreover, the heat-up of the financial crisis in 2008 has led to a sudden increase in the term premia and a drop in the expectation component, which has been particularly marked for core EA countries. Thereafter, the evolution of the risk-neutral yields points towards persistent expectations, on the part of investors, of short-term interest rates around 0 or even in negative domain. This trend has been

[19]See Appendix B.1 for details on the data, the countries included and the aggregation approach.

interrupted in the peripheral EA economies in July 2011, when the ECB unexpectedly increased its policy rate, which was then immediately decreased in August of the same year. The risk-neutral yield has then decreased again to values close to 0 as of September 2012.

As to the term premia, they have surged in both groupings after the collapse of Lehman Brothers, thus indicating the strong presence of portfolio rebalancing effects. However, they have decreased to levels comparable to the pre-2008 period after November 2014.

This preliminary analysis already highlights some important differences between the two groupings of core and peripheral EA economies, in particular as far as the formation of expectations on the part of investors is concerned. In order to evaluate which of the four TSMs considered is the most suitable to deliver a good approximation of the portofolio rebalancing and the signalling channels, the risk-neutral yields extracted from the 1-year government bond yields are compared with the expectations on short-term interest rates derived from the EONIA futures rates, as in Lloyd (2017). Notably, the average of implied rates from the $0, 1, \ldots, 12$-month-ahead EONIA futures on the final day of each calendar month is compared with the risk-neutral yields extracted from the 1-year government bond yields by computing the root mean square error (RMSE). Table 2.3.1 reports the results for both the overall sample (January 2005-July 2019) and for three different subperiods, broadly corresponding to the regimes of ECB's monetary policy strategy according to the narrative.

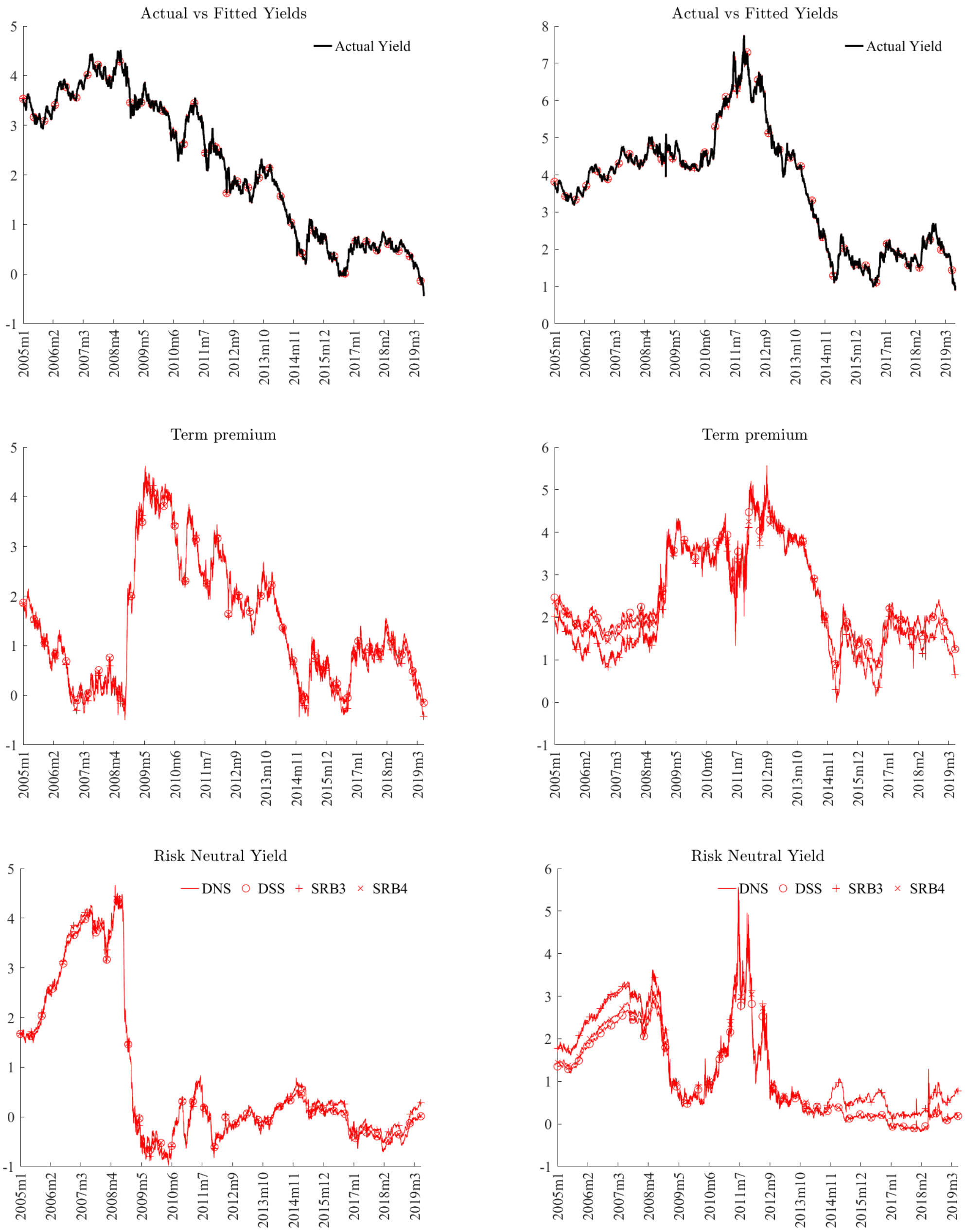
Table 2.3.1: RMSE of the 1-year risk-neutral yield vs the EONIA 1-year implied expectations

Group/Model	DNS	DSS	SRB3	SRB4
Jan 2005-Jul 2019				
Core EA	0.730	0.701	0.717	**0.695**
Peripheral EA	1.159	**1.057**	1.175	1.086
Jan 2005-Aug 2008				
Core EA	0.369	**0.364**	0.371	0.367
Peripheral EA	0.481	0.619	0.482	**0.544**
Sep 2008-Jul 2012				
Core EA	1.251	1.176	1.225	**1.166**
Peripheral EA	2.000	**1.799**	2.030	1.878
Aug 2012-Jul 2019				
Core EA	0.201	0.277	0.203	**0.271**
Peripheral EA	0.369	0.222	0.371	**0.211**

Notes: RMSE of the 1-year risk-neutral yields from each of the four TSMs in comparison to the EONIA-implied expectations. Models are computed using daily data from 1 January 2005 to 31 July 2019. For the monthly aggregation, we take the value on the last day of each month. Minimum values are emboldened.

Figure 2.3.1: Decomposition of daily 10-year government bond yields from 3 January 2005 to 31 July 2019.

(a) Core EA (b) Peripheral EA



Legend: – DNS; O DSS + SRB3; × SRB4.

Regardless of the model considered, the RMSE values are on average higher for peripheral EA countries compared to the core EA. Moreover, the RMSE is particularly high in both groupings in the period from September 2008 to July 2012. The SRB4 model delivers better results in the last part of the sample (August 2012-July 2019) for both groups, while it outperforms the other three models for core EA over the entire sample and between September 2008 and July 2012. For peripheral EA, on the other hand, SRB4 seems better-suited over the period January 2005 and August 2008. In all other periods DSS appears to be the best model. However, differences in RMSE estimates for DSS and SRB4 are not statistically significant. Therefore, the remainder of the chapter will be based on the results provided by the SRB4 model.

2.3.2 Proxy for UMP shocks in the euro area

The evidence on the decomposition of the yield curve in Section 2.3.1 already unveils some important heterogeneity across core and peripheral EA countries that warrant for an in-depth analysis, especially in regard to the movements in investors' expectations. Further insights in this respect can be gathered by analysing how yields, term premia and the expectation component have moved around some important UMPs announcements made by the ECB over the period 2007-2019 (Table 2.3.2). These announcements can be classified according to the taxonomy discussed in Section 2.2, by disentangling among credit policies (C), balance sheet policies (L) and forward guidance (F). The latter encompasses the ECB's directions on both future interest rates and balance sheet policies, which have often taken place on the same day.

Figure 2.3.3 depicts the daily changes in fitted yields, term premia and risk-neutral yields for core and peripheral EA around all UMPs announcements (Figure 2.3.3a), announcements on balance sheet and credit policies (Figures 2.3.3b and 2.3.3c) and events of forward guidance on both interest rates and balance sheet policies (Figure 2.3.3d).

Generally speaking, ECB's UMPs appear to have a much stronger negative impact on yields of the peripheral EA economies (-117 bps on average), with decreases mainly driven by risk-neutral yields, i.e. the signalling channel, at all maturities (from ~72% of total change for 5-year bonds to 95% at the 10-year maturity). Conversely, for core EA countries, the overall effect is positive (+3 bps on average) and mainly driven by increases in term premia, this effect becoming more evident at longer-term maturities (55%, 63% and 67% for 2-year, 5-year and 10-year bonds respectively). Comparing the changes across the different types of announcements, the same evidence holds true for balance sheet policies events (Figure 2.3.3b), where the signalling channel is predominant in pushing down the bond yields of peripheral EA countries (> 80%), while increases in the term premia drive the yields up in the core EA (> 70%). Conversely, credit policies announcements have a much higher impact on the yields of core EA, such an effect mainly deriving from increases in the term premia that are the more pronounced the longer the maturity. Changes around forward guidance events, on the other hand, are qualitatively more homogeneous across the two groups. Notably, forward guidance announcements (Figure 2.3.3d) determine decreases in the yield curve of both core and peripheral EA mainly through a drop in the expectation component. However, the magnitude of such changes is much bigger in peripheral EA countries (-50.49 bps on average) than in core EA (-10.58 bps). All in all, however, a broader trend emerging from this preliminary exercise is that term premia and risk-neutral yields in core and peripheral EA tend to move in opposite direction around the UMPs announcements, with portofolio rebalancing seeming to be the strongest channel in core EA, whereas the signalling mechanism is more evident in peripheral EA. In addition, UMPs tend to be more effective at shorter maturities in peripheral EA and at longer ones in core EA, with the only exception of changes around forward guidance events.

These findings might seem at odds with standard monetary policy theory, as increases in the core EA yields around ECB's UMP announcements might be interpreted as a *tightening* in financial conditions, something that contradicts the rationale behind the implementation of these measures. However, as also emphasized by President Draghi in past, the transmission mechanism of monetary policy in the euro area heavily relies on intra-euro area spreads vis-à-vis Germany. Therefore, it is more appropriate to look at spreads rather than at pure yields (Rogers et al. (2014)). From Equation (2.2) it easily follows that the spread against a common benchmark (German Bund) can be simply expressed as the sum of the spreads of the term premia and the risk-neutral yields against the term premium and the risk-neutral yield of the benchmark. The spreads for core and peripheral EA against Germany can be then decomposed at different maturities. Figure 2.3.2 shows the changes in fitted spreads, the term premium spreads and the risk-neutral spreads in correspondence of different UMPs events. In this case, overall changes are more aligned with what expected: UMPs announcements lead to an overall decrease in spreads, which is more pronounced in peripheral EA countries. As to the different components, term premia seem to be the main driver in both core and peripheral EA, for balance sheet and credit policies announcements, whereas the expectation component is dominant in peripheral EA for episodes of forward guidance. Moreover, in core EA countries changes in term premia and expectation components usually go in opposite

Table 2.3.2: ECB announcements and description

#	Date	Description	Type	
1	09/08/2007	Special fine-tuning operations	C	
2	22/08/2007	Supplementary LTRO	C	
3	08/10/2008	FRFA on MROs	C	
4	07/05/2009	LTROs and CBPP1	L+C	"[...]we will conduct liquidity-providing longer-term refinancing operations with a maturity of 12 months.[...]the Eurosystem will purchase euro-denominated covered bonds issued in the euro area."
5	09/05/2010	SMP	L	"[The Governing Council has decided] To conduct interventions in the euro area public and private debt securities markets (Securities Markets Programme)."
6	06/10/2011	CBPP2	L	"[...]the Governing Council has decided to launch a new covered bond purchase programme (CBPP2)."
7	08/12/2011	LTRO	C	"the Governing Council decided [...] to conduct two longer-term refinancing operations (LTROs) with a maturity of 36 months."
8	26/07/2012	"Whatever it takes" speech	F	"Within our mandate, the ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough."
9	02/08/2012	OMT	F+L	
10	05/06/2014	TLTRO I	C	"[...]we will be conducting a series of targeted longer-term refinancing operations (TLTROs). All TLTROs will mature in September 2018, i.e. in around 4 years."
11	04/09/2014	ABSPP & CBPP3	L	"The Eurosystem will purchase [...] asset-backed securities (ABSs) [...] under an ABS purchase programme (ABSPP).[...]the Eurosystem will also purchase a broad portfolio of euro-denominated covered bonds [...] under a new covered bond purchase programme (CBPP3)."
12	22/01/2015	PSPP	L	"[...] the Governing Council [...] decided to launch an expanded asset purchase programme, encompassing the existing purchase programmes for asset-backed securities and covered bonds."
13	10/03/2016	TLTRO II	L+C	"[...] we decided to launch a new series of four targeted longer-term refinancing operations (TLTRO II), starting in June 2016, each with a maturity of four years."
14	02/06/2016	CSPP	F+C	
15	14/06/2018	End of APP net purchases	F+L	
16	25/07/2019	New round of purchases	F+L	"We intend to continue reinvesting, in full, the principal payments from maturing securities purchased under the asset purchase programme for an extended period of time [...] and in any case for as long as necessary to maintain favourable liquidity conditions and an ample degree of monetary accommodation."

Notes: C: Credit policy; L: Balance sheet policy; F: Forward guidance.

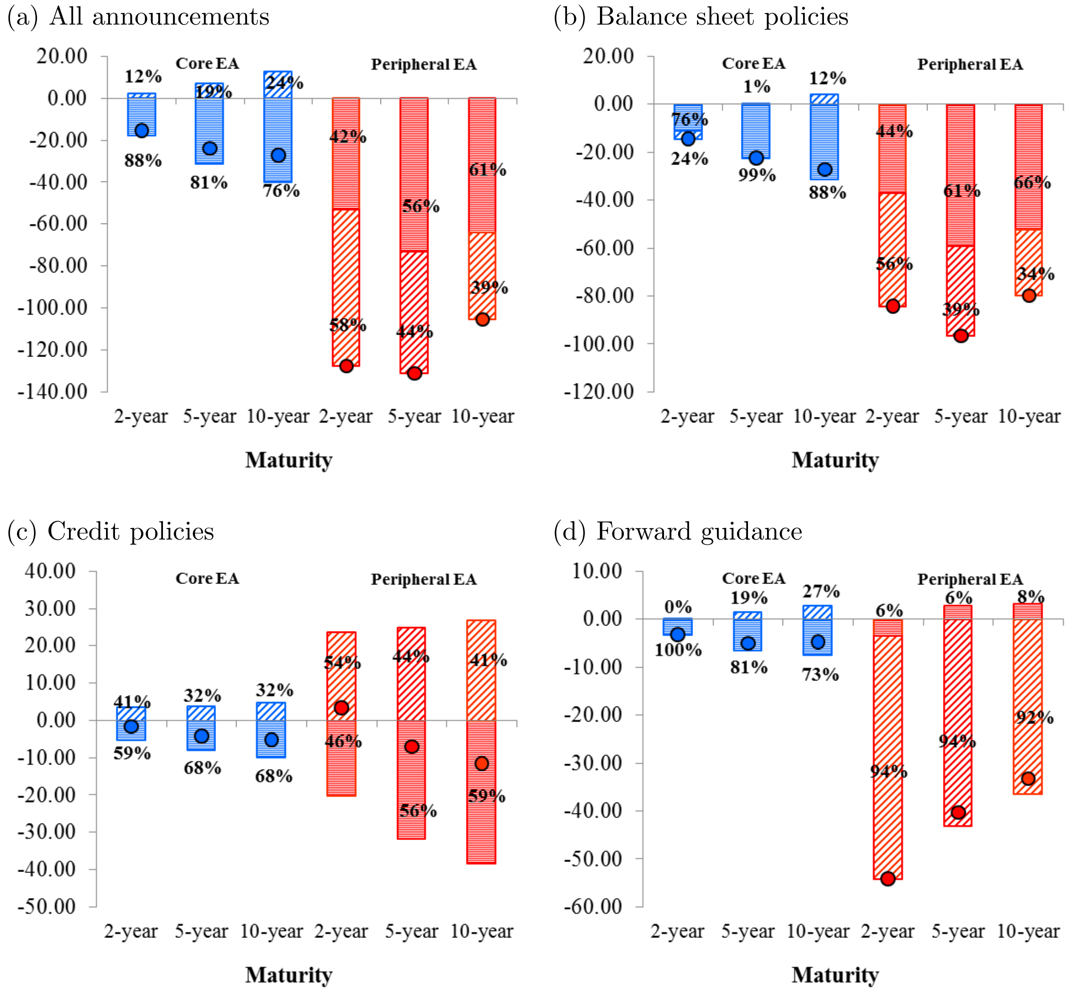
direction, especially for longer maturities, while in peripheral EA economies that is the case only for credit policies announcements.

2.3.2.1 Event study

The present section complements the empirical evidence discussed above with an assessment of the significance of daily changes in actual spreads, Δy_t, fitted spreads, $\Delta \hat{y}_t$, term premium spreads, ΔTP_t, and risk-neutral spreads, Δer_t for 2, 5 and 10-year government bonds on each of the 16 event dates. This is done by running the following regression:

$$\Delta x_{n,t} = \alpha_{x,n} + \mathbf{Event}_t \beta_{x,n} + \mathbf{D}_t \gamma_{x,n} + \varepsilon_{x,n,t}, \tag{2.3}$$

Figure 2.3.2: Cumulative changes of fitted spreads, term premium spreads and expectation component spreads for 2, 5 and 10-year maturities for all the UMPs events.



Notes: All figures are in basis points. Percentage figures indicate the share of total change due to changes in the subcomponents.
Legend: Core EA; Peripheral EA; fitted spread; term premium spread; expectation component spread.

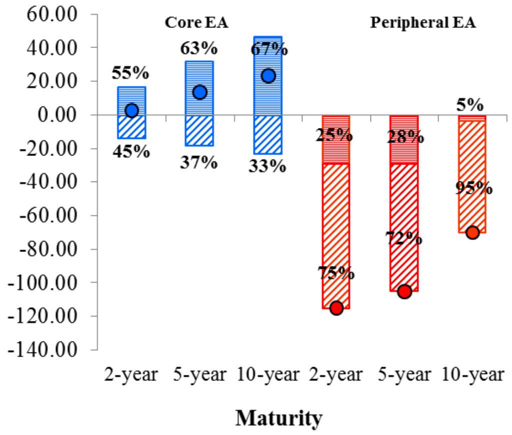
where $\Delta x_{n,t} = \{\Delta y_{n,t}, \Delta \hat{y}_{n,t}, \Delta TP_{n,t}, \Delta er_{n,t}\}$, n is the maturity and $\mathbf{Event}_t$ is a 1×16 vector of dummy variables that refer to the UMPs announcements reported in Table 2.3.2. Notably, such dummies are set equal to 1 on the date of the announcement they are linked to and 0 otherwise. In addition, the right hand side of Equation (3.2) includes a $1 \times (K + P)$ matrix of control variables, $\mathbf{D}_t$, that is partitioned as:

$$\mathbf{D}_t = \left[\begin{array}{c|c} \mathbf{R}_t & \mathbf{P}_t \end{array} \right],$$

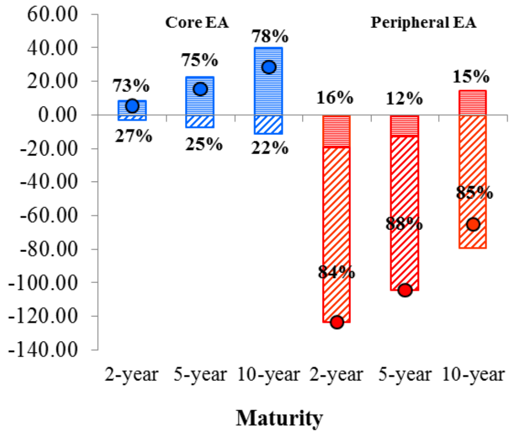
where $\mathbf{R}_t$ is a $1 \times K$ matrix of dummy variables that are equal to 1 on the date of release of other macroeconomic data and 0 otherwise, while $\mathbf{P}_t$ is a $1 \times P$ matrix including dummy variables that equal 1 on the dates of request of financial assistance by Cyprus, Greece,

Figure 2.3.3: Cumulative changes of yields, term premia and expectation components for 2, 5 and 10-year maturities for all the UMPs events.

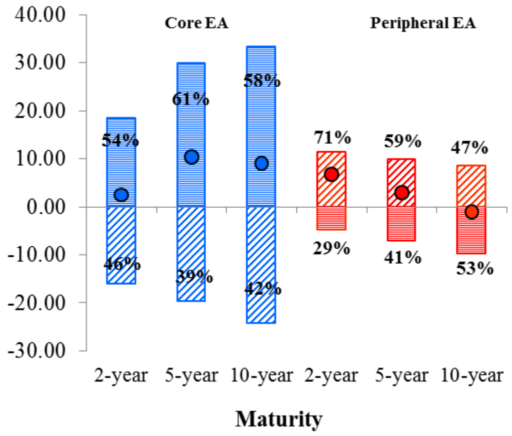
(a) Alla announcements



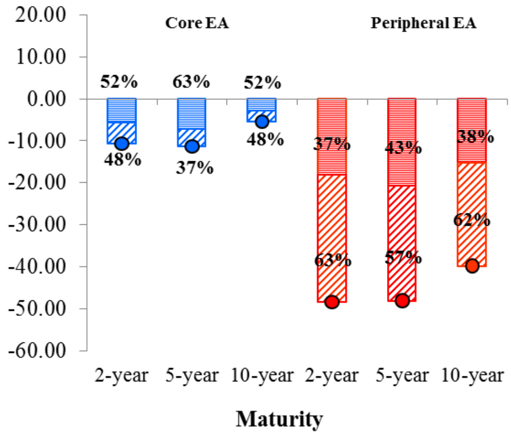
(b) Balance sheet policies



(c) Credit policies



(d) Forward guidance



Legend: for 2, 5 and 10-year maturities for all the UMPs events in Table 2.3.2.
Notes: All figures are in basis points. Percentage figures indicate the share of total change due to changes in the subcomponents.
Legend: Core EA; Peripheral EA; fitted yield; term premium; expectation component.

Ireland, Portugal and Spain, and 0 otherwise[20]. Specifically, $\mathbf{R}_t$ collects information on $K = 6$ macroeconomic releases in the EA: Consumer Price Index Estimate, Actual Consumer Price Index, Real Gross Domestic Product, Unemployment Rate, Industrial Production and Consumer Confidence Index[21].

The parameter of interest in Equation (3.2) is the 1×16 vector $\beta_{x,n}$, whose i-th ele-

[20] These events have created tensions in the government bond markets of the euro area that have often triggered interventions by the ECB (see Chapter 3).

[21] An alternative specification, proposed by Altavilla et al. (2016), consists of replacing the non-zero elements of $\mathbf{R}_t$ with a measure of "news" associated with each data release. Such measure is given by the difference between the median forecast of a certain indicator, as reported by Bloomberg, and the actual released value. As a robustness chech, Equation (3.2) is also estimated using this different definition. Results are not significantly different.

ment represents the difference between the change in variable x on UMP announcement day i, with $i = 1, \ldots, 16$, and the average daily change of x on other dates, excluding the UMPs announcements, the release days of other EA macroeconomic data and days when financial assistance was requested. If the i-th element of $\hat{\beta}_{x,n}$ is statistically significant, then UMP announcement i has a significant effect on x at the n-year maturity. In addition, the joint significance of the elements of $\beta_{x,n}$ is assessed via a Wald test with null $H_0 : \sum_{i=1}^{16} \hat{\beta}_{ix,n} = 0$. This will indicate whether the whole set of events in $\textbf{Event}_t$ has a cumulative significant impact on x at n-year maturity. Figure 2.3.4 displays the estimated coefficients for spreads and their subcomponents at 2 (Figure 2.3.4a), 5 (Figure 2.3.4b) and 10-year (Figure 2.3.4c) maturities for each single event in the set. Figure 2.3.5, on the other hand, depicts the cumulative estimates broken down by the different types of announcements[22] in Appendix B.2 below..

Estimates for single events show that the effect of UMPs has decreased over time both in the core and the peripheral EA countries. There is indeed a shift in the magnitude of changes in both term premium and risk-neutral spreads after the "Whatever it takes" (London) speech in July 2012, which is more evident for shorter maturities. Moreover, estimates of significant cumulative changes seem to confirm what already observed in Figure 2.3.2, and notably that decreases in spreads around UMPs announcements are mainly driven by changes in the term premia rather than in the risk-neutral yields. In addition, the portfolio and the signalling channels seem to operate in opposite directions for core EA economies especially at longer maturities. This is also the case for peripheral EA around credit policy announcements (Figure 2.3.5c). Moreover, there are two instances where the coefficients indicate an exclusive activation of the portfolio channel in core EA: i) for the decrease in the 5-year spreads corresponding to balance sheet policies announcements (Figure 2.3.5b); ii) for the decrease of 2-year spreads around forward guidance events (Figure 2.3.5d).

In light of the apparent time variation in the reaction of spreads to UMPs announcements, Equation (3.2) is re-run by splitting the announcements sample before and after the London speech on 26 July 2012. Figure 2.3.6 reports the significant cumulative changes for all the events before (Figure 2.3.6a) and after (Figure 2.3.6b) that date. Besides a marked reduction in the level shifts for both core and peripheral EA spreads,

[22] The charts are based on the results reported in Tables B.1 to B.5

the "post-London-speech" announcements have increased the expectations for a raise of interest rates and, at the same time, induced a noticeable reduction in movements of term spreads in core EA. For the peripheral EA, on the other hand, the same announcements have not only reduced spreads, though to a lesser extent, but also reduced expectations of further cuts in the interest rates, especially at longer maturities[23]. This finding might be also due to the ECB's decision to implement a negative deposit rate as of June 2014 and hit the effective zero-lower-bound (ELB). Splitting the announcements sample by that date leads to slightly different results, with risk-neutral spreads increasing in both core and peripheral EA around UMPs announcements from 2014 onward (Figure 2.3.6d).

The preliminary evidence provided so far highlights three important sources of heterogeneity:

1) **between groups**, with movements in the spreads of peripheral EA being more pronounced compared to those for core EA[24];
2) **across events**, with balance sheet policies announcements being more impactful;
3) **over time**, with far less pronounced effects on spreads after July 2012, in coincidence with the "Whatever it takes speech", together with a change in the relevance of the portfolio rebalancing and signalling channels.

In next section, a TVP-SVAR-SV is constructed to account for the findings discussed so far.

2.4 Time-varying parameter VAR

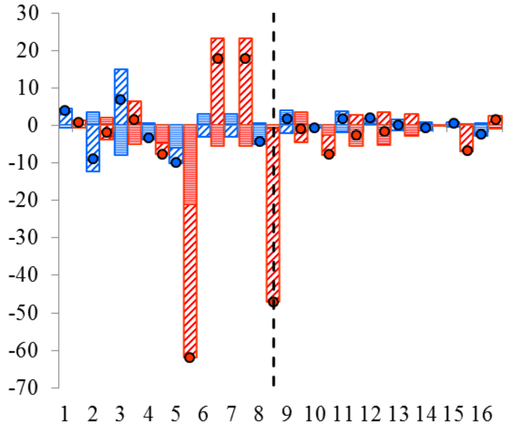
The choice of a time-varying VAR model with stochastic volatility (TVP-VAR-SV) is of particular relevance to capture the macroeconomic structure in place during the GFC. Since the seminal papers by Cogley and Sargent (2001, 2005) and Primiceri (2005), indeed, this empirical framework has become a benchmark for analysing the evolving relationships across multiple macroeconomic variables (see Benati (2008) and Koop and Korobilis (2013)). For instance, models with time-varying parameters and stochastic volatility are found to provide better forecasts compared to their constant-coefficient

[23]This is in line with part of the existing literature (e.g., Altavilla et al. (2015)).

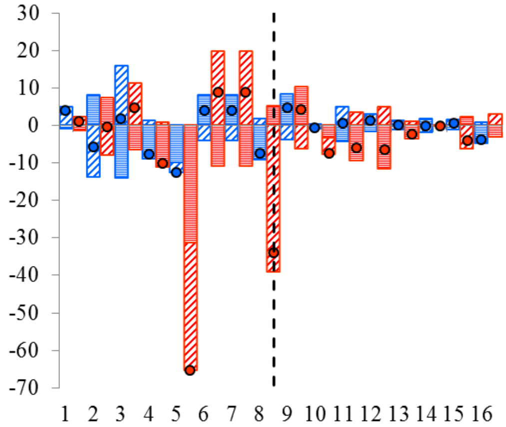
[24]It might be argued that these results are also driven by the historically higher mean and volatility of peripheral EA yields compared to the the core EA. All the computations have been then repeated using demeaned and standardized spreads series. Results confirm the evidence exposed so far.

Figure 2.3.4: Significant daily changes of fitted spreads, term premium spreads and expectation component spreads for 2, 5 and 10-year maturities around the UMPs events.

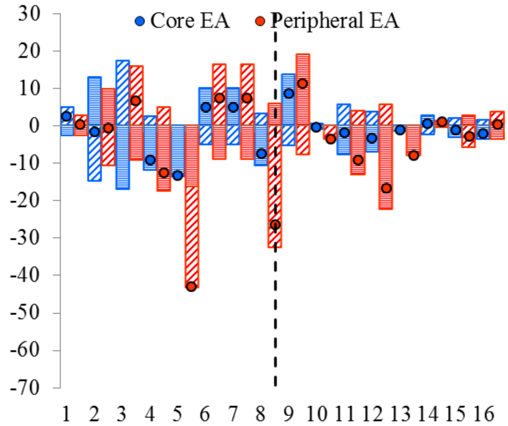
(a) 2-year spreads



(b) 5-year spreads



(c) 10-year spreads



Notes: All figures are in basis points. The events are reported on the x-axis numbered as in Table 2.3.2.
Legend: Core EA; Peripheral EA; London Speech (26 July 2012); fitted spread; term premium spread; expectation component spread.

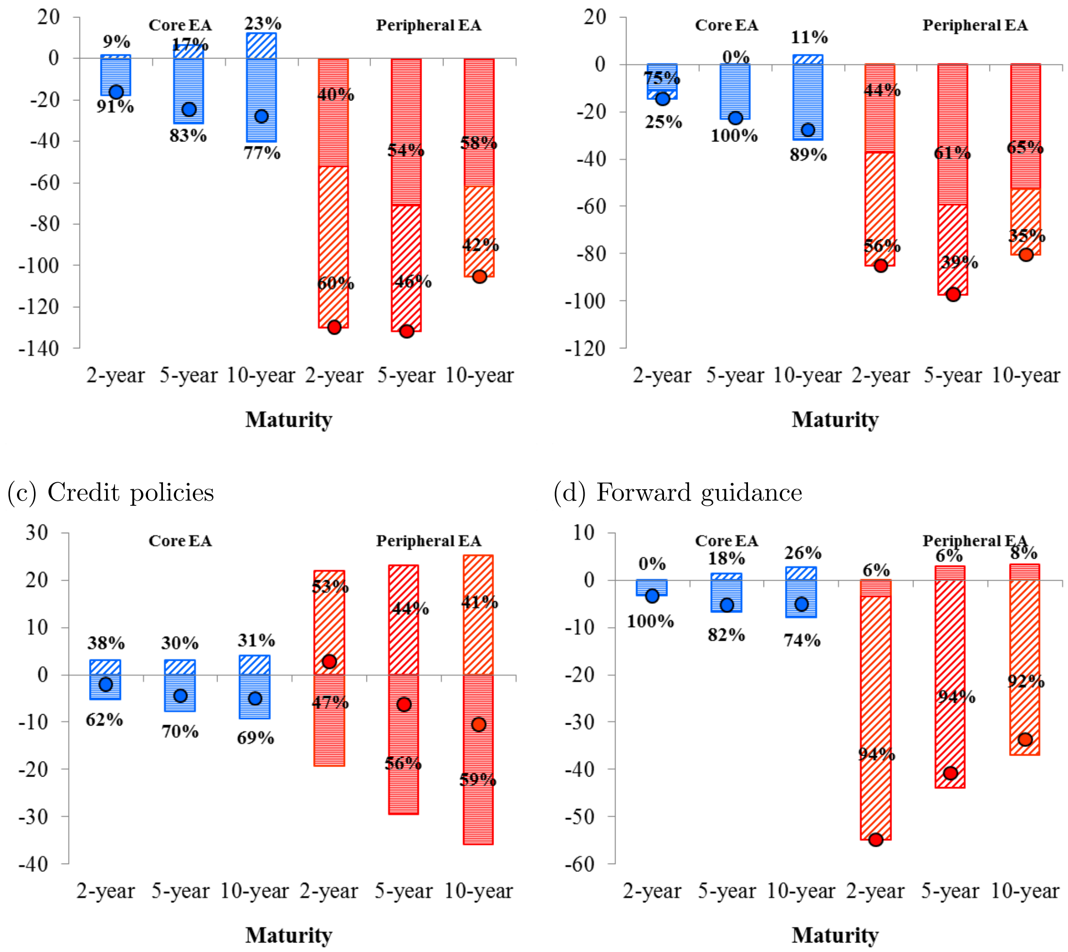
counterparts, in that they don't impose strong restrictions on the evolution of the economic relationships (D'Agostino et al. (2013)). In addition, other studies show that drifting-coefficient models are also able to well capture discrete breaks (Benati and Mumtaz (2007), Baumeister and Peersman (2013,)).

Such models have proved to be also particularly suitable to evaluate alternative hypotheses. In assessing the underlying causes of the Great Moderation, for instance, some researchers have argued that the monetary policy regime was an important factor[25], something that would correspond to a change in the reduced-form VAR coefficients. Others have found that Great Moderation can be mostly explained by a change in the

[25] See Cogley and Sargent (2001) and Boivin and Giannoni (2006)

Figure 2.3.5: Significant cumulative changes of fitted spreads, term premium spreads and expectation component spreads for 2, 5 and 10-year maturities for all the UMPs events.

(a) All announcements (b) Balance sheet policies (c) Credit policies (d) Forward guidance



Notes: All figures are in basis points. Percentage figures indicate the share of total change due to changes in the subcomponents.
Legend: Core EA; Peripheral EA fitted spread; term premium spread; expectation component spread.

volatility of the endogenous shocks[26].

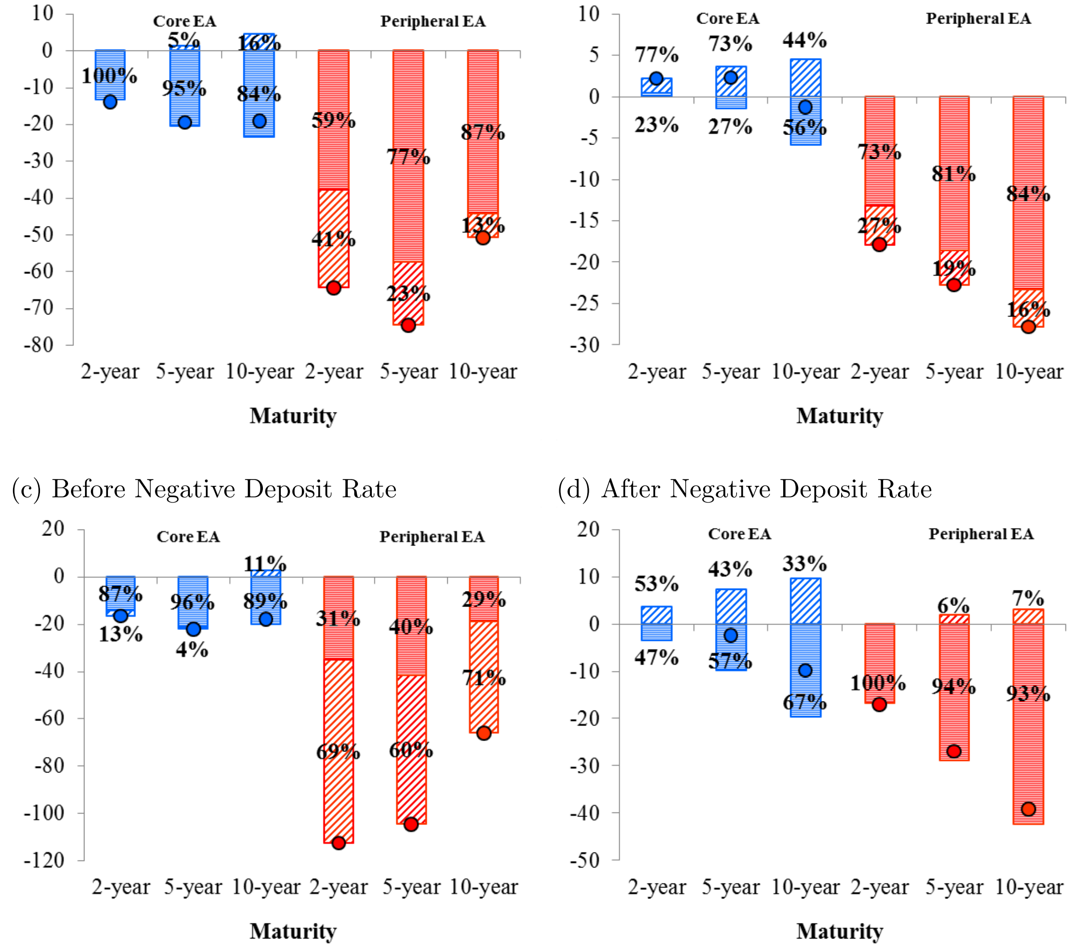
When evaluating the impact of UMPs on real economic activity, it sounds plausible to assume that the GFC has entailed substantial changes in the key structural macroeconomic relationships, which would make constant-coefficient models less suitable. Moreover, previous empirical studies about the transmission of conventional monetary policy provide evidence in support of models featuring smoothly evolving coefficients and heteroskedastic shocks (e.g. Primiceri (2005), Canova and Gambetti (2009), Koop et al. (2009)). Along this reasoning, Kapetanios et al. (2012), Baumeister and Benati (2013)

[26]See Benati (2008) and Sims and Zha (2006).

Figure 2.3.6: Significant cumulative changes of fitted spreads, term premium spreads and expectation component spreads for 2, 5 and 10-year maturities for all the UMPs events before and after the London speech (top panels) and the introduction of Negative Deposit Rate (bottom panels).

(a) Before London speech (b) After London speech

(c) Before Negative Deposit Rate (d) After Negative Deposit Rate



Notes: All figures are in basis points. Percentage figures indicate the share of total change due to changes in the subcomponents.
Legend: Core EA; Peripheral EA; fitted spread; term premium spread; expectation component spread.

and Feldkircher and Huber (2018) use similar models to assess the effects of UMPs as well.

Against this background, this section develops a TVP-SVAR-SV to quantify the impact of unconventional monetary policies implemented by the ECB after the 2007-2008 financial crisis. Differently from existing contributions, however, the proposed framework aims at evaluating the relative importance of the channels of transmissions over time. On top of this, the effectiveness of UMPs in the two EA aggregates (core vs peripheral) is assessed separately to capture the heterogeneity characterizing the Eurozone economy.

The methodology consists of three main steps: i) unconventional monetary policy shocks are identified by leveraging on the transmission channels inside two *monthly* TVP-SVAR-SV for core and peripheral euro area countries; ii) the economic impact of the UMPs is then assessed by imposing different identification schemes, both across country groups and over time, that are informed by the event study in Section 2.3.2; iii) conditional on the estimated parameters of the TVP-SVAR-SV, a counterfactual experiment is used to evaluate whether and how a quicker loosening of the ECB's monetary policy would have induced a significantly different macroeconomic outcome.

2.4.1 The model

The benchmark specification of the *monthly* TVP-SVAR-SV includes the term premium (tp) and expectation component (er) spreads of the 10-year government bonds, as computed in Section 2.3, the annual growth of Industrial Production (y) and the annual HICP inflation excluding energy (π) for core and peripheral EA economies[27]. Notably, the following model is set up as in Cogley and Sargent (2005), Primiceri (2005) and Cogley et al. (2010):

$$\mathbf{Y}_t = B_{0,t} + B_{1,t}\mathbf{Y}_{t-1} + \cdots + B_{p,t}\mathbf{Y}_{t-p} + \mathbf{u}_t \equiv \mathbf{X}_t'\theta_t + \mathbf{u}_t, \tag{2.4}$$

where $\mathbf{Y}_t$ is the $N \times T$ vector of endogenous variables. The vector $\theta_t \equiv [B_{0,t}, B_{1,t} \ldots B_{p,t}]$ and the matrix $\mathbf{X}_t \equiv [\mathbf{1}, \mathbf{Y}_{t-1} \ldots \mathbf{Y}_{t-p}]$ hence provide the state-space representation of the model, while $\mathbf{u}_t$ is an $N \times 1$ vector of unconditionally heteroskedastic disturbance terms. As postulated by Cogley and Sargent (2001, 2005), Primiceri (2005) and Del Negro and Primiceri (2015), θ evolves following a random walk:

$$\theta_t = \theta_{t-1} + \eta_t, \tag{2.5}$$

where $\eta_t \equiv [\eta_{1,t}, \ldots, \eta_{N\cdot(1+Np),t}]'$ and $\eta_t \sim \mathcal{N}(0, \mathbf{\Omega})$, where $\mathbf{\Omega}$ is a diagonal matrix endogenously determined by the model.

The VAR's reduced-form innovations in Equation (2.4) are assumed to be normally

[27]More specifically, in Equation (2.4) below $\mathbf{Y}_t \equiv [tp_t^i, er_t^i, y_t^i, \pi_t^i,]'$, with $i \in \{core, periphery\}$. Data are monthly and cover the period from January 2007 to March 2019. See Appendix B.1 for details.

distributed, with zero mean and variance-covariance matrix $\mathbf{\Sigma}_t$ factored as:

$$\mathbf{\Sigma}_t = \mathbf{F}_t \mathbf{\Lambda}_t (\mathbf{F}_t)', \tag{2.6}$$

where $\mathbf{\Lambda}_t$ is a diagonal matrix containing the stochastic volatilities and $\mathbf{F}_t$ is a lower triangular matrix:

$$\begin{aligned}
\mathbf{\Lambda}_t &\equiv \begin{bmatrix} \bar{s}_1 \exp(\lambda_{1,t}) & 0 & 0 & \dots & 0 \\ 0 & \bar{s}_2 \exp(\lambda_{2,t}) & 0 & \dots & 0 \\ 0 & 0 & \bar{s}_3 \exp(\lambda_{3,t}) & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \dots & \bar{s}_N \exp(\lambda_{N,t}) \end{bmatrix}, \\
\mathbf{F}_t &\equiv \begin{bmatrix} 1 & 0 & 0 & \dots & 0 \\ f_{21,t} & 1 & 0 & \dots & 0 \\ f_{31,t} & f_{32,t} & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ f_{N1,t} & f_{N2,t} & \dots & f_{N(N-1),t} & 1 \end{bmatrix}.
\end{aligned} \tag{2.7}$$

In addition, $\bar{s}_i, i = 1, \dots, N$ are known scaling parameters and

$$\lambda_{i,t} = \gamma \lambda_{i,t-1} + \nu_{i,t}, \qquad \nu_{i,t} \sim N(0, \phi_i). \tag{2.8}$$

The set of parameters to be estimated includes $\theta = \{\theta_t, t = 1, \dots, T\}$, $f^{-1} = \{f_i^{-1}, i = 1, \dots, N\}$, $\lambda = \{\lambda_{i,t}, i = 1, \dots, N, t = 1, \dots, T\}$ and $\mathbf{\Phi} = \{\phi_i, i = 1, \dots, N\}$. Estimation makes use of the Bayesian methods described in Appendix B.3.1.

The reduced-form model in Equation (2.4) can be rewritten in structural form as follows:

$$A_{0,t}\mathbf{Y}_t = C_{0,t} + A_{1,t}\mathbf{Y}_{t-1} + \dots + A_{p,t}\mathbf{Y}_{t-p} + \varepsilon_t, \tag{2.9}$$

where $A_{0,t}$ is the matrix of time-varying contemporaneous coefficients and $\varepsilon_t \sim \mathcal{N}(0, H_t)$ is a vector of structural shocks with a diagonal variance-covariance matrix H_t. It follows that $\mathbf{u}_t = A_{0,t}^{-1}\varepsilon_t$, which, in turn, implies that $E(\mathbf{u}_t\mathbf{u}_t') = \mathbf{\Sigma}_t = A_{0,t}^{-1} H_t A_{0,t}^{-1\prime}$[28]. The

[28] Similarly, it is easy to rewrite the set of reduced-form coefficients, θ_t, as a function of the structural-form coefficients, $\tilde{\theta}_t \equiv [C_{0,t}, A_{1,t}, \dots, A_{p,t}]$. Specifically: $\theta_t = A_{0,t}^{-1}\tilde{\theta}_t$.

identification of the structural shocks takes place by imposing restrictions on the matrix $A_{0,t}$. This is done by building on the methodology developed in Rubio-Ramírez et al. (2010) and Arias et al. (2018), which is detailed in Appendix B.3.2 below.

2.4.1.1 Identification of Unconventional Monetary Policy Shocks

In our setting, an unconventional monetary policy (UMP) shock is identified as an innovation in both the term and the risk-neutral spreads which would mostly decrease the former, while either leaving the latter unchanged in core EA or decreasing them to a lesser extent in peripheral EA. In addition, the identification of a "pure" UMP shock requires restrictions on the response of the other endogenous variables, i.e. industrial production and inflation.

Combinations of zero and sign restrictions have been used in the literature before (e.g., Peersman (2011), Kapetanios et al. (2012) Baumeister and Peersman (2013,), Gambacorta et al. (2014), Bluwstein and Canova (2016)) as they present the key advantage of being, in principle, fully compatible with general equilibrium models.

As shown in Section 2.3.2 above, there has been a stark change in the response of spreads to UMP announcements after June 2014, when the ELB was hit. This requires adapting the set of restrictions to the time period considered. The approach here proposed departs from the existing literature and the standard methodology illustrated in Appendix B.3.2, by introducing in the model "dynamic" zero and sign restrictions, whereby the matrices $\mathbf{S}_j$ and $\mathbf{Z}_j$ in Equations (B.56) and (B.57) depend on time for each variable $j = 1, \ldots, N$.

Besides the unconventional monetary policy shock (UMP), we identify two additional shocks: i) demand non-policy and ii) supply, which prove useful to pin down the shock of interest[29]. Table 2.4.1 reports the set of *contemporaneous* restrictions (i.e., on matrix $A_{0,t}$) for the different time periods.

We postulate that an UMP loosening lowers the term premium spreads in both core and peripheral EA, regardless of the period considered. The same shock has also an impact on the expectation component that is both group and time dependent. Notably, in core EA an UMP shock does not impact the expectation component before June 2014, while it increases it in the post-ELB period. On the other hand, in peripheral EA

[29]See Uhlig (2005), Benati (2008), Baumeister and Benati (2013) and Lloyd (2017).

Table 2.4.1: Identification schemes

Shock \ Variable	y_t	π_t	tp_t		er_t	
			I	II	I	II
Core EA						
UMP	0	0	<0	<0	0	>0
Demand	>0	>0	·	·	·	·
Supply	>0	<0	·	·	·	·
Peripheral EA						
UMP	0	0	<0	<0	<0	0
Demand	>0	>0	·	·	·	·
Supply	>0	<0	·	·	·	·

Notes: I: pre-June 2014; II: post-June 2014; · :unrestricted.

the UMP shock decreases the risk-neutral spread before June 2014, while the impact on the same variable is 0 thereafter. As to the other endogenous variables, we assume that an UMP shock affects both output and inflation with a one-month delay, which accommodates the fact that UMPs are usually announced before they are implemented (Gambacorta et al. (2014), Lloyd (2017)).

2.4.2 Results

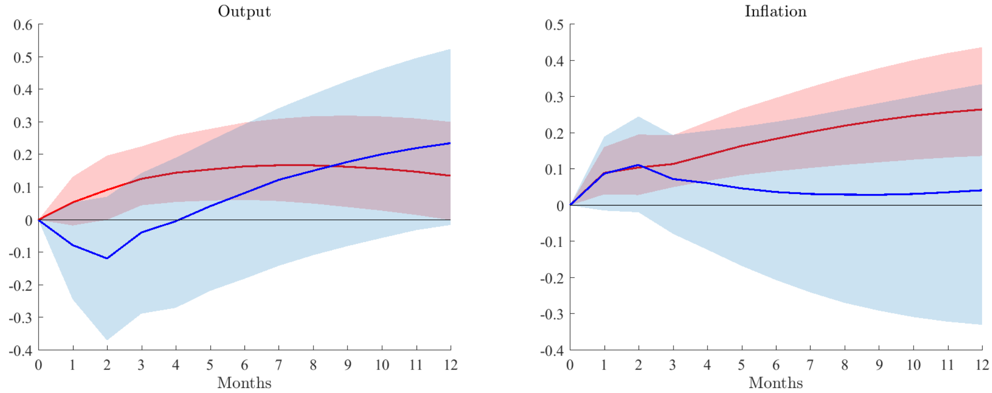
Figure 2.4.1 displays the average IRFs to a decrease in term spreads by 100bps for output and inflation in core EA (Figure 2.4.1a) and peripheral EA (Figure 2.4.1b), before and after June 2014[30].

As expected, there is a stark difference in the reaction to an UMP loosening before and after June 2014. While indeed the effects on output and inflation are significant and more impactful before the cutoff date, they are greatly diminished (peripheral EA) and sometimes become completely insignificant (core EA) after then (see also Table 2.4.2 and Figure 2.4.2). Notably, in the case of core EA economies, an UMP loosening has an expansionary effect on the economy, which materialises via increases in both industrial production (on average by 0.03 percentage points in the month after the shock) and inflation (+0.05 percentage points), before June 2014; however, the impact gets statistically irrelevant in the second part of the sample. By looking at the maximum cumulative impact over 20 months, for output the maximum value of the cumulative IRF occurs in June 2014 (+2.5 percentage points), while the same estimate for inflation peaks in December 2010 (+4.2 percentage points).

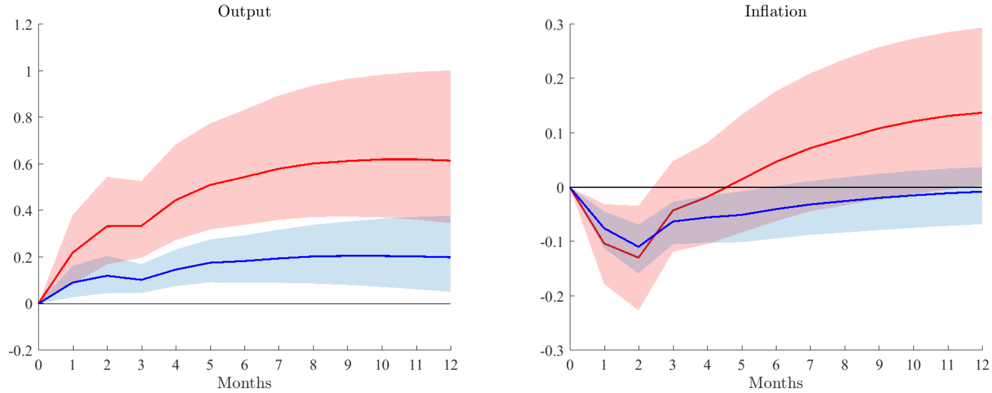
[30] Figure B.1 in Appendix B.4 shows the complete set of median IRFs at each date in the sample

Figure 2.4.1: Median IRFs of output (left panels) and inflation (right panels) to a decrease in term spreads by 100bps.

(a) Core EA



(b) Peripheral EA

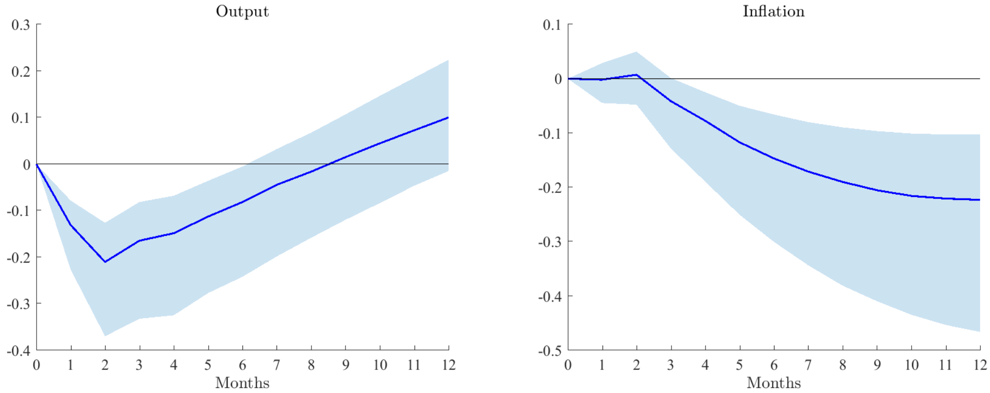


Legend: before June 2014; after June 2014.
Notes: Shaded areas are 68% confidence bands.
Source: Author's calculations.

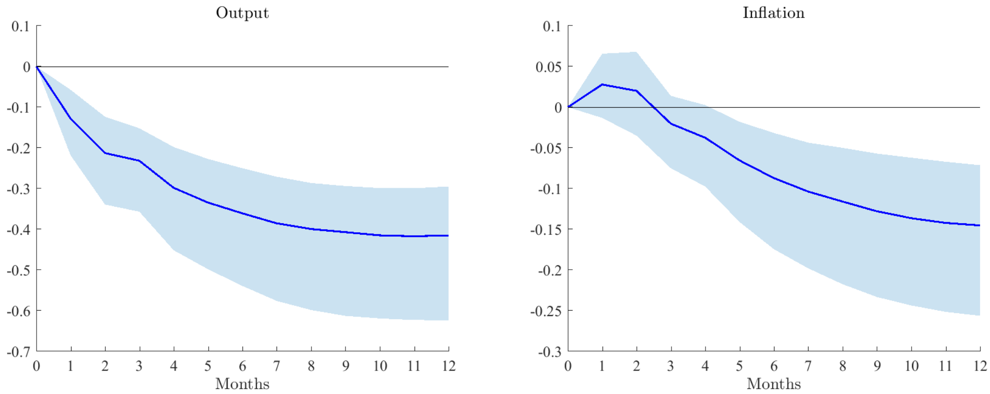
As regards peripheral EA, on the other hand, while the impact of UMPs is always significant regardless of the time period considered, there is an evident reduction in the macroeconomic response to such policies after June 2014, especially as regards output (on average, +0.14 before and +0.05 percentage points after June 2014). Conversely, the impact on inflation is counter-intuitive, in that a loosening in UMP entails a decrease in inflation (~-0.07 percentage points before June 2014 and -0.05 percentage points after). Moreover, estimates of cumulative IRFs over a 20-month horizon indicate that an UMP loosening has a maximum impact on output and inflation of 12.6 and -0.6 percentage points respectively, the former corresponding to January 2012 and the latter taking place in January 2016. These findings are anyways aligned with a stream of literature focusing on the so-called "missing inflation puzzle" in the Eurozone. Since the GFC, indeed, there has been a persistent decline in inflation as well as price expectations in the euro area, in spite of the Eurosystem's loose monetary policy stance. In this regard, much of the policy

Figure 2.4.2: Differences in IRFs of output (left panels) and inflation (right panels) to a decrease in term spreads by 100bps before and after June 2014

(a) Core EA



(b) Peripheral EA



Notes: Shaded areas are 68% confidence bands.
Source: Author's calculations.

debate has focused on the flattening of the Phillips curve (Ciccarelli and Osbat (2017)), while some scholars have rather hypothesized a joint decline in both output potential and trend inflation, the latter essentially being given by long-term expectations (Hasenzagl et al. (2018, 2019)). Another strand of the literature has identified the de-anchoring of long-term inflation expectations from the ECB's inflation target as the main rationale behind this phenomenon (Corsello et al. (2019))[31].

Differences across the two country groupings can also derive from the a-syncronicity across their business cycles. Indeed, a monetary stimulus in economies closer to their potential likely leads to higher inflation rather than increased output (Wieladek and García Pascual (2016))[32]. These dynamics might be ultimately linked to a drop in the natural rate of interest. In Equation (2.1b), indeed, the output gap is a positive function

[31] Contrary to these views, Ball and Mazumder (2020) have recently provided a partial answer to the "missing inflation puzzle" based on the textbook Phillips curve.

[32] Notably, in the New Keynesian framework described by Equations (2.1a) and (2.1b), $\tilde{y}_t \to 0$ implies that inflation becomes a linear function of $i_t - r_t^n$ only.

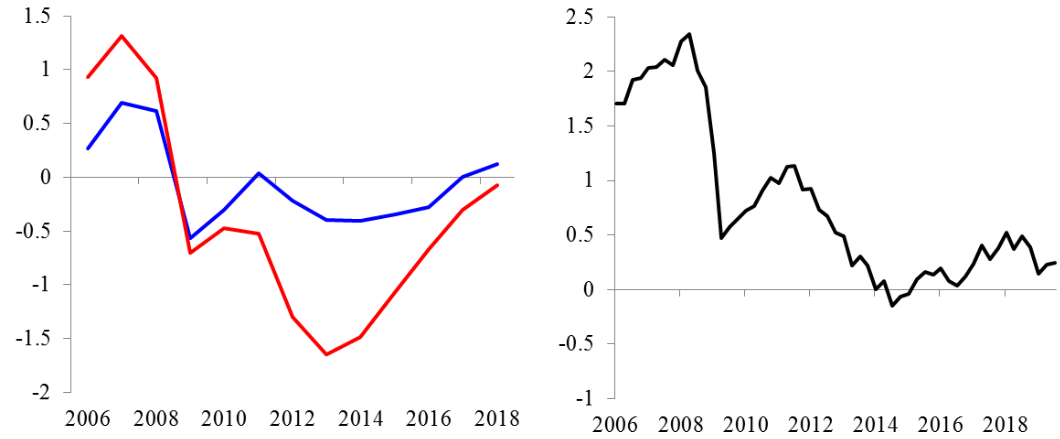
Table 2.4.2: Responses to UMP shocks

		Output		Inflation	
		(1)	(2)	(1)	(2)
Core EA					
Impact*		Pre June 2014	0.030		**0.051**
		Post June 2014	-0.043		0.051
Max. Impact		Dec 2011	0.055	Dec 2014	0.091
Peak		Jun 2014	**2.547**	Dec 2010	**4.264**
Peripheral EA					
Impact		Pre June 2014	**0.145**		**-0.068**
		Post June 2014	**0.054**		**-0.045**
Max. Impact		Jan 2012	**0.273**	Sep 2018	**-0.077**
Peak		Jan 2012	**12.640**	Jan 2016	**-0.588**

Notes: * response one month after the shock. (1) date; (2) estimate. Bold numbers refer to estimates that are statistically significant at 68% confidence level.

Figure 2.4.3: Output gap and natural rate of interest in the euro area

(a) $\tilde{y}_t$ (b) r^n_t



Legend: Core EA; Peripheral EA.
Notes: The output gap is expressed as percentage share of potential output. The natural rate of interest is computed using the Holston-Laubach-Williams (HLW) model.
Source: IMF World Economic Outlook (WEO) Database, Holston et al. (2017) and author's calculations.

of r^n_t. A decrease in this term leads to a decrease in $\tilde{y}_t$, which then has a downward effect onto current inflation, π_t, via Equation (2.1a) (Brand et al. (2018)). This mechanism seems to have been at play in the euro area, where peripheral countries have been featuring a more negative gap than core economies since 2009 (see Figure 2.4.3a) and the estimated natural rate of interest has dropped to a minimum in 2014 (see Figure 2.4.3b).

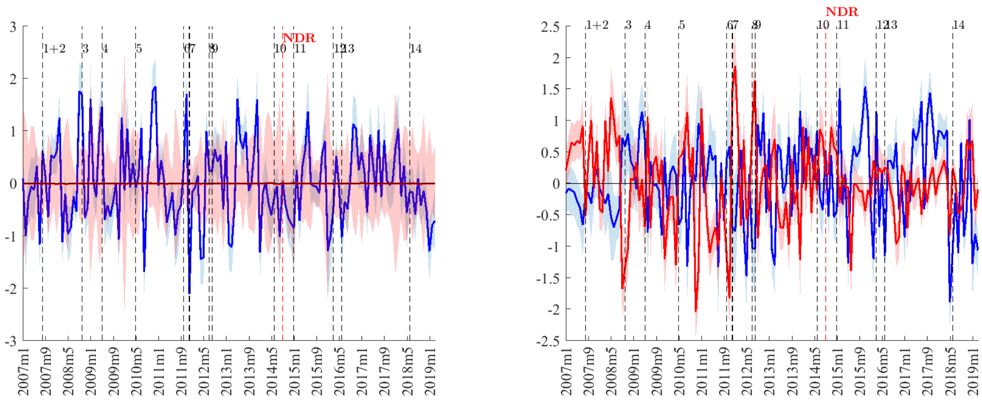
Additional insights are provided by the series of structural shocks, depicted in Figure 2.4.4. While the model is able to well capture the UMP events, there is a stark difference between core and peripheral EA in terms of composition of the UMP shocks[33],

[33]In our model, the UMP shock is determined by movements in both the term spreads and the risk-

in that the relevance of the expectation component is much more pronounced for the latter group. However, it is also noticeable that, in the same group, movements in the risk-neutral yields have become more and more muted over time, above all after the London speech.

Figure 2.4.4: Structural shocks series

(a) Core EA (b) Peripheral EA



Legend: Term spreads; Risk-neutral spreads.
Notes: Shaded areas are 68% confidence bands. Dashed lines correspond to UMPs announcements as numbered in Table 2.3.2.
Source: Author's calculations.

2.4.2.1 Counterfactual simulations

In the context of the ongoing debate around the effectiveness of the ECB's UMPs, it has been often wondered how different the developments in the euro area macroeconomic performance would have been, had the central bank adopted a more aggressive monetary policy stance since the onset of GFC. An answer to the question might be sought for by focusing on a particular episode, namely the ECB's policy rate hikes in April and July 2011 (Figure 2.4.5). That episode is often indicated as the main example of an excessive tightening on the part of the ECB[34] and can be read through the lens of the model by looking at the reaction of the term premia and the expectation components[35]. Market participants considered the April decision as highly temporary, as indicated by the drop in longer-term OIS future rates around the announcement (Figure 2.4.5a). On the other hand, the jump in the same rates across all maturities around the July monetary policy event shows that the subsequent hike was completely unanticipated

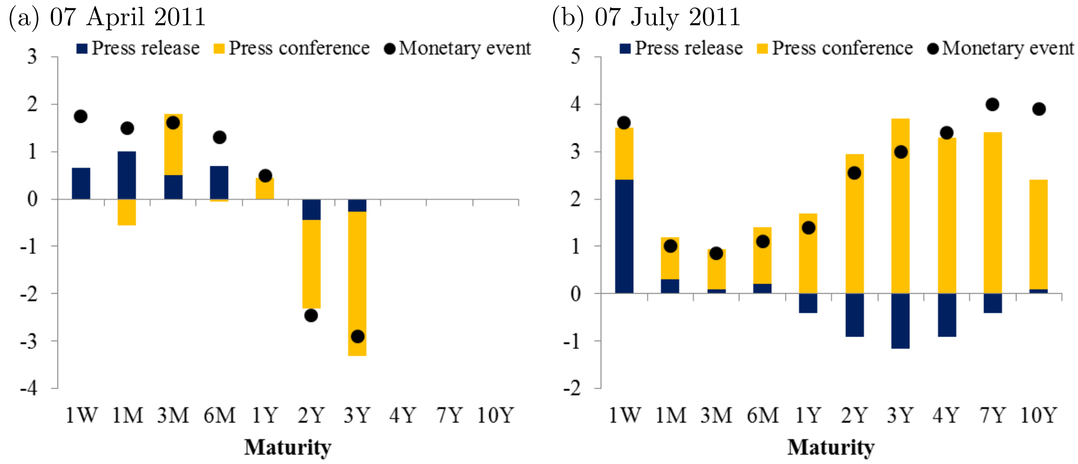
neutral spreads.

[34]In his post "One Size Fits One, Redux (Wonkish)" on 15 June 2011, Paul Krugman wrote: "[the ECB]'s tightening when only Germany even arguably needs it."

[35]This episode also sparked very different reactions across the euro area economies, with a sudden increase of the peripheral risk-neutral yields as displayed in Figure 2.3.1.

(Figure 2.4.5b). This course of action was indeed heavily criticised until August 2011, when the ECB decided to cut its policy rate again. The model is flexible enough to capture these developments, since the originated changes in the two monetary policy instruments resemble the market reaction to an UMP shock in spite of the technically conventional nature of the measure.

Figure 2.4.5: Changes in OIS rates at different maturities, around the monetary events in April and July 2011



Notes: the ECB policy decision is announced in two separate steps. First, at 13.45 CET, a brief press release provides the policy decision without any explanation and rationale. Then, at 14.30 CET the ECB President reads a prepared text, the Introductory Statement (IS), on the rationale behind the decision. Changes in rates are computed around both the two steps separately (dark blue and yellow bars) and around the overall event (black dots). Data for 4-, 7- and 10-year maturities are not available in April 2011.
Source: Altavilla et al. (2019).

Against this background, a counterfactual analysis is run based on the following steps:

i) the historical series of structural shocks is reconstructed, conditional on the parameters of the TVP-SVAR;

ii) the shock series is then modified by applying a counter-shock on the risk-neutral spreads, so that they are kept at pre-hikes averages throughout the period from March 2011 to April 2012;

iii) output and inflation series are then simulated using this modified shock series[36].

Figure 2.5.1 displays the results for core (Figure 2.5.1a) and peripheral (Figure 2.5.1b) economies. While the paths of output and inflation do not differ between the actual (hikes) and counterfactual (no hikes) scenarios for core EA economies, on the other hand the economic performance of peripheral EA economies seem to have been much penalized

[36]The approach here proposed is devised to address Lucas critique, as explained in Baumeister and Benati (2013).

by the 2011 ECB's policy decision, especially as far as output growth is concerned.

This seems confirmed by the difference between estimates of the baseline and the counterfactual scenarios (Figure 2.5.2). In peripheral EA members, indeed, output and inflation would be 0.4 and 0.3 percentage points higher under the counterfactual scenario, compared to the historical series.

2.5 Concluding remarks

After the 2007-2008 financial crisis, the ECB, like other major central banks, has employed a variety of unconventional monetary measures to address the freeze on the inter-bank market and later on to avert a severe sovereign debt crisis in the peripheral Member States. Starting from 2013, the ECB has implemented additional measures to boost the stagnating economic activity in the Eurozone, thus providing stimulus for the recovery.

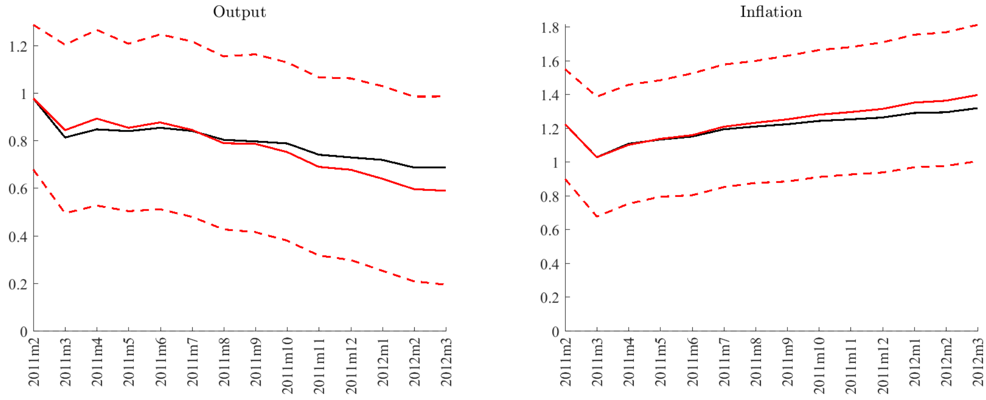
This chapter contributes to the already rich literature assessing the macroeconomic impact of UMPs along the following dimensions: i) it uses the decomposition of sovereign spreads into term premium and risk-neutral spreads to isolate the portfolio and signalling channels in core and peripheral economies; ii) it shows how these channels have been more or less relevant in the two different groupings over time and how their contribution to the movements in the spreads has drastically changed after June 2014; iii) on the basis of this evidence, it assesses the macroeconomic impact of ECB's UMPs using a TVP-SVAR-SV and implementing a novel identification strategy based on "dynamic" restrictions.

The main finding is that the impact of UMPs on both core and peripheral economies has decreased over time, especially for the former group of Member States. This trend has been mainly driven by a shutting down of the signalling channel after the implementation of the negative deposit rate in June 2014. Results also reveal the presence of the so-called "missing inflation puzzle" in peripheral EA, where monetary loosening has been accompanied by a decrease in the inflation rate.

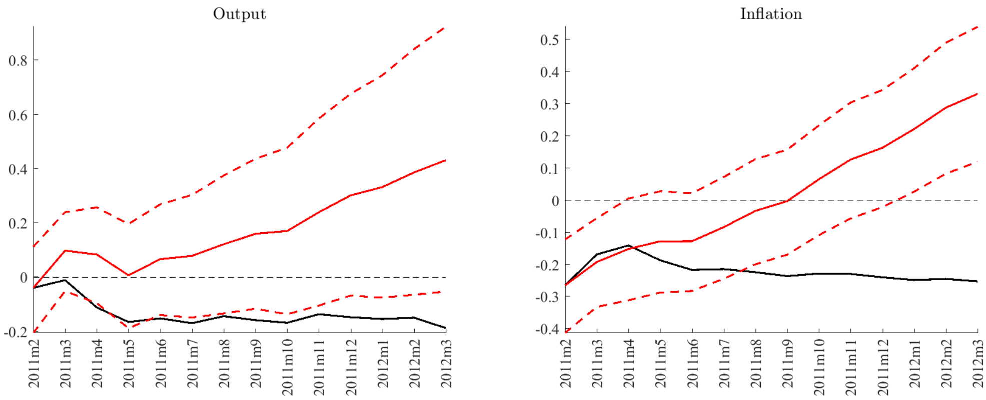
Finally, a counterfactual analysis based on the TVP-SVAR-SV estimates shows that the slowdown in the peripheral EA economies would have been less pronounced, if the ECB had been more aggressive in loosening its monetary stance.

Figure 2.5.1: Counterfactual analysis for the ECB's interest hikes in 2011

(a) Core EA



(b) Peripheral EA

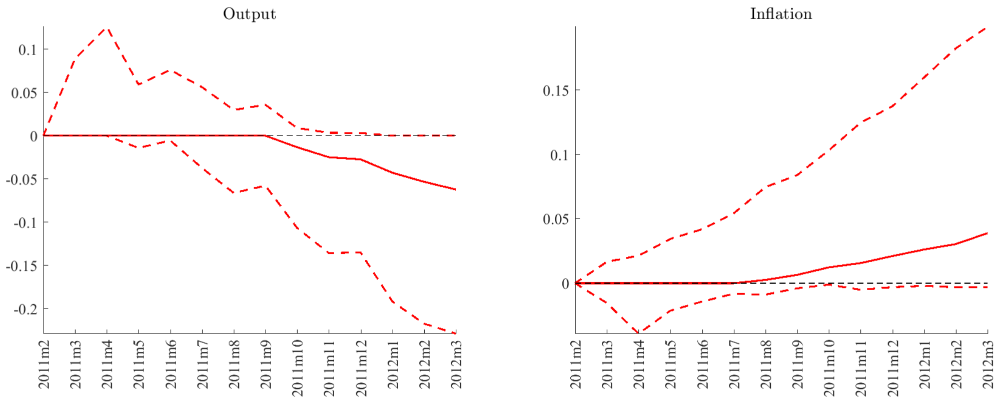


Legend: ▬ Actual; ▬ No hike.
Notes: Dashed lines are 68% confidence bands.
Source: Author's calculations.

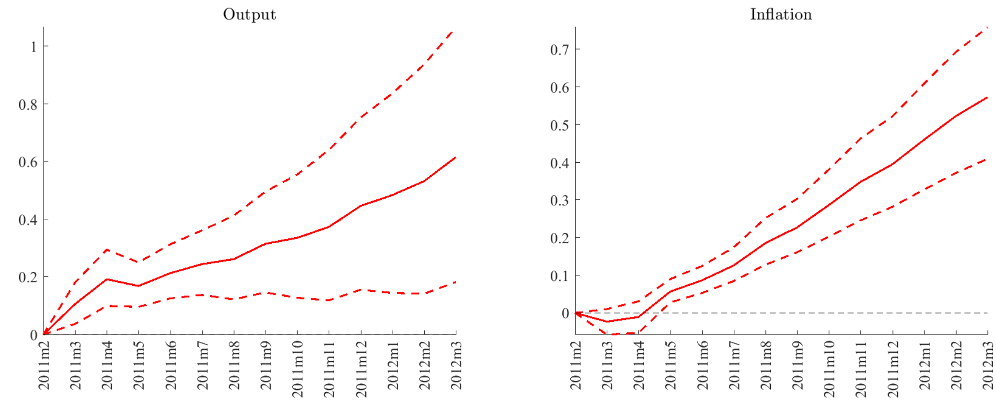
The framework adopted in this chapter shows several advantages, as it can accommodate different specifications aimed at tackling research questions that can add on the findings here explained. One venue for future research might consist of evaluating how results would change when expanding the monetary policy function to account for financial stability. A strand of literature relates the policy function to the financial cycle, by mainly focusing on the US (Filardo et al. (2019)). Differently from the US system, however, the euro area economy relies more heavily on bank intermediation, which hints to another possible channel of monetary policy transmission, namely the lending channel. The possible presence of such channel would then create a special relationship between the monetary policy function and the credit cycle, something that it is currently under investigation by expanding the TVP-SVAR-SV to include a measure of credit to the economy.

Figure 2.5.2: Counterfactual analysis for the ECB's interest hikes in 2011 - difference between the no hike and actual scenarios

(a) Core EA



(b) Peripheral EA



Notes: Dashed lines are 68% confidence bands.
Source: Author's calculations.

Chapter 3

The International Dimension of EMU deepening[1]

3.1 Introduction

> *[...in this] world where challenges are global, we've got to be together to be truly sovereign, to be true masters of our destinies, because on our own we would have no way to cope with these global challenges. The evidence is in front of our eyes every day* (Draghi (2019)).

Since the introduction of the euro, twenty years ago, both the global economy and the euro area economy have changed considerably as has the interaction between the two. On the one hand, the European Union (EU) has become not only the largest global trading block, handling 17.3% of world trade[2], but also a monetary union, whose currency has rapidly become the second most important in the international monetary system (see ECB IRE 2019). On the other hand, the international economy has experienced some dramatic changes, mainly driven by globalization and the rise of the so-called emerging market economies[3]. Moreover, these trends have been accompanied by a continued increase in financial integration, which has only slightly slowed down after the Great Financial Crisis (GFC), and a greater global correlation between real and financial macro-variables (see Ca' Zorzi et al. (2019)).

In light of these facts, the rich and controversial debate on deepening the European Economic and Monetary Union (EMU) needs to take into account how this process af-

[1] This chapter is based on a paper co-authored by Livio Stracca (European Central Bank) and Demosthenes Ioannou (European Central Bank)

[2] Excluding intra-EU trade, as reported by EC DG Trade 2019.

[3] According to IMF WEO 2019, the ratio between the world GDP share of advanced economies and that of emerging markets will be 36/63 by 2024.

fects and is affected by rising global economic change and integration[4]. Notably, the debate has to consider the international impact that an increase in the depth of European integration and an improvement in its quality (henceforth "EMU cohesion") would likely exert on the rest of the world. From a policy perspective, this analysis can help clarify the potential effects stemming from progress, or alternatively, a slowdown in the enhancement of EMU functioning, the latter being defined by the further development of micro- and macroeconomic policy tools, as well as institutions, presented in the Four Presidents' Report (2012) and Five Presidents' Report (2015)[5]. Such investigation becomes even more pressing in light of the risks deriving from the recent rise in protectionism and a potential reversal in the multilateral development of the international economic order.[6].

However, providing an answer to this research question is not an easy task in that, beyond the incomplete nature of EMU, the two processes of European and international integration have been deeply intertwined, with the direction of causality often running both ways and, hence, being difficult to identify. Against this backdrop, this chapter contributes to the ongoing debate by investigating the effects that the deepening (or lack thereof) of the EMU might exert on the rest of the world (RoW), something here referred to as the "international dimension of EMU deepening"[7].

Conceptually, this work builds on two main streams of research: i) the strand of literature aiming at quantifying the cross-border transmission of macroeconomic shocks[8] and, in particular, of monetary policy shocks[9]; ii) the papers focusing on crises periods to evaluate the international spillovers of the euro area crisis. Among the latter, Stracca (2015) shows that the global repercussions of the Eurozone crisis have mainly impacted the financial sector via a fall in equity returns, which has been more pronounced for countries with higher trade exposure to the euro area and a currency pegged to the

[4]See Pisani-Ferry and Zettelmeyer (2019) for a collection of policy-oriented articles by academic observers.

[5]The two reports postulate that the completion of EMU should rely on four unions developed in parallel: financial (including banking and capital markets union (CMU)), fiscal, economic and political.

[6]As pointed out in Corsetti (2015): "The future of the Eurozone (EZ) therefore rests on developing an institutional framework that can credibly deliver stability at the EZ level."

[7]This aspect can be seen as an extension of the Four Presidents' Report (2012) and the Five Presidents' Report (2015), as the two reports remain largely silent on the international dimension of EMU completion apart from a call for the consolidation of the euro area's external representation.

[8]See Dungey et al. (2011) and Forbes (2012) for a survey.

[9]See, among others, Forbes et al. (2017)) and Chen et al. (2017).

euro, as well as for non-EA members of the European Union (EU)[10]. In a similar vein, Aizenman et al. (2012) show that the effects of the euro area crisis in emerging economies are generally smaller than the responses to the global financial crisis. On the other hand, Ahmad et al. (2013) find that the transmission of shocks from the peripheral euro area economies to the emerging markets can feature either contagion (e.g. in the case of the BRICS) or interdependence (e.g. for Indonesia and South Korea)[11]. With a somewhat different focus, Claessens et al. (2011) analyse the behavior of firm-level stock returns of EU and non-EU companies and find that the effects of euro area crisis events ultimately depend on a series of country and firm-level characteristics.

Differently from these contributions, however, the main aim of this chapter consists of quantifying the changes in the *cohesion* of the euro area economy as a whole. Therefore, the proposed empirical strategy is applied both to crisis and non-crisis periods. Specifically, a Structural Vector Autoregressive model is built up with euro area and global financial variables where shocks to EMU cohesion ("euro area stress shocks") are disentangled from "external" shocks, i.e. shocks originating outside of the euro area, by means of sign, magnitude and narrative restrictions. This approach, which is novel in the literature studying the effects of the euro area crisis, successfully teases out shocks that originate inside the euro area from global risk aversion shocks, in spite of the fact that they are qualitatively very similar.

The second part of the analysis uses the identified structural shock series to assess their broader macroeconomic implications. Notably, it is shown that euro area stress shocks negatively impact the economic activity of the RoW and entail a temporary slowdown in global trade whose magnitude can become substantial if no corrective action is undertaken. To the best of my knowledge, a quantification of both EMU deepening and its spillovers on to extra-EA economies is an original contribution to the existing research[12].

The remainder of the chapter is structured as follows: Section 3.2 introduces the methodology used to isolate "euro area stress shocks" and presents the main results;

[10] Allegret et al. (2017) provide similar results using a Smooth Transition Regression (STR) framework.

[11] Similarly, Bird et al. (2017) disentangle between contagion and safe-haven effects, when evaluating the spillovers of the euro area sovereign debt crisis onto the non-EA neighbours.

[12] Most of the related literature, indeed, mainly focuses on the macroeconomic repercussions that the euro area crisis had on its Member States. In this regard, see Neri and Ropele (2015)

Section 3.3 quantifies the effects that these shocks have on the RoW from a macroeconomic perspective; Section 2.5 concludes.

3.2 Methodology

The whole analysis in this chapter relies on an empirical strategy consisting of two main building blocks: i) identification of euro area stress shocks by means of a daily SVAR with sign, magnitude and narrative restrictions (Section 3.2.2) ; ii) assessment of the effects on a set of macroeconomic variables for the RoW via panel local projections (Section 3.3). Before proceeding to i), however, Section 3.2.1 constructs a quantitative measure of EMU cohesion to be used to identify euro area stress shocks.

3.2.1 The proxy for euro area cohesion (EASTR)

The proxy for EMU cohesion (EASTR henceforth) is given by the average 10-year government bond spread between Italy and Spain on the one hand and Germany on the other. This definition essentially relates the degree of cohesion among the euro area Member States to the stress of their sovereign bond markets relative to the benchmark (Germany)[13]. The choice of average sovereign spreads as stress indicators for euro area cohesion is supported by a series of stylized facts and empirical evidence provided by the relevant literature. While a non-zero bond yield spread should be seen as normal in a monetary union in presence of country-specific macroeconomic conditions and policies, large and abrupt fluctuations of bond spreads may be interpreted as a demand for higher risk premia on the part of market participants because of uncertainty arising from the incomplete nature of EMU. Such premia vis-à-vis the benchmark sovereign exhibiting safe haven status during peak stress moments, i.e. the German Bund, are not necessarily linked to the macroeconomic and fiscal fundamentals of individual euro area Member States.

In this regard, Attinasi et al. (2009) provide evidence that the increase in euro area sovereign spreads over the period 2008-2009 was due to a reassessment on the part of investors of sovereign risk following the announcements of several bank rescue packages. Di Cesare et al. (2012) find that the high levels of sovereign yields over the period 2011-

[13]The measure excludes countries that had temporarily lost market access during the crisis to control for idiosyncratic movements in sovereign spreads.

2012 in several euro area countries were mainly due to an increase in the perceived risk of a break-up of the euro area, rather than to macroeconomic and fiscal developments[14]. Similarly, De Grauwe and Ji (2013) show that a significant part of the surge in the spreads of the peripheral euro area economies during 2010-2011 was not linked to the deterioration of the underlying fundamentals, but it was rather determined by strong negative self-fulfilling market sentiments as of the end of 2010. Finally, Afonso et al. (2018) find that the OMT announcement in August 2012 marked a regime shift in the pricing of sovereign bonds in the euro area, whereby the link between sovereign spreads and fundamentals has grown weaker, while spreads and re-denomination risk have become relatively higher compared to the pre-crisis period[15].

Besides the support provided by this collection of findings, the EASTR measure is also found to be highly correlated with other commonly-used indicators of within-euro area stress, e.g., the sum of TARGET2 balances (Figure 3.2.1a) and 5-year CDS premia (Figure 3.2.1b), with an estimated correlation coefficient swinging over time between -0.77 and 0.78 for the former and ranging from 0.6 (peripheral bank CDS premia) to 0.74 (peripheral sovereign CDS premia) for the latter[16]. Moreover, there is also a high degree of co-movement with the redenomination risk measure of De Santis (2019), which is based on 3-year quanto CDS spreads vis-à-vis Germany (Figure 3.2.1d)[17].

The evolution of the EASTR measure is also consistent with the institutional response of the euro area authorities to the financial and the euro area debt crises, as quantified by the European Institutional Integration Index (EURII) which measures the steps of institutional and policy deepening along a comprehensive set of dimensions[18]. Figure 3.2.1c shows that periods of tension to EMU cohesion corresponding to increases in the EASTR variable (financial crisis of 2007-2009, euro area debt crisis of 2010-12)

[14]De Santis (2012) also shows that a "regional risk factor" is one of the main drivers of the generalized increase in euro area sovereign spreads in 2008-2011.

[15]In this regard, see also von Hagen et al. (2011), Afonso et al. (2014, 2015) and Manganelli and Wolswijk (2014).

[16]On the relationship between TARGET2 balances and macroeconomic adjustments in the euro area, see Fagan and McNelis (2014). On the use of CDS premia on sovereign and bank bonds as proxy for the sovereign-bank nexus, see De Bruyckere et al. (2013), Angelini et al. (2014), Acharya et al. (2014).

[17]I would like to thank Roberto De Santis for providing the estimated measure of redenomination risk for Spain, Italy and France.

[18]Notably, the EURII includes the following sub-components: Free Trade Area and Customs Union, Supranational institutions and decision-making, Financial Markets Union, Coordination of monetary and exchange rate policies, Democratic legitimacy and accountability, Internal Market, Economic Union, Fiscal Union and Monetary Union (see Dorrucci et al. (2015)).

are followed by increases in the EURII index capturing the implementation of EMU deepening measures such as the establishment of the European Stability Mechanism (ESM) or the setup of the Banking Union thorugh the creation of European banking supervision and resolution (2013-2016).

Given all this, the EASTR measure can be interpreted as a quantitative measure of the viability of the euro area. It is in this sense, then, that "EMU cohesion" has to be interpreted in this chapter.

3.2.2 The SVAR model

The first step of the empirical exercise consists of disentangling between shocks to EMU cohesion originating inside the euro area and risk aversion shocks influencing global financing conditions. One can think of singular events during the euro area sovereign debt crisis in 2010-2012 as an example of the former, and peak events during the global financial crisis like the Lehman Brothers bankruptcy as an instance of the latter. With this aim, a *daily* Structural Vector Autoregression model (SVAR) is setup as follows:

$$A_0 Y_t = \mathbf{c} + A_1 Y_{t-1} + \cdots + A_p Y_{t-p} + \varepsilon_t, \tag{3.1}$$

where ε_t is a vector of structural shocks which are assumed to be Gaussian with mean zero and variance I_N, conditional on past information and the initial conditions $(Y_0, \ldots, Y_{-p})$[19]. The vector Y_t includes seven financial variables, both euro area-based and global: the EASTR measure, the Chicago Board Options Exchange (CBOE) Volatility Index (VIX), the world equity price index excluding the euro area ("RoW equity"), the equity price index for the euro area ("EA equity"), the nominal effective exchange rate of the euro (NEER), the US 10-year benchmark government bond yield and the spread of JP Morgan's Emerging Market Bond Index Plus (EMBI+)[20]. Data cover the period from January 1999 to July 2019.

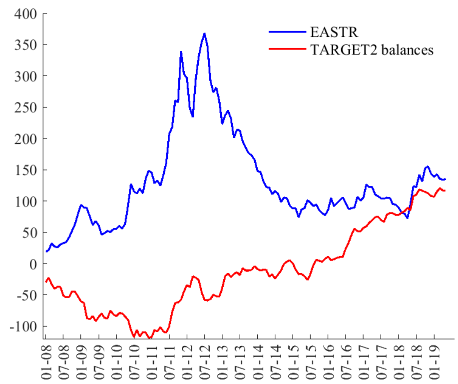
Two types of shocks are identified within the SVAR, namely: i) a within-euro area (EA) stress shock influencing the market perception about the long term viability of the monetary union and ii) a global risk aversion shock. Teasing out the two shocks

[19] In what follows, p is set equal to 1, as indicated by the Schwartz Information Criterion.

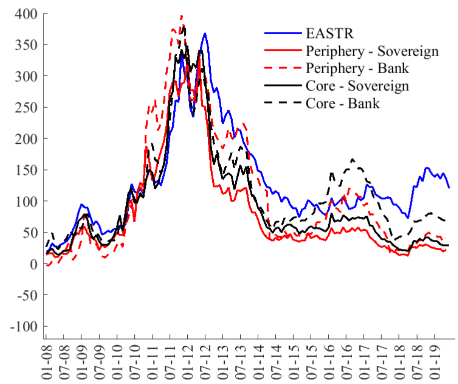
[20] The VIX, the equity price indexes and the euro effective exchange rate are included in log terms, while all the variables are demeaned and standardized. See also Appendix C.1 for data sources.

Figure 3.2.1: Comparison between EASTR and other indicators.

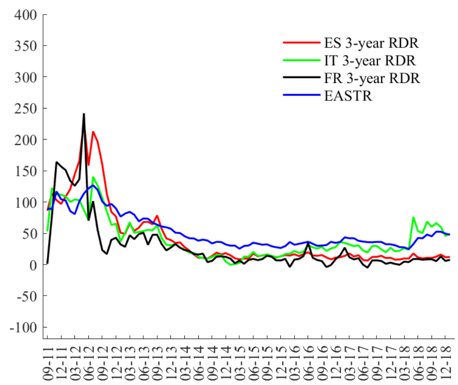
(a) EASTR vs TARGET2 balances



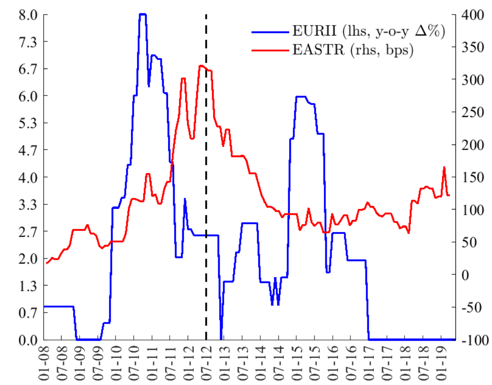
(b) EASTR vs 5-year CDS premia



(c) EASTR vs Redenomination Risk



(d) EASTR vs EURII



Notes: CDS premia are defined as the 5yr euro-denominated CDS spreads vis-à-vis Germany; redenomination risk is computed using 3-year CDS premia; in Figures 3.2.1a and 3.2.1b, EASTR, CDS premia and TARGET2 balances are indexed with 2010 = 100; in Figure 3.2.1c series are indexed with 2011 = 100; in Figure 3.2.1d, EURII index is in annual percentage change and the dashed vertical line corresponds to the London speech.
Sources: ECB, Datastream, De Santis (2019) and authors' calculations.

is challenging because within-euro area stress shocks can become global risk shocks for the rest of the world (Stracca (2015)). Following Antolín-Díaz and Rubio-Ramírez (2018), the identification strategy is based on a combination of sign, magnitude and narrative restrictions. The underlying intuition is that global shocks entail generalized fluctuations in the spreads across different regions, which should then move in a similar manner (both direction and magnitude-wise). Therefore, events of positive (negative) global risk aversion shocks are partially identified by imposing the restrictions below:

i) there must be an increase (decrease) in the VIX;

ii) the EA stress variable and the EMBI+ spread must both increase (decrease);

iii) the EMBI+ spread must react more than the EA stress variable (*magnitude restriction*);

iv) the US 10-year government bond yield must decrease (increase).

On the other hand, positive (negative) EA stress shocks are identified as follows:

i) there must be a decrease (increase) in the EA stress variable;

ii) the EA stress variable must react more than the EMBI+ spread (*magnitude restriction*);

iii) the euro nominal effective exchange rate must appreciate (depreciate).

Table 3.2.1 compares the daily changes in the variables of interest around some well-known global and euro area events over the period 2008-2017. The preliminary evidence seems to support the initial intuition.

3.2.2.1 Event study

In order to check that the changes in Table 3.2.1 are significant and, hence, that the restrictions to be imposed on the daily SVAR are supported by the data, an event study is performed around those events.

Table 3.2.1: Daily changes around selected events

	Date	EA stress	€NEER	VIX	EMBI	EA eq.	RoW eq.	US10Y
Global events								
Lehman Brothers default	*16/09/2008*	0.65	-0.46	4.06	10.67	-69.66	-4.19	-0.02
Taper tantrum	*22/05/2013*	9.60	-0.01	0.18	11.67	-58.23	-2.88	-0.02
Chinese stock market bubble burst[1]	*Jun-Aug 2015*	-3.45	0.30	-5.75	-23.67	64.760	1.320	0.108
EA events								
Greece requests for programme	*23/04/2010*	11.30	-0.16	0.67	-0.67	28.93	0.81	0.00
Ireland requests for programme	*22/11/2010*	14.50	-0.56	1.86	7.00	-72.06	-0.30	-0.03
Spain and Cyprus request for programme	*27/06/2012*	10.95	-0.27	0.25	4.00	-7.99	0.15	-0.04
London speech+	*26/07/2012*	-35.05	0.16	-0.75	-16.33	50.18	2.05	0.11
Greek bailout referendum	*06/07/2015*	3.50	-0.39	-0.65	4.33	-71.01	3.54	-0.03
EG* agrees on Greek third programme	*09/07/2015*	-24.30	0.66	-3.02	-11.33	108.78	-0.05	0.08
Brexit referendum	*23/06/2016*	24.65	-0.63	7.98	18.00	-261.77	-6.07	-0.19
Sintra speech+	*27/06/2017*	-2.35	0.77	-0.97	2.00	-2.62	-0.05	0.02

Notes: [1] This refers to the sum of daily changes around a series of salient events that have featured the Chinese stock market turbulence between mid-2015 and beginning of 2016; these events include two stock market crashes (27 July 2015 and 24 August 2015) and the devaluation of Renminbi on 11 August 2015; [2] by "programme" we refer to EU/IMF economic adjustment programmes; + ECB President's speeches; * EG = Eurogroup.

Notably, the study is based on the estimation of the following regression:

$$\Delta x_t = \alpha_x + \mathbf{Event}_t \beta_x + \mathbf{D}_t \gamma_x + \varepsilon_{x,t}, \tag{3.2}$$

where $\Delta x_t = \{\Delta EASTR_t, \Delta EURNEER_t, \Delta VIX_t, \Delta EMBI_t, \Delta EAEQ_t, \Delta RoWEQ_t, \Delta US10yr_t\}$ and $\mathbf{Event}_t$ is a $1 \times M$ vector of dummy variables that refer to the events in Table 3.2.1. Such dummies are set equal to 1 on the date of the event they are linked to and 0 otherwise. In addition, Equation (3.2) also includes a $1 \times (K + P)$ matrix of control variables, $\mathbf{D}_t$, that is partitioned as:

$$\mathbf{D}_t = \left[\begin{array}{c|c} \mathbf{R}_t & \mathbf{P}_t \end{array} \right],$$

where $\mathbf{R}_t$ is a $1 \times K$ matrix of dummy variables that are equal to 1 on the date of the release of European macroeconomic data and 0 otherwise, while $\mathbf{P}_t$ is a $1 \times P$ matrix including dummy variables that equal 1 on the dates of release of US macroeconomic data, and 0 otherwise. In the current setting, 6 macroeconomic releases for the euro area and the US are considered: Consumer Price Index Estimate, Actual Consumer Price Index, Real Gross Domestic Product, Unemployment Rate, Industrial Production and Consumer Confidence Index.

The parameter of interest in Equation (3.2) is the $1 \times M$ vector β_x, whose i-th element represents the difference between the change in variable x on event day i, with $i = 1, \ldots, M$, and the average daily change of x on other dates, excluding the events and the release days of other macroeconomic data either in the euro area or US. Therefore, if the i-th element of $\hat{\beta}_x$ is statistically significant, then event i has a significant effect on x. In addition, a Wald test is performed to check for the joint significance of the elements of β_x, the null hypothesis being $H_0 : \sum_{i=1}^{M} \hat{\beta}_{i,x} = 0$. This would indicate whether the whole set of events in $\mathbf{Event}_t$ had a cumulative significant impact on x.

Table 3.2.2: Significance of daily changes around global and European events

	EA stress	€NEER	VIX	EMBI	EA eq.	RoW eq.	US10Y
Global events							
Lehman Brothers default	0.13	**-1.282*** **	**2.971*** **	**1.246*** **	**-1.470*** **	**-2.537*** **	**-0.273*** **
	(0.15)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
Taper tantrum	**1.257*** **	**-0.057*** **	**0.162*** **	**1.336*** **	**-1.328*** **	**-1.764*** **	**-0.406*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Chinese stock market bubble burst	**-0.460*** **	**0.692*** **	**-4.083*** **	**-2.684*** **	**1.492*** **	**0.743*** **	**1.871*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
EA events							
Greece requests for programme	**1.480*** **	**-0.426*** **	**0.520*** **	**0.472*** **	**0.664*** **	**-0.061*** **	**-0.070*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Ireland requests for programme	**1.900*** **	**-1.443*** **	**1.384*** **	**-0.200*** **	**-1.646*** **	**-0.496*** **	**0.805*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Spain and Cyprus request for programme	**1.434*** **	**-0.707*** **	**0.215*** **	**0.072*** **	**-0.181*** **	**-0.702*** **	**0.462*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
London speech	**-4.602*** **	**0.381*** **	**-0.511*** **	**1.223*** **	**1.150*** **	**1.877*** **	**-1.857*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Greek bailout referendum	**0.457*** **	**-1.027*** **	**-0.439*** **	**2.126*** **	**-1.622*** **	**-0.458*** **	**0.500*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
EG* agrees on Greek third programme	**-3.192*** **	**1.664*** **	**-2.160*** **	**-0.049*** **	**2.491*** **	**1.318*** **	**-1.287*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Brexit referendum	**3.232*** **	**-1.637*** **	**5.829*** **	**-3.697*** **	**-5.986*** **	**-3.204*** **	**2.059*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Sintra speech	**-0.311*** **	**1.927*** **	**-0.671*** **	**-0.049*** **	**-0.058*** **	**0.398*** **	**0.234*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Notes: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, p-values in parentheses. t-statistics are computed using Newey and West standard errors. All figures are in standard deviation terms.
For clarifications on the events, see the footnote to Table 3.2.1 above.

Regression results, reported in Table 3.2.2, show that changes around the majority of events is highly significant across all the endogenous variables. Moreover, they provide a clear indication on the restrictions to impose on the matrix of contemporaneous relations (A_0) as explained below.

3.2.2.2 Identification

Based on the estimates in Table 3.2.2, Table 3.2.3 reports the baseline restrictions for A_0 (baseline setting)[21].

Table 3.2.3: Baseline sign restrictions

Variables \ Shocks	EA stress	Global
EASTR	> 0	≥ 0
€NEER	≤ 0	$<$ EA shock
VIX		> 0
EMBI+ spread	$<$ EASTR	$\geq$ EASTR
EA equity	≤ 0	
RoW equity	$<$ EA Equity	≤ 0
US10Y		< 0

In addition, the proposed identification strategy also encompasses narrative restrictions corresponding to some identified important events. Notably, the sign of the shocks is constrained on the dates of five events:

i) Lehman Brothers bankruptcy (15 September 2008): *positive* global shock;

ii) FED's "Taper tantrum" (22 May 2013): *positive* global shock;

iii) Request of financial assistance by Spain and Cyprus (27 June 2012): *positive* euro area shock;

iv) ECB President's London Speech (26 July 2012): *negative* euro area shock;

v) Approval of the 3^{rd} economic adjustment programme for Greece (9 July 2015): *negative* euro area shock.

For some of these events, the sign restrictions on the structural shocks are complemented with additional restrictions on the magnitude of the contribution to either the EASTR variable or the VIX. Specifically, the default of Lehman Brothers is considered as a positive global risk aversion shock, which is also the most important contributor to the historical decomposition of the VIX. Similarly, the ECB President's London speech is classified as a negative EA stress shock, which is then the most important contributor to the historical decomposition of the EASTR variable. Table 3.2.4 summarizes all the narrative restrictions in the SVAR[22].

[21] The number of restrictions imposed is more than what would be required to identify the two shocks. However, part of the literature has underlined the importance of implementing all the theoretically plausible restrictions to pin down the shocks of interest (see, among others, Baumeister and Benati

Table 3.2.4: Narrative restrictions

Date	Event	Shock	
		Type	Contribution
15-Sep-08	Lehman Brothers bankruptcy	Global+*	$\xrightarrow{+} VIX^{**}$
22-May-13	FED "Taper tantrum"	Global+	
27-Jun-12	Spain and Cyprus request for programme	EA+	
26-Jul-12	London speech	EA-	$\xrightarrow{+} EASTR$
09-Jul-15	Eurogroup agrees on Greek 3rd programme	EA-	

Notes: * $z+$: positive z-shock, $z-$: negative z-shock;
** $\xrightarrow{+} x$: most important contributor in historical decomposition of variable x. For a formal definition of these types of restrictions, see Appendix C.2.

3.2.3 Results

Figure 3.2.2 displays the Impulse Response Functions (IRFs) for a 10-basis-point increase in the EASTR variable and a 0.61 percentage points (pps) increase in the VIX which, in this framework, correspond to a negative shock to EMU cohesion and a positive shock to global risk aversion[23]. Generally speaking, the two shocks lead to different responses across the variables of interest. For instance, a euro area stress shock has a greater impact on euro area equity prices, the €NEER and the US 10-year yields, while the impact of global risk aversion shocks is more relevant for RoW equity prices as well as the EMBI+ spreads.

Specifically, an increase in the EASTR variable by 10 basis points (bps) affects EA equity prices and the €NEER, which both decrease on impact by 1.0 and 0.32 pps respectively. The same shock also leads to an increase in the US 10-year yield by ~5 basis points, while leaving the EMBI+ spread unaffected over a one-month horizon. On the other hand, a global risk aversion shock given by a comparable increase in the VIX (~0.61 pps) entails an immediate drop in the equity prices for both the RoW (-0.27 pps) and the euro area (-0.23 pps). This also leads to a substantial decrease in the US 10-year yield (-2.28 bps) and an increase in the EMBI+ spread (+1.68 bps).

These results suggest that global shocks work their way through equity markets, while euro area stress shocks have more pervasive negative effects through the bond

(2013)).

[22]The selection of events is done on the basis of an algorithm that considers different combinations from the list reported in Table 3.2.1. The final outcome consists of the subset of events, out of 254 different combinations, with the highest number of draws that satisfy the narrative restrictions. Refer to Appendix C.2 for the technical details of the estimation.

[23]For comparison purposes, it is considered a euro area shock that entails the same increase in the VIX as a global risk aversion shock.

markets, as also confirmed by the estimated differences across IRFs to the two shocks (Figure 3.2.3).

3.2.3.1 Dynamic multipliers

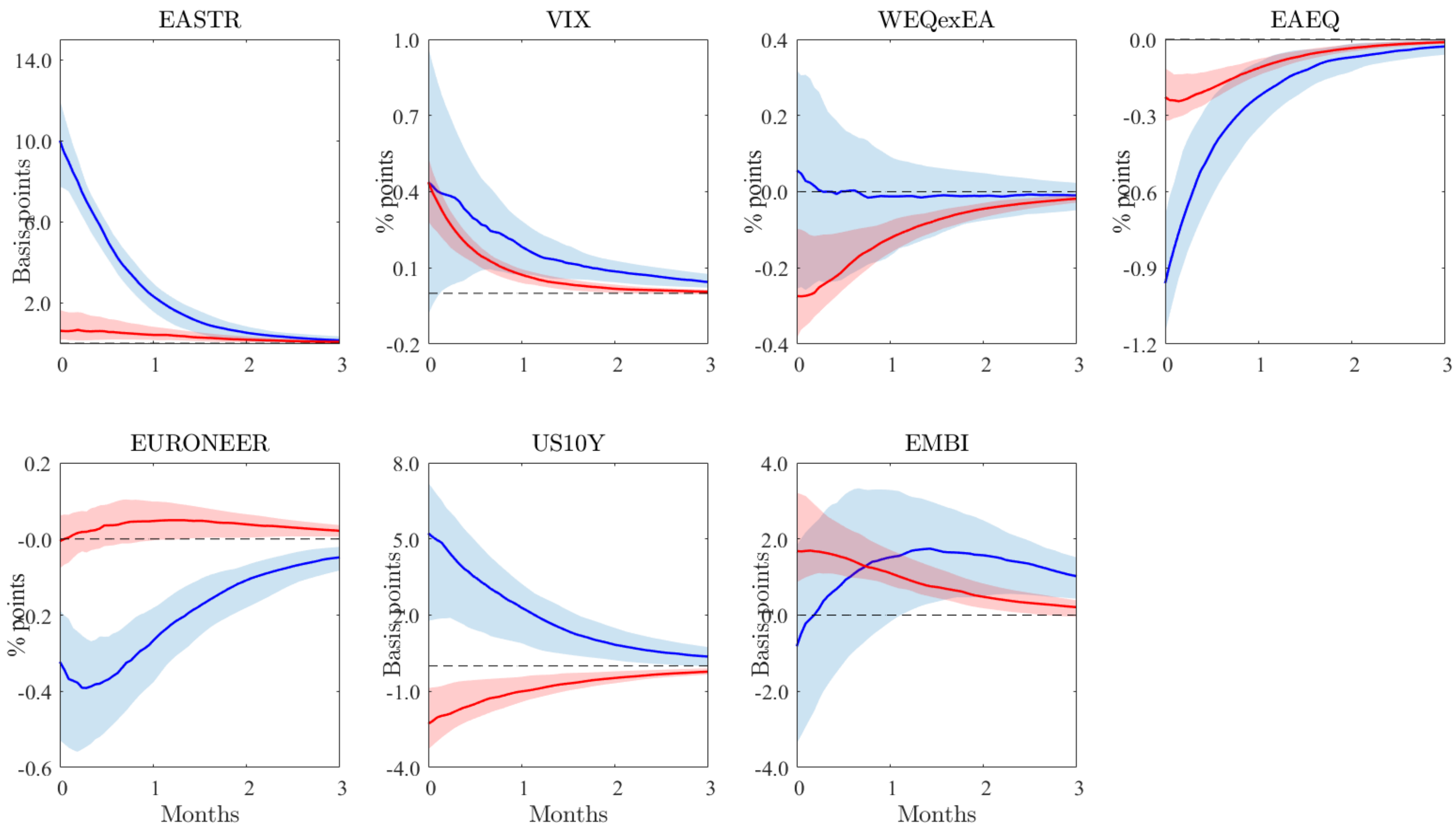
The direct comparison of IRFs magnitudes is subject to an important caveat, namely that the functional form as well as the assumptions of our model are ad-hoc and might disregard other important relations across the endogenous variables (e.g., the EMBI+ is by construction a function of the US Treasury yield curve). Therefore, as in Section 1.3.1 above, it looks more appropriate to evaluate the reaction of the variables of interest by means of conditional dynamic multipliers, which are computed as the ratio between the cumulative IRFs of two variables against a common shock of interest. Notably, the conditional dynamic multiplier of variable y vis-à-vis variable z is computed as follows:

$$\Phi_{yz}(k) \equiv \left| \frac{\sum_{k=0}^{K} \frac{\partial y_{t+k}}{\partial \varepsilon_t^x}}{\sum_{k=0}^{K} \frac{\partial z_{t+k}}{\partial \varepsilon_t^x}} \right| \tag{3.3}$$

where $\sum_{k=0}^{K} \frac{\partial y_{t+k}}{\partial \varepsilon_t^x}$ is the cumulative IRF of variable y to shock x at horizon K. These statistics are particularly useful in this context because they make it possible to study the relations across different variables without requiring any assumption on the form that such relations should take[24]. Table 3.2.5 reports the estimates of Equation (3.3) for the two different shocks, with y and z given by: i) the EMBI+ spread and the US 10-year government bond yield; ii) the equity price indices for the euro area and the rest of the world; iii) the EASTR and the US 10-year government bond yield; iv) the EASTR and the EMBI+ spread. When comparing the US 10-year yield and the EMBI+, there is no statistically significant difference between the effects of the two shocks in that the confidence bands for the estimated multipliers both include 1. Moving to the pair EASTR variable/US 10-year yield, on the other hand, the median values show that the US yield is much more impacted by a global shock than the EASTR variable, while the contrary holds true after a euro area stress shock, with estimates of the dynamic multiplier being significantly above 1. According to the results, EASTR also reacts much more to euro area stress shocks than the EMBI+, while global shocks have very

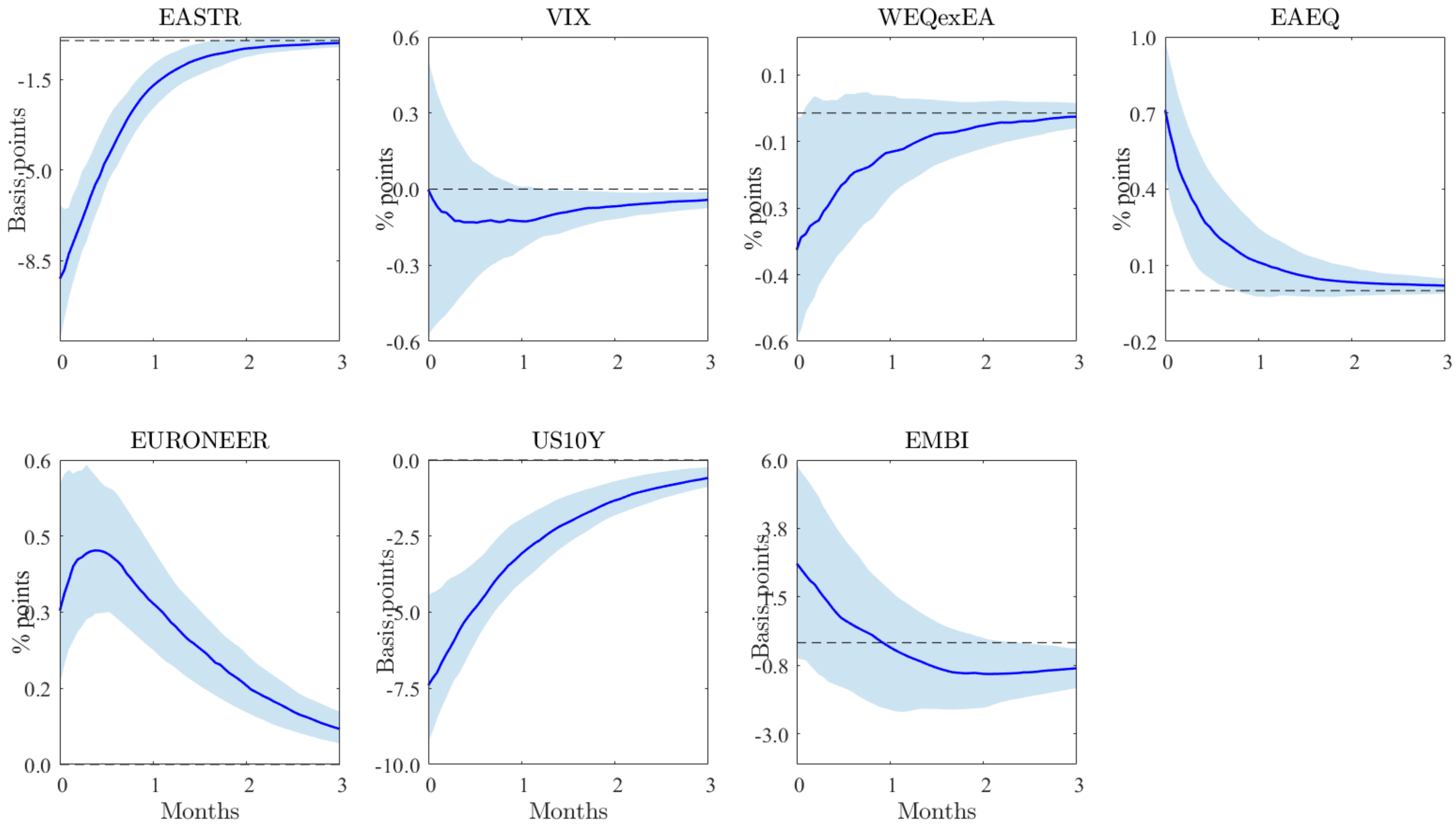
[24]The type of multipliers here adopted is the static version of the time-varying multipliers in Section 1.3.1, which in turn are based on Barnichon and Mesters (2019) and Galí and Gambetti (2019).

Figure 3.2.2: IRFs - euro area stress (blue) and global risk aversion (red) shocks



Notes: Shaded areas represent 68% confidence bands.
Source: Authors' calculations.

Figure 3.2.3: Differences across IRFs to euro area stress and global shocks.



Notes: Shaded areas are 68% confidence bands.
Sources: Authors' calculations.

Table 3.2.5: Maximum dynamic multipliers for EA stress and global risk aversion shocks

	16th percentile	Median	84th percentile
EMBI+/US10Y			
EA shock	0.25	1.02	4.11
Global shock	0.47	1.12	3.12
EASTR/EMBI+			
EA shock	2.31	5.40	21.00
Global shock	0.18	0.44	0.61
EA equity/World equity			
EA shock	2.13	4.35	16.72
Global shock	0.69	0.93	1.35
EASTR/US10Y			
EA shock	1.38	1.99	4.07
Global shock	0.17	0.39	1.10

Notes: Multipliers are computed as $\max_k \Phi_{yz}(k)$, where $\Phi_{yz}(k)$ is defined in Equation (3.3).

similar effects on both variables. Finally, effects of global shocks on world equity prices are not statistically different from the effects on European prices, while the latter react much more than the former in the case of a euro area stress shock.

In line with part of the existing literature, these findings suggest that both euro area and global shocks provoke relevant portfolio re-balancing effects deriving from a shift in the sentiment of investors. However, the nature of such shift appears to be different between the two instances, as euro area stress shocks have generalized negative repercussions on extra-European bond markets as signalled by the increase in the US 10-year yield. Global risk aversion shocks, on the other hand, imply a more typical flight-to-safety reaction as indicated by the decrease in US yields and the increase in EMBI+ spreads.

3.2.3.2 Historical decomposition of shocks

Additional evidence around the results so far discussed can be provided by the historical decomposition analysis (Figure 3.2.4). Generally speaking, while historical decompositions display higher volatility since the onset of the GFC (2007-2008) and until mid-2012 (London speech), contributions of both global risk aversion and euro area stress shocks have followed a much stabler path thereafter, between 2012 and the end of 2017. Moreover, Figures 3.2.4f and 3.2.4g unveil interesting dynamics for the US 10-year government bond yield and the EMBI+ spread respectively. Indeed, while global risk aversion shocks have been predominant contributors until the ECB President's London speech in July 2012 and the ECB's announcement of OMT, euro area stress shocks have later become relatively more relevant. Ever since, movements in both US and EMBI+ spreads have been driven by euro area stress and global shocks alike, without presenting any spike in volatility.

In the second half of 2017, the fall in economic tension in the euro area led to a slight appreciation of the euro (Figure 3.2.4e) and a small drop in the EASTR variable (Figure 3.2.4a). This trend was, however, more than offset at the beginning of 2018 after the ECB announced the stop of net purchases under the Extended Asset Purchase Programme (EAPP). In the first half of 2019, which corresponds to the last part of the sample, global shocks returned to play a major role compared to euro area stress shocks, not only in bond, but also in equity markets (Figure 3.2.4d).

3.3 The impact of euro area stress shocks

This section evaluates to what extent euro area stress shocks, as identified in Section 3.2.2, have affected the euro area economy and the rest of the world. This is done by assessing the impact exerted on a set of *monthly* macroeconomic indicators for the euro area and a group of Advanced Economies (AEs) as well as Emerging Market Economies (EMs)[25]. With this aim, daily shocks are first aggregated at the monthly level (Figure 3.3.1b)[26] and, then, the intra-EA and cross-border effects are quantified by means of impulse response functions (IRFs) computed with Jordà's local projections approach. This methodology is particularly suitable in this case, given its appealing property of being both more robust to misspecifications and very easily adaptable to non-linear frameworks. Notably, the regression model is given by:

$$x_{i,t+h} = \alpha_i + \xi_h \varepsilon_t^z + \sum_{k=1}^{p} \beta_h x_{i,t-k} + \gamma \boldsymbol{Z}_{t-1} + \nu_{i,h,t+h} \tag{3.4}$$

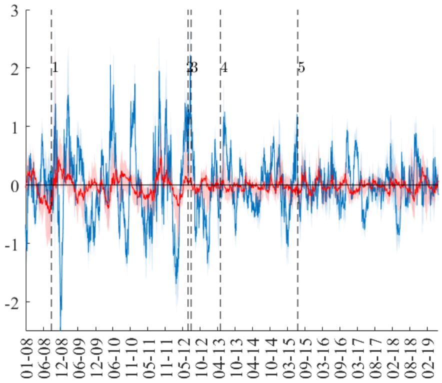
with $i = 1, \ldots, N$, $t = 1, \ldots, T$. The parameter of interest in Equation (3.4) is ξ_h, which measures the effect that a shock (ε_t^z) at time t has on the variable of interest, $x_{i,t}$, after

[25] See Appendix C.1 for a complete list of countries.

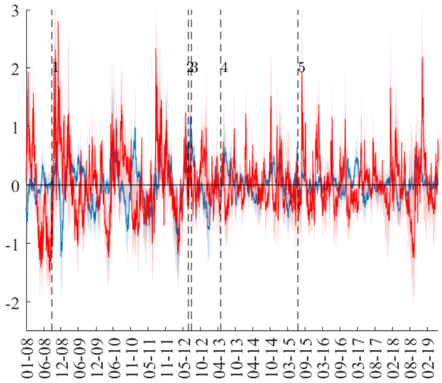
[26] Following Gertler and Karadi (2015) and Jarociński and Karadi (forthcoming), the aggregation is done by summing up the daily shocks on a monthly basis. As a robustness check, the analysis has been repeated using an aggregation method based on monthly averages. Results, available upon request, are very similar to what shown in the paper.

Figure 3.2.4: Historical decomposition - euro area stress (blue) and global risk aversion (red) shocks.

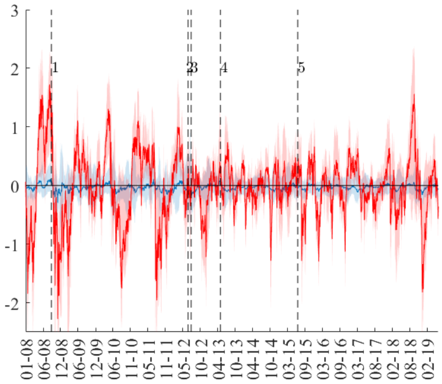
(a) EASTR



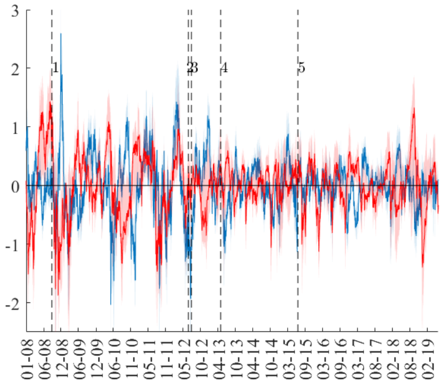
(b) VIX



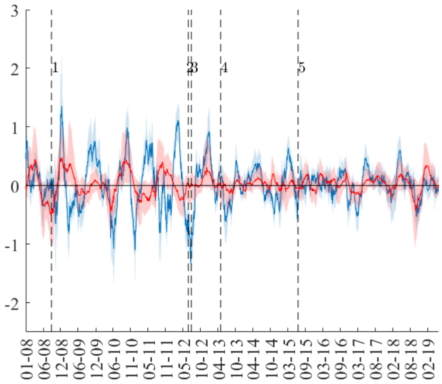
(c) World Equity prices



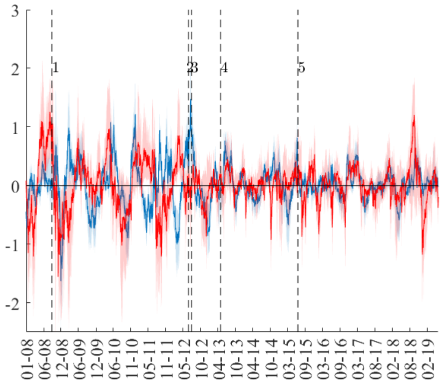
(d) Euro area equity index



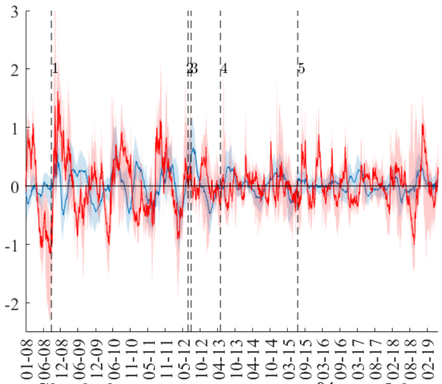
(e) Euro effective exchange rate



(f) US 10-year yield



(g) EMBI+ spread

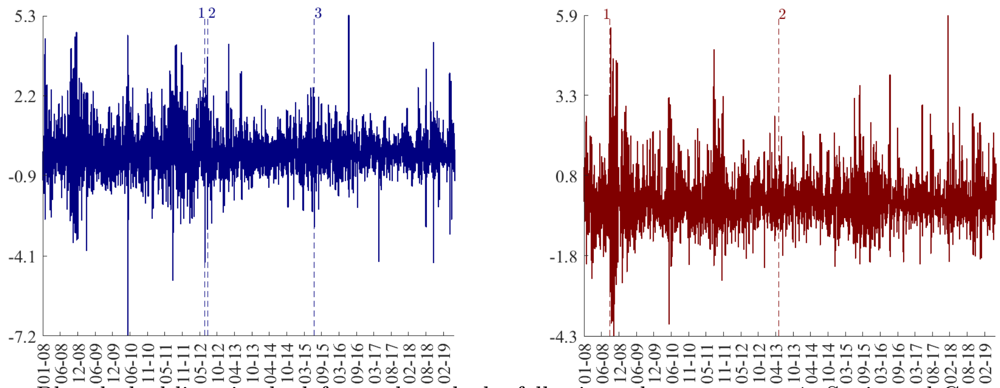


Notes: Shaded areas represent 68% confidence bands. Black dashed lines mark the following relevant events: 1. Lehman Brothers collapse; 2. Spain and Cyprus request for programme; 3. London speech; 4. Fed's "Taper tantrum"; 5. EG agrees on Greek 3^{rd} programme.

Source: Authors' calculations.

Figure 3.3.1: Daily shock series.

(a) Euro area stress (b) Global risk aversion



Notes: Blue dashed lines in the left panel mark the following relevant events: 1. Spain and Cyprus request for programme; 2. London speech; 3. EG agrees on Greek 3^{rd} programme. Red dashed lines in the right panel correspond to the following events: 1. Lehman Brothers collapse; 2. Fed's "Taper tantrum."

Source: Authors' calculations.

h months. Moreover, $\boldsymbol{Z}_{t-1}$ is a vector of exogenous regressors containing the (log) USD nominal effective exchange rate and the (log) oil price. In what follows, we estimate Equation (3.4) by alternatively including the aggregated monthly euro area stress and global risk aversion shocks on the right hand side.

3.3.1 Results

Euro area stress shocks and global risk aversion shocks both exert a significant impact on relevant economic variables in the EA as well as AEs and EMs.

For instance, euro area stress shocks have negative effects on both EA industrial production and inflation, whose magnitude is sometimes comparable to what observed for a global risk aversion shock (see Table 3.3.1 and Figure 3.3.2a)[27]. A positive EA stress shock, for instance, drops both EA industrial production and inflation by a maximum of 1.13% and 1.84pps respectively (Figure 3.3.2b) against a peak reduction of 0.5% and 1.97pps after a global shock. Euro area stress shocks can also impact intra-EA trade flows over the medium-term, by decreasing exports and imports by 2.76% and 2.30% respectively. Global risk shocks on the other hand produce more marked slowdowns in trade flows over the longer-term (Figures 3.3.2c and 3.3.2d), something which is in line with the part of literature identifying globalization as the biggest driver of European trade after 1992 (see Corsetti et al. (2019)).

[27]These estimates refer to a unit increase in the shock of reference. As the shock series are standardised, this corresponds to a one-standard-deviation increment.

Table 3.3.1: Maximum impact of euro area stress and global risk aversion shocks

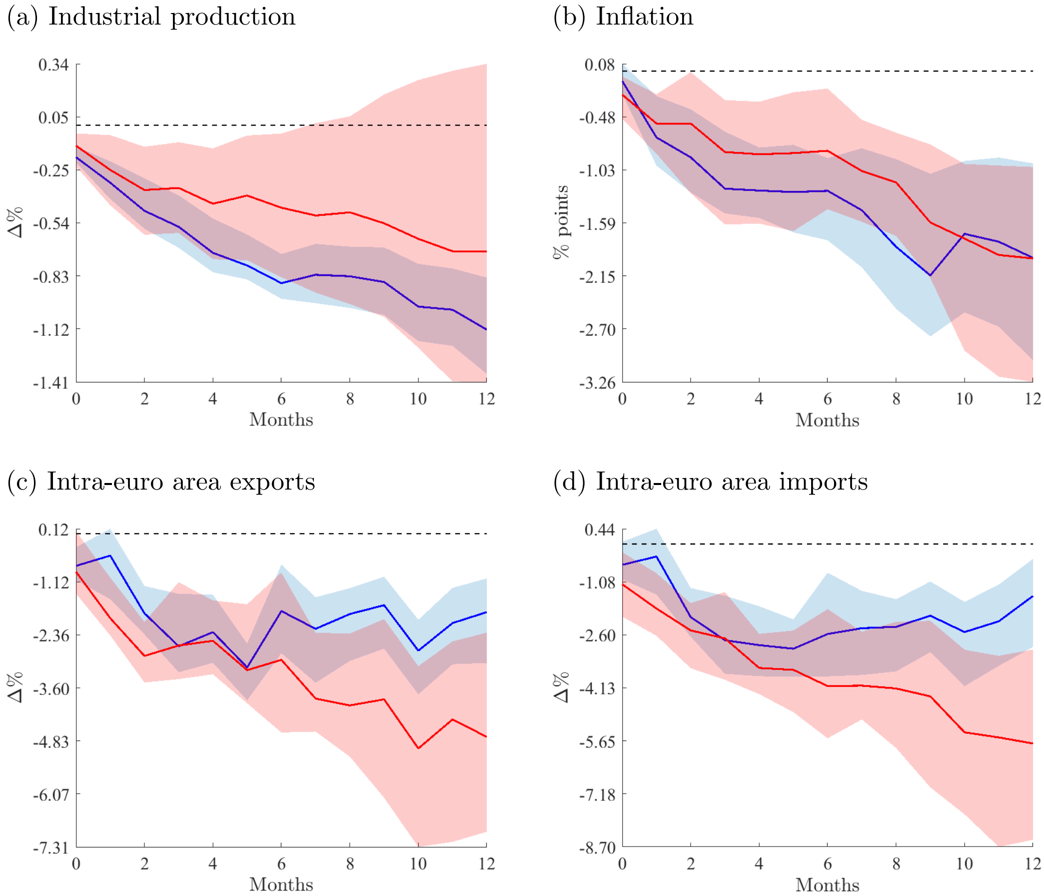
Shock \ Variable	IP	Inflation	Exports to EA	Exports to RoW	Imports from EA	Imports from RoW
Euro Area						
EA	-1.13%	-1.84pps	-2.76%		-2.30%	
	(12)*	(8)	(3)		(4)	
Global	-0.5%	-1.97pps	-5.73%		-3.86%	
	(6)	(12)	(12)		(9)	
Advanced Economies						
EA	-1.04%	-0.24pps	-2.64%	-2.09%	-1.58%	-1.85%
	(7)	(9)	(10)	(7)	(3)	(5)
Global	-1.53%	-0.14pps	-3.64%	-3.61%	-2.86%	-3.50%
	(12)	(11)	(12)	(10)	(12)	(12)
Emerging Markets						
EA	-0.50%	-0.38pps	-2.45%	-1.84%	-1.41%	-1.31%
	(3)	(9)	(10)	(3)	(5)	(5)
Global	-1.37%	-0.19pps	-2.83%	-3.37%	-2.84%	-2.77%
	(12)	(12)	(12)	(12)	(12)	(12)

Notes: * Numbers in parentheses represent the amount of months after a shock has taken place. As the shocks series are standardized, coefficients refer to a unit increment in the relevant shocks, which corresponds to an increase by one standard deviation.

Looking at results for extra-EA economies, a euro area stress shock can trigger significant real economy effects in AEs via a compression in industrial production by -1.04% over a seven-month horizon, against a drop by 1.53% one year after a global shock (Figure 3.3.3a). In EMs, on the other hand, the negative impact on industrial production is more muted compared to AEs, as the contraction peaks at 0.5% three months after the shock (Figure 3.3.4a). Conversely, euro area stress shocks are more relevant than global shocks when it comes to assessing demand effects, since the downward pressure on RoW inflation (both AEs and EMs) is bigger than in the case of a global shock (-0.24pps vs -0.14 pps in AEs and -0.38 pps vs -0.19 pps in EMs). However, the deflationary pressures deriving from a global shock seem more persistent than the effects stemming from euro area stress shocks.

As to international trade activity, euro area stress shocks entail a slowdown in exports and imports to and from non-EA economies, which is significant in both AEs (Figures 3.3.3e and 3.3.3f) and EMs (Figures 3.3.4e and 3.3.4f), though slightly more relevant for the former. Generally speaking, the impact of such shocks tends to be smaller compared to global risk aversion shocks. In addition, the latter seem to trigger more long-lasting slowdowns in both macroeconomic aggregates and global trade, while the repercussions of changes in euro area stress tend to fade away in a shorter time

Figure 3.3.2: **Euro Area** - Impulse responses to a positive one s.d.euro area stress shock (blue) and a positive one s.d. global risk aversion shock (red)



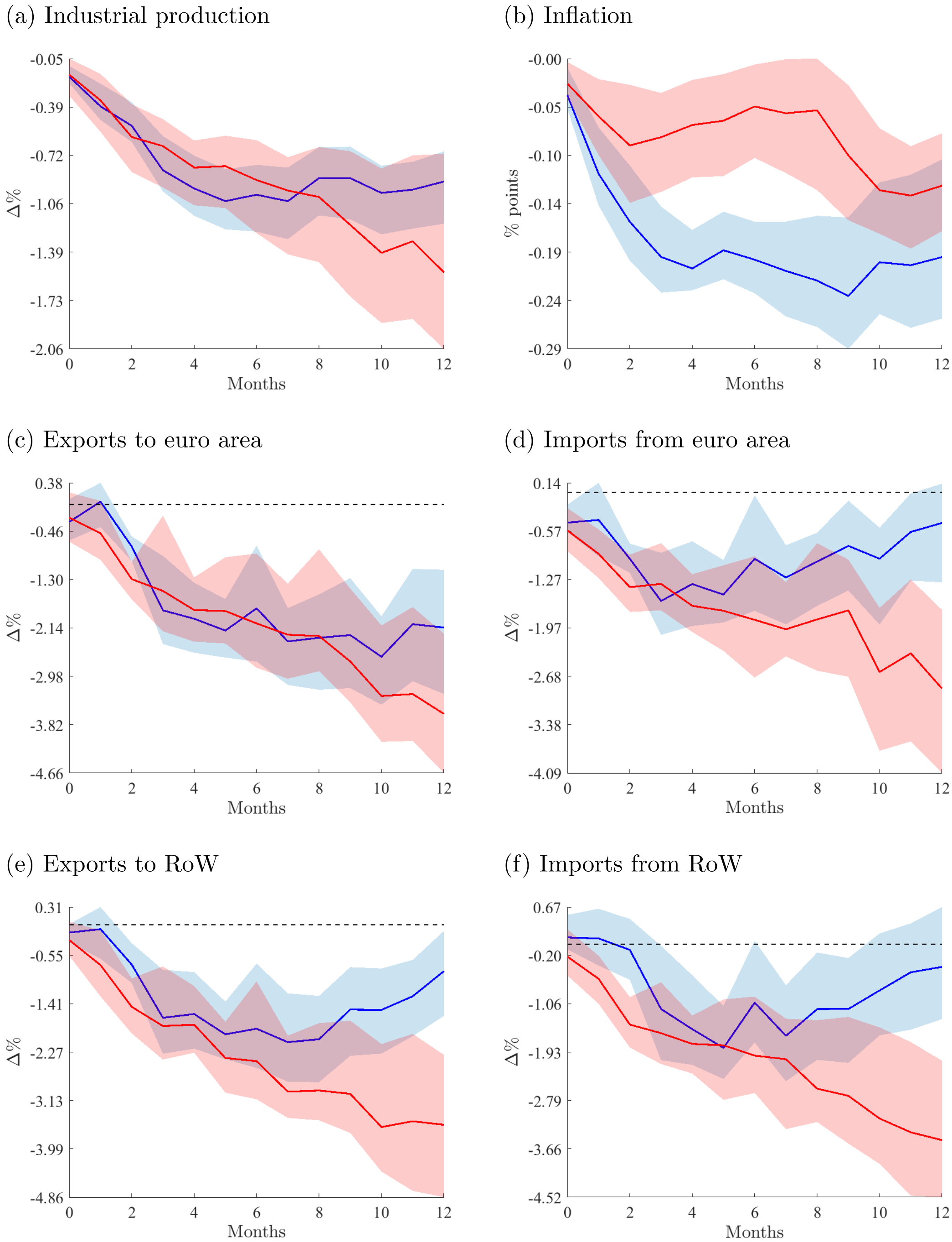
Notes: Inflation is defined as the y-o-y percentage change of the CPI. Δ%: log-change. Shaded areas are 68% confidence bands.
Source: Authors' calculations.

frame[28]. *Ceteris paribus*, a positive one-standard-deviation euro area stress shock has the following *cumulative* y-o-y effects: i) it decreases industrial production by 10% in AEs and 3% in EMs; ii) it pushes down yearly inflation by 2.38 pps in AEs and 3.19 pps in EMs; iii) it depresses euro area trade flows due to a decrease in both exports and imports with AEs (-12% and -23% respectively) and imports and exports with EMs (-21% and -10%); iv) it shrinks exports to the RoW by 17% in AEs and 12% in EMs, as well as imports from the RoW by EMs (10%).

Nevertheless, when disentangling between positive and negative shocks, a decrease in EMU tensions, corresponding to a negative euro area stress shock, can have more enduring positive spillovers compared to a setback (Figures 3.3.5 and 3.3.6). Though the maximum impact is roughly symmetric across positive and negative shocks, effects of

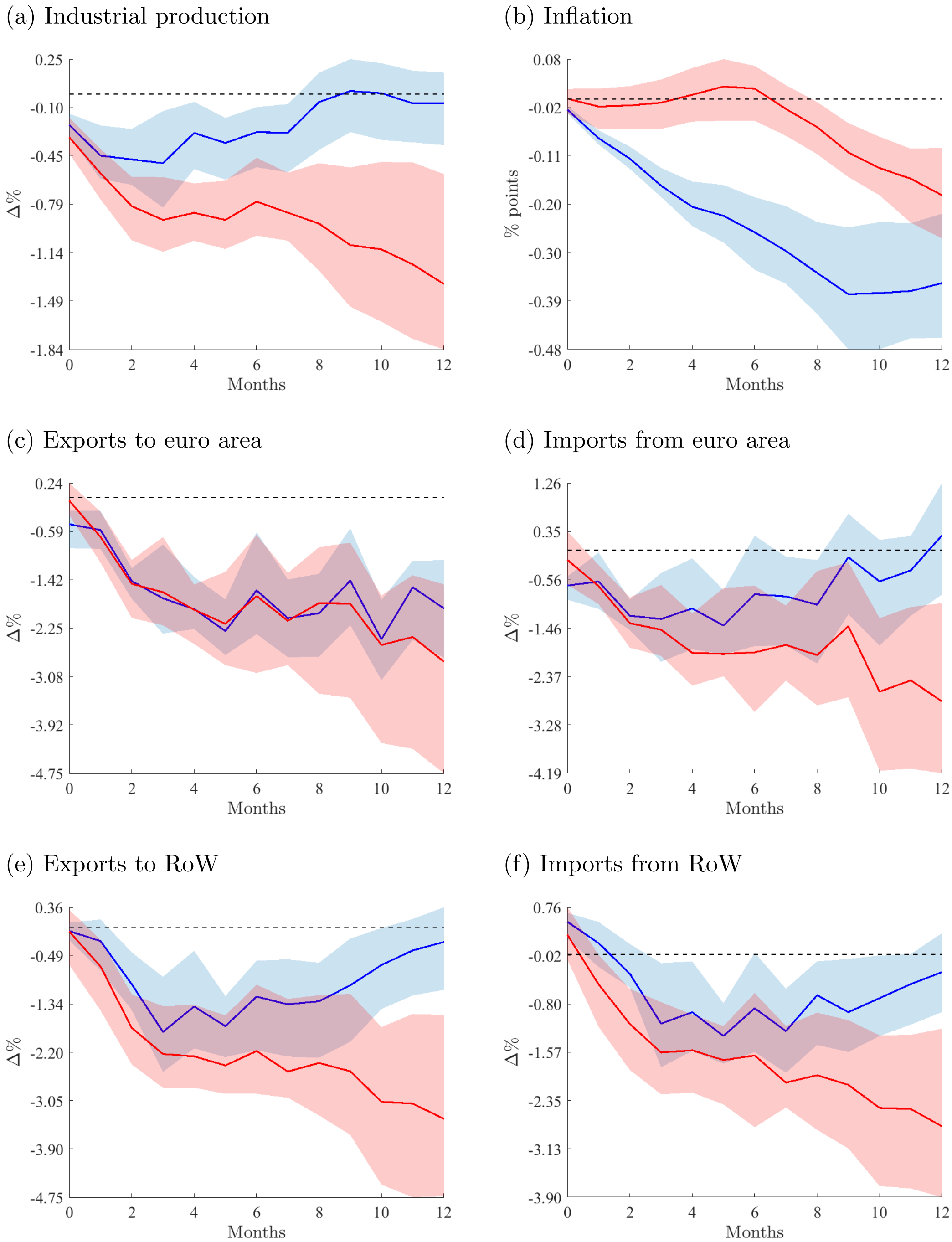
[28] A caveat to these findings derives from the inclusion in our sample of some (non-EA) EU members, which might bias our estimates given their particular linkages with EA members. However, our results are robust to the exclusion of these countries from the estimation sample, as shown in Appendix C.4.

Figure 3.3.3: **Advanced economies** - Impulse responses to a positive one s.d.euro area stress shock (blue) and a positive one s.d. global risk aversion shock (red)



Notes: Inflation is defined as the y-o-y percentage change of the CPI. Δ%: log-change. Shaded areas are 68% confidence bands.
Source: Authors' calculations.

Figure 3.3.4: **Emerging and developing economies** - Impulse responses to a positive one s.d. EA stress shock (blue) and a positive one s.d. global risk aversion shock (red)



Notes: Inflation is defined as the y-o-y percentage change of the CPI. Δ%: log-change. Shaded areas are 68% confidence bands.
Source: Authors' calculations.

negative shocks can still be significant after one year, especially in AEs (Table 3.3.2). A negative one-standard-deviation euro area stress shock, indeed, implies that: i) industrial production increases y-o-y by 10% in AEs and 5% in EMs: ii) yearly inflation goes up by 1.36 pps in AEs and 2.34 pps in EMs; iii) euro area imports are pushed up by 19% from AEs and 23% from EMs, while exports to both AEs and EMs increase by around 8%: iv) exports of both AEs and EMs to the RoW are boosted by 14% and 19% respectively, while imports from the RoW jump by 8% in AEs and 11% in EMs.

Table 3.3.2: Maximum impact of euro area stress shocks - positive vs negative

Shock \ Variable	IP	Inflation	Exports to EA	Exports to RoW	Imports from EA	Imports from RoW
Advanced Economies						
EA+	-1.04%	-0.24pps	-2.64%	-2.09%	-1.58%	-1.85%
	(7)	(9)	(10)	(7)	(3)	(5)
EA-	0.99%	0.20pps	2.56%	1.51%	1.04%	1.01%
	(11)	(11)	(12)	(5)	(12)	(5)
Emerging Markets						
EA+	-0.50%	-0.38pps	-2.45%	-1.84%	-1.41%	-1.31%
	(3)	(9)	(10)	(3)	(5)	(5)
EA-	0.58%	0.37pps	2.34%	1.82%	1.22%	1.37%
	(2)	(11)	(5)	(2)	(2)	(5)

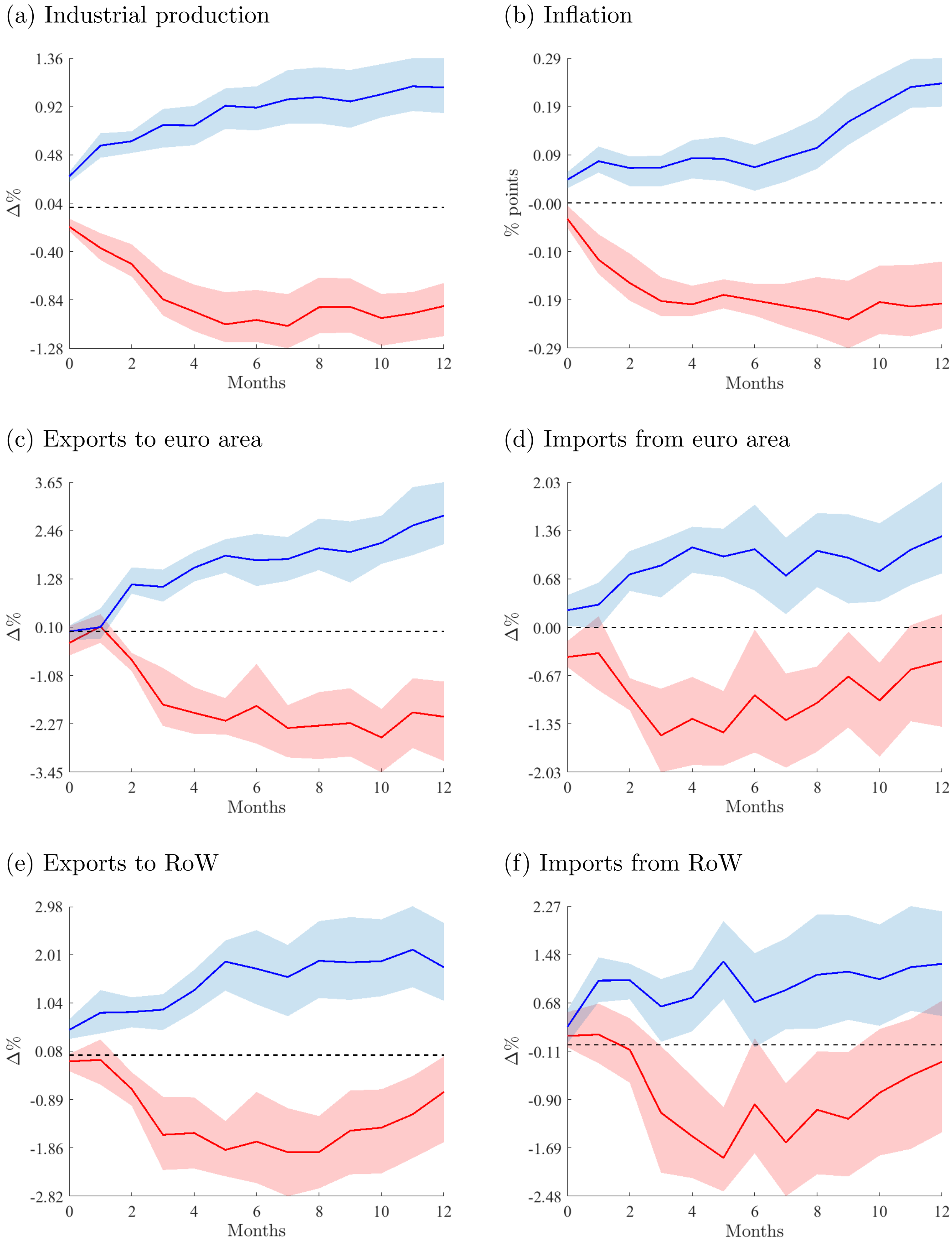
Notes: * Numbers in parentheses represent the amount of months after a shock has taken place; ** not significant. As the shocks series are standardized, coefficients refer to a unit increment in the relevant shocks, which corresponds to an increase by one standard deviation.

3.4 Concluding remarks

This chapter investigates the so-called "external dimension of EMU deepening", which consists of the potential effects of progress or setbacks in the completion of EMU on the global economy. In this sense, the herewith analysis provides an insightful contribution to the debate about the progress towards a complete Economic and Monetary Union.

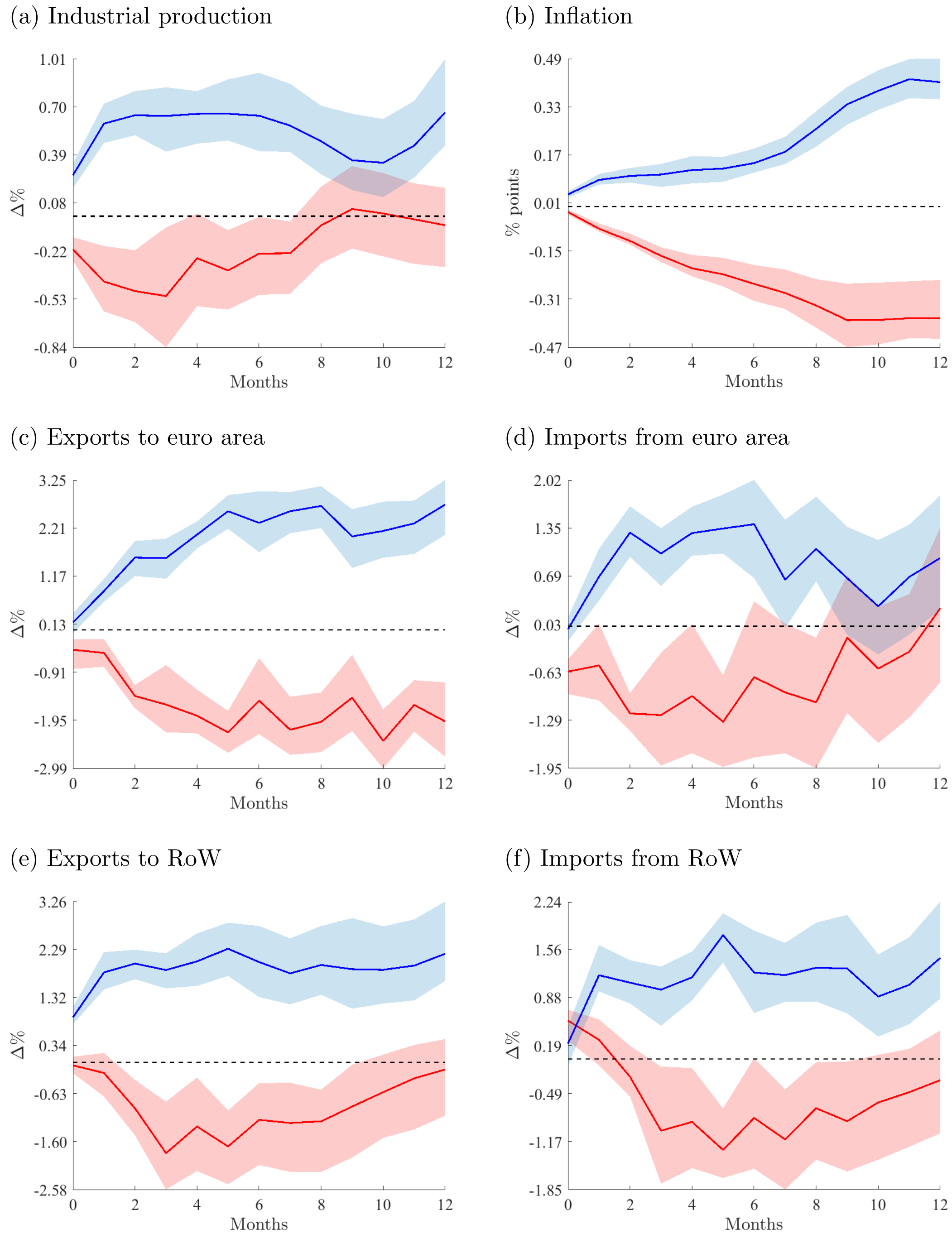
With this aim, Section 3.2.1 constructs a measure of EMU cohesion which is found to well approximate the progress (or slowdown) in the completion of EMU. The second step of the analysis consists of applying structural and narrative techniques to daily financial data to disentangle between "euro area stress shocks" and global risk aversion shocks. It is shown that, even if the effects of these shocks are qualitatively similar and therefore difficult to distinguish, the empirical strategy proposed in Section 3.2.1 is nonetheless able to tease the two out and to produce statistically different results.

Figure 3.3.5: **Advanced economies** - Impulse responses to a one s.d. negative (blue) and positive (red) euro area stress shock



Notes: Inflation is defined as the y-o-y percentage change of the CPI. Δ%: log-change. Shaded areas are 68% confidence bands.
Source: Authors' calculations.

Figure 3.3.6: **Emerging and developing economies** - Impulse responses to a one s.d. negative (blue) and positive (red) euro area stress shock



Notes: Inflation is defined as the y-o-y percentage change of the CPI. Δ%: log-change. Shaded areas are 68% confidence bands.
Source: Authors' calculations.

Finally, in Section 3.3 IRFs computed via panel local projections are constructed to estimate the effects of euro area stress shocks onto macroeconomic aggregates in the rest of the world. The main finding is that a decrease in the cohesion of the EMU has an overall negative impact on the economy of the rest of the world, both on the demand and the supply side. In addition, these shocks entail a generalized slowdown in global trade, not only because of a decrease in imports and exports from and to the euro area, but also due to a drop in trade flows outside the euro area. While these effects do not generally change across AEs and EMs and appear broadly symmetric, the positive impact of an increase in EMU cohesion is found to be generally more persistent over time than the drawbacks stemming from a setback in the completion of the EMU.

Looking forward, an interesting venue for further research could focus on the presence of possible non-linearities in the cross-border transmission of shocks, an issue that can be easily accounted for in the empirical framework used in Section 3.3.

Conclusion

This dissertation contributes to the ongoing discussions around the viability of the EMU and its institutions along three questions:

i) Is the heterogeneity across Eurozone members structural or state-contingent?

ii) Are the Union-wide policy tools suitable to address the divergence across Member States?

iii) Would a speeding in EMU completion help fix these problems?

Chapter 1 focuses on the divide between compensation and productivity growth in the euro area which has become more evident as of 1990s. The main finding is that both the aggregate euro area and its four biggest economies have experienced a significant decrease in the pass-through of productivity on to compensation, with the decoupling being a long-term phenomenon and presenting a certain degree of cross-country heterogeneity in terms of magnitude and timing. In addition, the chapter also sheds light on how different types of nominal rigidities can lead to similar dynamics in the macroeconomic data. Finally, it provides evidence of a significant time variation in the productivity-compensation relationship, as the gap has been closing up in more recent times in economies like France, Italy and Spain.

Chapter 2 assesses the macroeconomic impact of ECB's UMPs after the 2007 crisis. The channel of transmission considered is given by the interest rate, which is in turn broken down into portfolio rebalancing and signalling by decomposing the yield curve of euro area economies. The first part of the analysis shows that the portfolio rebalancing has generally been more relevant than the signalling channel after the "Whatever it takes" speech in July 2012. However, results also show a great degree of heterogeneity across core and peripheral economies, as well as over time. Such heterogeneity is further investigated in a TV-SVAR-SV, where UMP shocks are identified via "dynamic" sign restrictions. Differently from the existing literature, these restrictions are time-contingent, meaning that the identification scheme changes according to the time period considered in the estimation. Given the estimates produced by the model, the final part of the chapter performs a counterfactual analysis, which shows how a more aggressive stance on the part of the ECB could have helped support the economic performance of peripheral euro area economies over the period 2011-2012. Notably, if the ECB had not increased its rates in 2011, output growth and inflation in peripheral euro area would have been on average 0.4 and 0.3 percentage points higher.

Finally, Chapter 3 quantifies the economic effects that shocks to EMU cohesion can have on the rest of the world. With this purpose, the first part devises an identification strategy to isolate stress shocks to the euro area, which is based on the implementation of sign, magnitude and narrative restrictions in a daily SVAR model with financial variables. The effects of euro area stress shocks on the rest of the world are then further investigated by means of panel local projections for a set of advanced and emerging economies. It is found that shocks to EMU cohesion can exert a real impact not only on the euro area members but also on the rest of the world: a one standard deviation negative shock to euro area cohesion entails a slowdown of economic activity in the rest of the world, with industrial production dropping by 10% y-o-y in advanced economies and 3% in emerging economies, as well as contraction in global trade activity. On the contrary, a positive shock has more widespread effects on both economic performance and international trade, with a y-o-y boost of industrial production by 10% in advanced economies and 5% in emerging markets.

The findings discussed in the chapters of this dissertation seem to indicate that, in spite of the great steps undertaken so far, EMU is still perfectible as the crisis has shown how divergences across Member States are more structural than transient. In addition, while the UMPs implemented after 2007 have marked a new institutional phase, the different reactions of core and peripheral economies to the same measures underscores the need of making the extra mile and complement the monetary policy leg with progress in other dimensions (e.g., fiscal and banking unions). Finally, the process of EMU completion should not be purely inward-looking, but should also consider the potentially substantial impact on extra-European economies.

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Appendices

A Appendix to Chapter 1

A.1 Data

Euro area

Quarterly data for euro area are taken from Eurostat, as of 1995Q1. For the period 1970Q1-1994Q4, series are backcast using the data from the Area-Wide Model database (see Fagan et al. (2005) and Warne et al. (2008)), which provides coverage from 1970Q1 to 2016Q3 for compensation, GDP, CPI, GDP deflator and unemployment rate. As to hours worked, the Eurostat aggregate series is backcast by using the q-o-q growth rates of the sum of hours across France, Germany, Italy and Spain over the period 1970Q1-1994Q4. In the case of Germany, the jump in the series corresponding to the re-unification (1991Q1) is corrected by backcasting data before 1991Q1 using q-o-q growth rates of hours worked in West Germany.

National data

The sources of national data are reported in Table A.1.

Table A.1: National data sources

Variables	**France**	**Germany**	**Italy**	**Spain**
Compensation	INSEE[1]	FSO[2]	ISTAT[3]	INE[4]
CPI	INSEE	Bbk[5]	ISTAT	INE
GDP	INSEE	FSO	ISTAT	INE OECD
GDP deflator	INSEE	FSO	OECD	OECD
Hours	INSEE	FSO Eurostat	ISTAT AMECO	OECD
Unemployment rate	OECD	Bbk	OECD	OECD

[1] Institut national de la statistique et des études économiques;
[2] Federal Statistical Office (Destatis); [3] Istituto Nazionale di Statistica;
[4] Instituto Nacional de Estadística; [5] Bundesbank.

Notes

- **Germany**: data before 1991Q1 are backcast using q-o-q (hours) and y-o-y (GDP) growth rates of West Germany series; GDP is backcast using Gross Value Added;
- **Italy**: quarterly data for hours before 1980Q1 are estimated by backcasting the series using y-o-y growth rates obtained by interpolating annual growth rates from AMECO via Chow-Lin with real GDP y-o-y growth rate as index;
- **Spain**: GDP data before 1980Q1 are obtained by backcast, using y-o-y real GDP growth rates from OECD; hours worked are computed by multiplying hours per employee times the number of employees in the economy (both from OECD).

A.2 The Time-Varying Parameter Median Unbiased estimator (TVP-MUB)

The approach checks for random-walk time variation in the regression model:

$$comp_t = \mu + \alpha(L)comp_{t-1} + \beta(L)prod_{t-1} + \varepsilon_t \equiv \theta' Z_t + \varepsilon_t, \tag{A.1}$$

where $\alpha(L), \beta(L)$ are lag polinomials, $\theta = [\mu, \alpha(L), \beta(L)]$, $Z_t = [1, comp_{t-1}, \ldots, prod_{t-p}]$, and p is set according to the Schwartz Information Criterion (SIC)[29]. The time-varying version of Equation (A.1) is given by:

$$x_t = \theta_t' Z_t + \varepsilon_t, \tag{A.2a}$$

$$\theta_t = \theta_{t-1} + \eta_t \tag{A.2b}$$

where $x_t = comp_t$. Moreover, $\eta_t \overset{iid}{\sim} \mathcal{N}(0_{4p+1}, \lambda^2\sigma^2 Q)$, $\sigma^2 \equiv Var(\varepsilon_t)$, $Q = E[Z_t Z_t']^{-1}$ and $E[\eta_t \varepsilon_t] = 0$. The coefficients of the transformed regression, $E[Z_t Z_t']^{-1/2} Z_t$, evolve according to a standard $(4p+1)$-dimensional random walk, where λ^2 is the ratio between the variance of each transformed innovation and the variance of ε_t. Following Benati and Lubik (2014), the matrix Q is estimated as $\hat{Q} = [T^{-1} \sum_{t=1}^{T} z_t z_t']^{-1}$.

The innovation variance, σ^2, is computed via the OLS estimation of Equation (A.1). *exp*- and *sup*-Wald joint tests are then performed to check for a single unknown break in μ and the sum of α's and β's, using the Newey and West (1987) HAC covariance

[29] Notably, $p = 2$ for euro area aggregates, $p = 1$ for Germany, $p = 5$ for France, $p = 5$ for Italy and $p = 1$ for Spain.

matrix estimator. As in Stock and Watson (1998), the empirical distribution of the test statistic is computed over a 100-point grid of values for λ in the interval $[0, 0.1]$. For each $\lambda_j, j = 1 \ldots 100$, the corresponding estimate of Q is given by $\hat{Q}_j = \lambda_j^2 \hat{\sigma}^2 \hat{Q}$. Conditional on $\hat{Q}_j$, the model Equation (A.2a)-Equation (A.2b) is simulated 10,000 times, drawing the innovations from a pseudo-random iid $N(0, \hat{\sigma}^2)$. The median-unbiased estimate of λ is given by the particular value at which the median of the empirical simulated distribution of the test is closest to the test statistic computed with actual data. The p-value is computed based on the empirical distribution of the test conditional on $\lambda_j = 0$, which is in turn estimated as in Benati (2007) [30].

A.3 Estimation of the TVP-VAR-SV

In the framework described by Equation (1.3a), Equation (1.3b) and Equation (1.3c) it is assumed that:

$$\nu_t \sim \mathcal{N}(0, \Sigma_t) \tag{A.3a}$$

$$\theta_t = \theta_{t-1} + \eta_t, \qquad \eta_t \sim \mathcal{N}(0, \Omega), \tag{A.3b}$$

where the variance-covariance matrix, Ω, is diagonal and is endogenously determined by the model. Without loss of generality, Σ_t can be decomposed as:

$$\Sigma_t = F_t \Lambda_t F_t', \tag{A.4}$$

[30] A special thank goes to Luca Benati for providing the MATLAB routine to perform the tests.

with

$$F_t = \begin{bmatrix} 1 & 0 & \dots & \dots & 0 \\ f_{21,t} & 1 & \dots & \dots & 0 \\ f_{31,t} & f_{32,t} & \ddots & & 0 \\ \vdots & \vdots & & \ddots & \vdots \\ f_{N1,t} & f_{N2,t} & \dots & f_{N(N-1),t} & 1 \end{bmatrix},$$

$$\Lambda_t = \begin{bmatrix} \bar{s}_1 \exp(\lambda_{1,t}) & 0 & \dots & \dots & 0 \\ 0 & \bar{s}_2 \exp(\lambda_{2,t}) & \dots & \dots & 0 \\ \vdots & & \ddots & & 0 \\ \vdots & & & \ddots & \vdots \\ 0 & \dots & \dots & 0 & \bar{s}_N \exp(\lambda_{N,t}) \end{bmatrix}. \tag{A.5}$$

where $\bar{s}_i, i = 1, \dots, N$ are known scaling parameters and $\lambda_{i,t}, i = 1, \dots, N$ are dynamic processes that introduce heteroskedasticity in the model. Notably:

$$\lambda_{i,t} = \gamma \lambda_{i,t-1} + v_{i,t}, \qquad v_{i,t} \sim \mathcal{N}(0, \phi_i). \tag{A.6}$$

The set of parameters that need to be estimated consists of $\theta = \{\theta_t, t = 1, \dots, T\}$, $f^{-1} = \{f_i^{-1}, i = 1, \dots, N\}$, $\lambda = \{\lambda_{i,t}, i = 1, \dots, N, t = 1, \dots, T\}$ and $\phi = \{\phi_i, i = 1, \dots, N\}$. Assuming independence across θ, f^{-1} and λ, the posterior density can be written as:

$$f(\theta, \Omega, f^{-1}, \lambda, \phi | y) \propto f(y|\theta, f^{-1}, \lambda)\pi(\theta|\Omega)\pi(\Omega)\left(\prod_{i=2}^{N} \pi(f_i^{-1})\right)\left(\prod_{i=2}^{N} \pi(\lambda_{i,t}|\phi_i)\right)\left(\prod_{i=2}^{N} \pi(\phi_i)\right). \tag{A.7}$$

By the independence of the residuals, ν_t, the likelihood function can be written as:

$$f(y|\theta, f^{-1}, \lambda) \propto \prod_{t=1}^{T} |F_t \Lambda_t F_t'|^{-1/2} \exp\left(-\frac{1}{2}(y_t - \bar{X}_t\theta_t)'(F_t\Lambda_t F_t')^{-1}(y_t - \bar{X}_t\theta_t)\right). \tag{A.8}$$

The likelihood function in Equation (B.30) can also be reformulated in compact form, by setting:

$$\underbrace{\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_T \end{bmatrix}}_{NT\times 1} = \underbrace{\begin{bmatrix} \bar{X}_1 & 0 & \dots & 0 \\ 0 & \bar{X}_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \bar{X}_T \end{bmatrix}}_{NT\times pT} \underbrace{\begin{bmatrix} \theta_1 \\ \theta_2 \\ \vdots \\ \theta_T \end{bmatrix}}_{pT\times 1} + \underbrace{\begin{bmatrix} \nu_1 \\ \nu_2 \\ \vdots \\ \nu_T \end{bmatrix}}_{NT\times 1} \tag{A.9}$$

or

$$y = \bar{X}\Theta, \quad \nu \sim N(0, \bar{\Sigma}), \quad \bar{\Sigma} = \underbrace{\begin{bmatrix} \Sigma_1 & 0 & \dots & 0 \\ 0 & \Sigma_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \Sigma_T \end{bmatrix}}_{NT \times NT}.$$

Therefore:

$$f(y|\theta, \Sigma) \propto |\bar{\Sigma}|^{-1/2} \exp\left(-\frac{1}{2}(y - \bar{X}\Theta)'\bar{\Sigma}^{-1}(y - \bar{X}\Theta) \right) \tag{A.10}$$

Priors are set as follows:

$$\begin{aligned} &\theta|\Omega \sim \mathcal{N}(0, \Omega_0) \\ &\omega_i \sim IG\left(\frac{\chi_0}{2}, \frac{\psi_0}{2}\right) \\ &f_i^{-1} \sim \mathcal{N}(f_{i,0}^{-1}, \Upsilon_{i,0}) \\ &\lambda_i|\phi_i \sim N(0, \Phi_0) \\ &\phi_i \sim IG\left(\frac{\beta_0}{2}, \frac{\delta_0}{2}\right). \end{aligned} \tag{A.11}$$

The prior for λ_i deserves some additional remarks. Equation (A.6) implies that each $\lambda_{i,t}$ depends on $\lambda_{i,t-1}$, which makes the formulation of $\pi(\lambda_i|\phi_i)$ complicated. There are two alternative approaches that can be considered in this case. The first one is based on the formulation of a joint prior for $\lambda_{i,1}, \dots, \lambda_{i,T}$ accounting for the dependence across different sample periods and builds upon the sparse matrix methodology of Chan and Jeliazkov (2009). The second one consists of separating $\pi(\lambda_i|\phi_i)$ into T different priors, where the prior for each individual period t will be conditional on period $t-1$, thus accounting for the dependence with the previous sample period. The joint formulation would result in a joint posterior which takes a non-standard form, so that a Metropolis-Hastings step is required (see below)[31]. In this chapter the first approach is given preference for both λ_i and θ. Notably, from Equation (A.6), any value $\lambda_{i,t}$ eventually depends on the initial value $\lambda_{i,0}$ and the shocks $v_{i,t}, t = 1, \dots, T$. Therefore,

[31]The same reasoning holds also for the prior of θ. Even in this case, two alternative formulations can be considered: 1. compact formulation: $\theta|\Omega \sim \mathcal{N}(0, \Omega_0)$; 2. conditional formulation: $\pi(\theta|\Omega) = \pi(\theta_1|\Omega) \prod_{t=2}^{T} \pi(\theta_t|\Omega, \theta_{t-1})$.

Equation (A.6) can be reformulated as:

$$GL_i = v_i, \quad i = 1, \dots, N \tag{A.12}$$

with

$$G = \begin{bmatrix} 1 & 0 & 0 & \dots & 0 \\ -\gamma & 1 & 0 & \dots & 0 \\ 0 & -\gamma & 1 & \dots & 0 \\ \vdots & & \ddots & & \vdots \\ 0 & \dots & 0 & -\gamma & 1 \end{bmatrix}, \quad L_i = \begin{bmatrix} \lambda_{i,1} \\ \lambda_{i,2} \\ \vdots \\ \lambda_{i,T} \end{bmatrix}, \quad v_i = \begin{bmatrix} \gamma\lambda_{i,0} + v_{i,1} \\ v_{i,2} \\ \vdots \\ v_{i,T} \end{bmatrix}. \tag{A.13}$$

In this case, $\lambda_{i,0}$ is the initial value of the process, which is assumed to follow a normal distribution of the form $\mathcal{N}(0, \frac{\phi_i(\omega-1)}{\gamma^2})$, where ω is a known variance parameter. This implies that:

$$\begin{aligned} var(\gamma\lambda_{i,0} + v_{i,1}) &= var(\gamma\lambda_{i,0}) + var(v_{i,1}) \\ &= \gamma^2 var(\lambda_{i,0}) + var(v_{i,1}) \\ &= \gamma^2 \frac{\phi_i(\omega-1)}{\gamma^2} + \phi_i \\ &= \phi_i\omega. \end{aligned} \tag{A.14}$$

Following Cogley and Sargent (2005), ω is set equal to 1000 in order to get a diffuse prior for $\lambda_{i,1}$. Equations (A.6), (B.35) and (B.36) imply that:

$$v_i \sim \mathcal{N}(0, \phi_i I_\omega), \qquad I_\omega = \begin{bmatrix} \omega & 0 & \dots & \dots & 0 \\ 0 & 1 & \dots & \dots & 0 \\ \vdots & & \ddots & & \vdots \\ 0 & & \dots & 0 & 1 \end{bmatrix}. \tag{A.15}$$

Furthermore, Equation (B.34) implies that $L_i = G^{-1}v_i$, which, in turn, leads to:

$$L_i \sim \mathcal{N}(0, G^{-1}\phi_i I_\omega G^{-1\prime}), \tag{A.16}$$

or:

$$L_i \sim \mathcal{N}(0, \Phi_0), \quad \text{with } \Phi_0 = \phi_i(G' I_\omega^{-1} G)^{-1}. \tag{A.17}$$

Hence, the joint prior distribution of λ_i conditional on ϕ_i is a normal with mean 0 and covariance Φ_0.

Given the likelihood in Equation (B.30) and the priors in Equation (B.33), the joint posterior density is:

$$\begin{aligned}
&f(\theta, \Omega, f^{-1}, \lambda, \phi|y) \\
&\propto \prod_{t=1}^{T} |F_t \Lambda_t F_t'|^{-1/2} \exp\Bigg(-\frac{1}{2}(y_t - \bar{X}_t\theta_t)'(F_t\Lambda_t F_t')^{-1}(y_t - \bar{X}_t\theta_t)\Bigg) \\
&\times |\Omega_0| \exp\Big(-\frac{1}{2}\Theta'\Omega_0^{-1}\Theta\Big) \\
&\times \prod_{i=1}^{N} \omega_i^{-\frac{\chi_0}{2}-1} \exp\Big(-\frac{\psi_0}{2\omega_i}\Big) \\
&\times \prod_{i=1}^{N} \exp\Bigg[-\frac{1}{2}(f_i^{-1} - f_{i,0}^{-1})'\Upsilon_{i,0}^{-1}(f_i^{-1} - f_{i,0}^{-1})\Bigg] \\
&\times |\Phi_0|^{-1/2} \exp\Bigg(-\frac{1}{2}L_i'\Phi_0^{-1}L_i\Bigg) \\
&\times \prod_{i=1}^{N} \phi_i^{-\frac{\beta_0}{2}-1} \exp\Big(-\frac{\delta_0}{2\phi_i}\Big).
\end{aligned} \tag{A.18}$$

Therefore, it is possible to derive the conditional posterior densities for each set of parameters of interest. Notably, for θ:

$$\begin{aligned}
&\theta|(y, \Omega, f^{-1}, \lambda, \phi) \sim N(\bar{\Theta}, \bar{\Omega}), \\
&\text{with} \quad \bar{\Omega}^{-1} = (\Omega_0^{-1} + \bar{X}'\bar{\Sigma}^{-1}\bar{X}) \\
&\text{and} \quad \bar{\Theta} = \bar{\Omega}(\bar{X}'\bar{\Sigma}^{-1}y).
\end{aligned} \tag{A.19}$$

As to the diagonal elements of Ω:

$$\begin{aligned}
&\omega_i|(y, \theta, \omega_{-i}, \Sigma) \sim IG(\bar{\chi}, \bar{\psi}), \\
&\text{with} \quad \bar{\chi} = \frac{\chi_0 + T}{2} \\
&\text{and} \quad \bar{\psi} = \frac{\theta_{i,1}^2/\tau + \sum_{t=2}^{T}(\theta_{i,t} - \theta_{i,t-1})^2 + \psi_0}{2}.
\end{aligned} \tag{A.20}$$

The non-zero elements of matrix F_t have the following conditional posterior densities:

$$
\begin{aligned}
& f_i^{-1}|(y,\theta,f_{-i}^{-1},\lambda,\phi) \sim N(\bar{f}_i^{-1}),\bar{\Upsilon}_i) \\
& \text{with} \quad \bar{\Upsilon}_i = \Big(\bar{s}_i^{-1}\sum_{t=1}^{T}\nu_{-i,t}\exp(-\lambda_{i,t})\nu_{i,t}' + \bar{\Upsilon}_{i0}^{-1}\Big)^{-1} \\
& \text{and} \quad \bar{f}_i^{-1} = \bar{\Upsilon}_i\Big(-\bar{s}_i^{-1}\sum_{t=1}^{T}\nu_{-i,t}\exp(-\lambda_{i,t})\nu_{i,t}' + \bar{\Upsilon}_{i0}^{-1}f_{i0}^{-1}\Big).
\end{aligned} \tag{A.21}
$$

On the other hand, the conditional posterior for λ is non-standard:

$$
\begin{aligned}
& \pi(\lambda_{i,t}|y,\theta,f^{-1},\lambda_{-i,-t},\phi) \\
& \propto \exp\Big(-\frac{1}{2}\Big\{\bar{s}_i^{-1}\exp(-\lambda_{i,t})(\nu_{i,t}+(f_i^{-1})'\nu_{-i,t})^2+\lambda_{i,t}\Big\}\Big) \\
& \times \exp\Big(-\frac{1}{2}\frac{(\lambda_{i,t}-\bar{\lambda}_i)^2}{\bar{\phi}}\Big) \\
& \text{with} \quad \bar{\phi} = \frac{\phi_i}{1+\gamma^2} \\
& \text{and} \quad \bar{\lambda} = \frac{\gamma}{1+\gamma^2}(\lambda_{i,t-1}+\lambda_{i,t+1}).
\end{aligned} \tag{A.22}
$$

Equation (B.44) requires a Metropolis-Hastings step, with the following acceptance function:

$$
\begin{aligned}
& \kappa(\lambda_{i,t}^{(m-1)},\lambda_{i,t}^{(m)}) \\
& = \exp\Big(-\frac{1}{2}\Big\{\exp(-\lambda_{i,t}^{(m)})-\exp(-\lambda_{i,t}^{(m-1)})\Big\}\bar{s}_i^{-1}(\nu_{i,t}+(f_i^{-1})'\nu_{-i,t})^2\Big) \\
& \times \exp\Big(\{\lambda_{i,t}^{(m)}-\lambda_{i,t}^{(m-1)}\}\Big).
\end{aligned} \tag{A.23}
$$

For $t=1$ and $t=T$, Equation (B.45) needs to be slightly adapted as follows. For the first period, a candidate is drawn from $\mathcal{N}(\bar{\lambda},\bar{\phi})$, with:

$$
\bar{\lambda} = \frac{\gamma\lambda_{i,2}}{\omega^{-1}+\gamma^2} \quad \text{and} \quad \bar{\phi} = \frac{\phi_i}{\omega^{-1}+\gamma^2}. \tag{A.24}
$$

The acceptance function is then given by:

$$
\begin{aligned}
& \kappa(\lambda_{i,1}^{(m-1)},\lambda_{i,1}^{(m)}) \\
& = \exp\Big(-\frac{1}{2}\Big\{\exp(-\lambda_{i,1}^{(m)})-\exp(-\lambda_{i,1}^{(m-1)})\Big\}\bar{s}_i^{-1}(\nu_{i,1}+(f_i^{-1})'\nu_{-i,1})^2\Big) \\
& \times \exp\Big(\{\lambda_{i,1}^{(m)}-\lambda_{i,1}^{(m-1)}\}\Big).
\end{aligned} \tag{A.25}
$$

For the last period, the candidate is drawn from $\mathcal{N}(\bar{\lambda}, \bar{\phi})$, with:

$$\bar{\lambda} = \gamma\lambda_{i,T-1} \quad \text{and} \quad \bar{\phi} = \phi_i. \tag{A.26}$$

The acceptance function is then given by:

$$\begin{aligned} &\kappa(\lambda_{i,T}^{(m-1)}, \lambda_{i,T}^{(m)}) \\ &= \exp\Big(-\frac{1}{2}\Big\{ \exp(-\lambda_{i,T}^{(m)}) - \exp(-\lambda_{i,T}^{(m-1)})\Big\} \bar{s}_i^{-1}(\nu_{i,T} + (f_i^{-1})'\nu_{-i,T})^2\Big) \\ &\times \exp\Big(\{\lambda_{i,T}^{(m)} - \lambda_{i,T}^{(m-1)}\}\Big). \end{aligned} \tag{A.27}$$

Finally, the conditional posterior distribution for ϕ is:

$$\begin{aligned} &\phi_i|(y, \theta, f^{-1}, \lambda, \phi_{-i}) \sim IG\Big(\frac{\bar{\beta}}{2}, \frac{\bar{\delta}}{2}\Big) \\ &\text{with} \quad \bar{\beta} = \beta_0 + T \\ &\text{and} \quad \bar{\delta} = \delta_0 L_i' G' L_i, \end{aligned} \tag{A.28}$$

Gibbs sampler

The Gibbs sampling algorithm for the model consists of the following steps:

1. Determination of the initial values ($\theta^{(0)}, \Omega^{(0)}, f^{-1(0)}, \lambda^{(0)}$ and $\phi^{(0)}$):
    - $\theta^{(0)}$ is given by the OLS estimate, $\hat{\theta}$ and $\Omega^{(0)} = diag(\hat{\theta}\hat{\theta}')$.
    - The time-invariant OLS estimate of Σ_t, $\hat{\Sigma}$, is decomposed using a triangular factorization: $\hat{\Sigma} = \hat{F}\hat{\Lambda}\hat{F}'$. $\hat{F}^{-1}$ is then computed and $f_i^{-1(0)}, i = 2, \ldots N$ are set as the non-zero and non-one elements of $\hat{F}^{-1}$.
    - $\lambda_{i,t}^{(0)} = 0, \forall t = 1, \ldots, T$ and $\forall i = 1, \ldots, N$.
    - $\phi_i^{(0)} = 1, \forall i = 1, \ldots, N$.
2. Determination of $\bar{s}_1, \ldots, \bar{s}_N$ using the estimated $\hat{\Lambda}$.
3. Computation of $\Lambda_t^{(0)}, \forall t = 1, \ldots, T$ using $\lambda_{i,t}^{(0)}$ and $\bar{s}_1, \ldots, \bar{s}_N$. Then: $\Sigma_t^{(0)} = F_t^{(0)}\Lambda_t^{(0)}F_t^{(0)\prime}, \forall t = 1, \ldots, T$.
4. At iteration m, the relevant parameters are drawn in the following order:
    - $\theta_t^{(m)}$ is drawn from Equation (B.41).
    - $\omega_i^{(m)}$ is drawn from Equation (B.42).
    - $f_i^{-1(m)}$ is drawn from Equation (B.43), where $\nu_{-i,t}^{(m)}$ and $\nu_{i,t}^{(m)}$ are computed from $\nu_t^{(m)} = y_t - X_t'\theta_t^{(m)}$. Then, $F_t^{-1(m)}$ is computed.

- $\phi_i^{(m)}$ is drawn from Equation (B.50).
- a candidate $\lambda_{i,t}^{(m)}, i = 1, \ldots, N, t = 1, \ldots, T$ is drawn from $\mathcal{N}(\bar{\lambda}, \bar{\phi})$ with $\bar{\lambda}$ and $\bar{\phi}$ set according to Equations (B.44), (B.46) and (B.48). The acceptance function in Equation (B.45) is then used and for $i = 1, \ldots, N$, $\lambda_{i,1}^{(m)}, \ldots, \lambda_{i,T}^{(m)}$ are stacked to obtain $L_i^{(m)}$.

5. Computation of $\Lambda_t^{(m)}$ using $\lambda^{(m)}$ and $\bar{s}_1, \ldots, \bar{s}_N$.
6. Computation of $\Sigma_t^{(m)}$ using $\Sigma_t^{(m)} = F_t^{(m)} \Lambda_t^{(m)} F_t^{(m)\prime}$.

Steps 4 to 6 are then repeated for each $m = 1, \ldots, M$. In the baseline estimation, $M = 10000$, with a burn-in of 5000 iterations.

B Appendix to Chapter 2

B.1 Data

Yield decomposition and event study

Data used to decompose the long-term government bond yields in the EA and to perform the event study in Section 2.3 are the nominal zero-coupon bond yields extracted from sovereign coupon-bearing instruments issued by the relevant authorities of the EA, as reported by the ECB. The extraction method is the one proposed by Söderlind and Svensson (1997).

The aggregate yield curves include the following countries:

Core EA Austria, France, Germany, Netherlands

Periphery EA Ireland, Italy, Portugal, Spain

Data are aggregated via a weighted average, with weights given by the shares of the general government consolidated debt reported by the national central banks (NCBs). Not seasonally adjusted data have been adjusted using the US Census X-13 ARIMA-SEATS seasonal adjustment program. For the spreads aggregates, we remove Germany from the sample, as measures are constructed vis-à-vis the yields of German Bunds.

Information on the releases of macroeconomic data for the EA are taken from Bloomberg, while information on the UMPs and programmes announcements are taken from the ECB.

Time-varying SVAR with SV

Besides the term and risk-neutral spreads extracted from yield curves in Section 2.3.1, the set of endogenous variables used for the monthly TVP-SVAR-SV includes: the yearly log-difference of Industrial Production and the yearly log-difference of the Consumer Price Index (CPI), aggregated for core and peripheral EA groupings. The monthly raw series for each country are taken from the ECB Statistical Data Warehouse (SDW) and cover the period from January 2007 to March 2019. For the purpose of aggregation, we use Real GDP weights.

B.2 Event study results

Tables B.1 to B.5 below report the results of the event study in Section 2.3.2.

Table B.1: Significance of daily changes in EA government bond spreads

		Maturity					
Date	Events	2-year		5-year		10-year	
		(1)	(2)	(1)	(2)	(1)	(2)
09/08/2007	ECB announces special fine-tuning operations	3.874***	0.732***	3.848***	1.058***	2.365***	0.286***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
22/08/2007	ECB announces supplementary LTRO	-8.933***	-1.884***	-5.759***	-0.517***	-1.686***	-0.750***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
08/10/2008	ECB introduces FRFA on MROs	4.792***	0.44	2.270***	4.925***	1.570***	7.110***
		(0.00)	(0.53)	(0.00)	(0.00)	(0.00)	(0.00)
07/05/2009	ECB announces LTROs and CBPP1	-3.407***	-7.897***	-7.694***	-10.235***	-9.250***	-12.527***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
09/05/2010	ECB announces SMP	-10.115***	-62.867***	-12.566***	-65.150***	-13.400***	-42.524***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
06/10/2011	ECB announces CBPP2	-2.308***	-12.475***	-2.914***	-12.912***	-2.190***	-8.666***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
08/12/2011	ECB announces LTRO	0.068	17.343***	3.871***	8.937***	4.786***	7.758***
		(0.11)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
26/07/2012	”Whatever it takes” speech	-4.423***	-47.323***	-7.448***	-33.895***	-7.474***	-26.288***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
02/08/2012	ECB announces OMT	1.784***	-1.898***	4.701***	4.365***	8.492***	11.943***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
05/06/2014	ECB announces TLTRO I	-0.732***	-7.872***	-0.673***	-7.654***	-0.427***	-3.665***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
04/09/2014	ECB announces ABSPP & CBPP3	1.704***	-2.661***	0.563***	-5.936***	-1.938***	-9.122***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
22/01/2015	ECB announces PSPP	2.010***	-1.561***	1.185***	-6.575***	-3.435***	-16.675***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
10/03/2016	ECB announces TLTRO II	-0.127***	-0.362**	0.192***	-2.408***	-1.117***	-7.551***
		(0.00)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)
02/06/2016	ECB announces CSPP	-0.742***	-0.075	-0.229***	-0.354***	0.423***	0.861***
		(0.00)	(0.64)	(0.00)	(0.01)	(0.00)	(0.00)
14/06/2018	ECB announces end of APP net purchases	0.566***	-6.760***	0.478***	-3.987***	-1.081***	-2.912***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
25/07/2019	ECB announces new round of purchases	-2.431***	1.382***	-3.959***	-0.139	-2.164***	0.243**
		(0.00)	(0.00)	(0.00)	(0.28)	(0.00)	(0.01)

Notes: (1) Core EA; (2) Peripheral EA. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, p-values in parentheses. t-statistics are computed using Newey and West standard errors. All figures are in basis points.

Table B.2: Significance of daily changes in EA government bond fitted spreads

		Maturity					
Date	Events	2-year		5-year		10-year	
		(1)	(2)	(1)	(2)	(1)	(2)
09/08/2007	ECB announces special fine-tuning operations	3.851***	0.815***	3.827***	1.034***	2.348***	0.216**
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.03)
22/08/2007	ECB announces supplementary LTRO	-8.902***	-1.938***	-5.763***	-0.517***	-1.696***	-0.700***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
08/10/2008	ECB introduces FRFA on MROs	6.911***	1.373*	1.802***	4.559***	0.408	6.566***
		(0.00)	(0.05)	(0.00)	(0.00)	(0.24)	(0.00)
07/05/2009	ECB announces LTROs and CBPP1	-3.278***	-7.755***	-7.715***	-10.229***	-9.317***	-12.575***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
09/05/2010	ECB announces SMP	-10.066***	-62.091***	-12.594***	-65.405***	-13.446***	-43.169***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
06/10/2011	ECB announces CBPP2	-2.318***	-12.664***	-2.902***	-12.875***	-2.170***	-8.541***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
08/12/2011	ECB announces LTRO	0.019	17.736***	3.914***	8.804***	4.856***	7.397***
		(0.65)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
26/07/2012	”Whatever it takes” speech	-4.473***	-47.121***	-7.437***	-34.028***	-7.445***	-26.505***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
02/08/2012	ECB announces OMT	1.767***	-0.864***	4.721***	4.169***	8.524***	11.238***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
05/06/2014	ECB announces TLTRO I	-0.749***	-7.860***	-0.660***	-7.644***	-0.405***	-3.657***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
04/09/2014	ECB announces ABSPP & CBPP3	1.688***	-2.619***	0.572***	-5.953***	-1.924***	-9.171***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
22/01/2015	ECB announces PSPP	1.857***	-1.638***	1.216***	-6.595***	-3.353***	-16.679***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
10/03/2016	ECB announces TLTRO II	0.122***	0.196	0.131***	-2.532***	-1.262***	-7.919***
		(0.00)	(0.22)	(0.00)	(0.00)	(0.00)	(0.00)
02/06/2016	ECB announces CSPP	-0.761***	-0.156	-0.225***	-0.341***	0.434***	0.903***
		(0.00)	(0.32)	(0.00)	(0.01)	(0.00)	(0.00)
14/06/2018	ECB announces end of APP net purchases	0.591***	-6.709***	0.473***	-4.003***	-1.095***	-2.955***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
25/07/2019	ECB announces new round of purchases	-2.365***	1.470***	-3.998***	-0.157	-2.231***	0.190*
		(0.00)	(0.00)	(0.00)	(0.22)	(0.00)	(0.05)

Notes: (1) Core EA; (2) Peripheral EA. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, p-values in parentheses. t-statistics are computed using Newey and West standard errors. All figures are in basis points.

Table B.3: Significance of daily changes in EA government bond term premium spreads

		Maturity					
Date	Events	2-year		5-year		10-year	
		(1)	(2)	(1)	(2)	(1)	(2)
09/08/2007	ECB announces special fine-tuning operations	**-0.626*** **	**-0.593*** **	**-1.020*** **	**-1.340*** **	**-2.625*** **	**-2.616*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
22/08/2007	ECB announces supplementary LTRO	**3.499*** **	**1.992*** **	**8.046*** **	**7.381*** **	**13.086*** **	**9.920*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
08/10/2008	ECB introduces FRFA on MROs	**-8.068*** **	**-4.995*** **	**-14.091*** **	**-6.589*** **	**-16.950*** **	**-9.269*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
07/05/2009	ECB announces LTROs and CBPP1	**-3.738*** **	**-4.729*** **	**-9.005*** **	**-11.124*** **	**-11.849*** **	**-17.480*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
09/05/2010	ECB announces SMP	**-5.906*** **	**-20.977*** **	**-9.978*** **	**-31.268*** **	**-12.766*** **	**-16.204*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
06/10/2011	ECB announces CBPP2	**-1.547*** **	**-2.923*** **	**-2.551*** **	**-3.417*** **	**-2.282*** **	**0.420*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
08/12/2011	ECB announces LTRO	**3.094*** **	**-5.549*** **	**8.004*** **	**-10.964*** **	**9.966*** **	**-8.977*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
26/07/2012	”Whatever it takes” speech	**-5.008*** **	**-0.926*** **	**-9.185*** **	**5.072*** **	**-10.632*** **	**6.000*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
02/08/2012	ECB announces OMT	**3.867*** **	**3.580*** **	**8.429*** **	**10.338*** **	**13.694*** **	**18.972*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
05/06/2014	ECB announces TLTRO I	**-0.750*** **	**-2.510*** **	**-0.945*** **	**-3.269*** **	**-0.940*** **	-0.103
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.37)
04/09/2014	ECB announces ABSPP & CBPP3	**-1.968*** **	**-5.467*** **	**-4.333*** **	**-9.523*** **	**-7.682*** **	**-13.136*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
22/01/2015	ECB announces PSPP	**0.312*** **	**-5.201*** **	**-1.716*** **	**-11.565*** **	**-6.966*** **	**-22.414*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
10/03/2016	ECB announces TLTRO II	**1.456*** **	**-2.789*** **	**1.334*** **	**-3.621*** **	0.068	**-7.329*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.31)	(0.00)
02/06/2016	ECB announces CSPP	**0.701*** **	**-0.205*** **	**1.746*** **	-0.099	**2.736*** **	**1.249*** **
		(0.00)	(0.00)	(0.00)	(0.37)	(0.00)	(0.00)
14/06/2018	ECB announces end of APP net purchases	**-0.308*** **	**0.388*** **	**-1.161*** **	**2.267*** **	**-3.101*** **	**2.828*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
25/07/2019	ECB announces new round of purchases	**-2.839*** **	**-1.010*** **	**-4.787*** **	**-3.153*** **	**-3.663*** **	**-3.474*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Notes: (1) Core EA; (2) Peripheral EA. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, p-values in parentheses. t-statistics are computed using Newey and West standard errors. All figures are in basis points.

Table B.4: Significance of daily changes in EA government bond risk-neutral spreads

		Maturity					
Date	Events	2-year		5-year		10-year	
		(1)	(2)	(1)	(2)	(1)	(2)
09/08/2007	ECB announces special fine-tuning operations	**4.477*** **	**1.407*** **	**4.847*** **	**2.374*** **	**4.973*** **	**2.832*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
22/08/2007	ECB announces supplementary LTRO	**-12.401*** **	**-3.931*** **	**-13.810*** **	**-7.898*** **	**-14.781*** **	**-10.621*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
08/10/2008	ECB introduces FRFA on MROs	**14.979*** **	**6.368*** **	**15.893*** **	**11.148*** **	**17.357*** **	**15.835*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
07/05/2009	ECB announces LTROs and CBPP1	**0.460*** **	**-3.027*** **	**1.290*** **	**0.895*** **	**2.532*** **	**4.905*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
09/05/2010	ECB announces SMP	**-4.160*** **	**-41.113*** **	**-2.616*** **	**-34.137*** **	**-0.680*** **	**-26.965*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
06/10/2011	ECB announces CBPP2	**-0.770*** **	**-9.741*** **	**-0.351*** **	**-9.458*** **	**0.112** **	**-8.961*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.03)	(0.00)
08/12/2011	ECB announces LTRO	**-3.076*** **	**23.285*** **	**-4.089*** **	**19.768*** **	**-5.110*** **	**16.374*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
26/07/2012	”Whatever it takes” speech	**0.534*** **	**-46.194*** **	**1.748*** **	**-39.100*** **	**3.187*** **	**-32.505*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
02/08/2012	ECB announces OMT	**-2.100*** **	**-4.443*** **	**-3.708*** **	**-6.169*** **	**-5.170*** **	**-7.734*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
05/06/2014	ECB announces TLTRO I	0.001	**-5.350*** **	**0.285*** **	**-4.376*** **	**0.535*** **	**-3.554*** **
		(0.98)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
04/09/2014	ECB announces ABSPP & CBPP3	**3.656*** **	**2.848*** **	**4.905*** **	**3.570*** **	**5.758*** **	**3.965*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
22/01/2015	ECB announces PSPP	**1.545*** **	**3.563*** **	**2.932*** **	**4.970*** **	**3.614*** **	**5.735*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
10/03/2016	ECB announces TLTRO II	**-1.334*** **	**2.985*** **	**-1.204*** **	**1.089*** **	**-1.330*** **	**-0.590*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
02/06/2016	ECB announces CSPP	**-1.462*** **	0.049	**-1.971*** **	**-0.242* **	**-2.302*** **	**-0.345*** **
		(0.00)	(0.77)	(0.00)	(0.09)	(0.00)	(0.01)
14/06/2018	ECB announces end of APP net purchases	**0.899*** **	**-7.097*** **	**1.634*** **	**-6.270*** **	**2.006*** **	**-5.784*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
25/07/2019	ECB announces new round of purchases	**0.475*** **	**2.480*** **	**0.790*** **	**2.996*** **	**1.432*** **	**3.664*** **
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Notes: (1) Core EA; (2) Peripheral EA. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, p-values in parentheses. t-statistics are computed using Newey and West standard errors. All figures are in basis points.

Table B.5: Significance of cumulative changes in EA government bond fitted, term premium and risk-neutral spreads

	2-year			5-year			10-year		
Events	$\Delta\hat{y}_t$	ΔTP_t	Δer_t	$\Delta\hat{y}_t$	ΔTP_t	Δer_t	$\Delta\hat{y}_t$	ΔTP_t	Δer_t
				Core EA					
All	**-16.105*** **	**-17.828*** **	**1.722** **	**-24.638*** **	**-31.212*** **	**6.574*** **	**-27.774*** **	**-39.907*** **	**12.133*** **
	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
L	**-14.598*** **	**-11.004*** **	**-3.594*** **	**-22.725*** **	**-22.795*** **	0.07	**-27.684*** **	**-31.791*** **	**4.107*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.80)	(0.00)	(0.00)	(0.00)
C	**-1.997*** **	**-5.106*** **	**3.109*** **	**-4.425*** **	**-7.630*** **	**3.205*** **	**-5.023*** **	**-9.182*** **	**4.159*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
F	**-3.346*** **	**-3.261*** **	-0.09	**-5.209*** **	**-6.652*** **	**1.443*** **	**-5.121*** **	**-7.901*** **	**2.781*** **
	(0.00)	(0.00)	(0.74)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
				Peripheral EA					
All	**-129.825*** **	**-51.913*** **	**-77.912*** **	**-131.713*** **	**-70.872*** **	**-60.841*** **	**-105.361*** **	**-61.612*** **	**-43.749*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
L	**-84.998*** **	**-37.070*** **	**-47.928*** **	**-97.259*** **	**-59.041*** **	**-38.218*** **	**-80.411*** **	**-52.479*** **	**-27.931*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
C	**2.830** **	**-19.106*** **	**21.936*** **	**-6.277*** **	**-29.443*** **	**23.166*** **	**-10.483*** **	**-35.801*** **	**25.318*** **
	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
F	**-54.868*** **	**-3.288*** **	**-51.580*** **	**-40.767*** **	**2.994*** **	**-43.761*** **	**-33.655*** **	**3.271*** **	**-36.926*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Notes: L: Balance sheet; C: Credit policy; F: Forward guidance. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, p-values in parentheses. t-statistics are computed using Newey and West standard errors. All figures are in basis points.

B.3 Bayesian Estimation

B.3.1 MCMC algorithm

The system given by Equations (2.4) to (2.8) is estimated using Bayesian methods. Notably, assuming independence across θ, f^{-1} and λ, the posterior density can be written as:

$$f(\theta, \mathbf{\Omega}, f^{-1}, \lambda, \mathbf{\Phi}|y) \propto f(y|\theta, f^{-1}, \lambda)\pi(\theta|\mathbf{\Omega})\pi(\mathbf{\Omega})\left(\prod_{i=2}^{N}\pi(f_i^{-1})\right)\left(\prod_{i=2}^{N}\pi(\lambda_{i,t}|\phi_i)\right)\left(\prod_{i=2}^{N}\pi(\phi_i)\right). \tag{B.29}$$

By the independence of the residuals, ν_t, the likelihood function can be written as:

$$f(y|\theta, f^{-1}, \lambda) \propto \prod_{t=1}^{T}|\mathbf{F}_t\mathbf{\Lambda}_t\mathbf{F}_t'|^{-1/2}\exp\left(-\frac{1}{2}(y_t - \bar{\mathbf{X}}_t\theta_t)'(\mathbf{F}_t\mathbf{\Lambda}_t\mathbf{F}_t')^{-1}(y_t - \bar{\mathbf{X}}_t\theta_t)\right). \tag{B.30}$$

The likelihood function in Equation (B.30) can also be reformulated in compact form, by setting:

$$\underbrace{\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_T \end{bmatrix}}_{NT\times 1} = \underbrace{\begin{bmatrix} \bar{\mathbf{X}}_1 & 0 & \dots & 0 \\ 0 & \bar{\mathbf{X}}_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \bar{\mathbf{X}}_T \end{bmatrix}}_{NT\times pT} \underbrace{\begin{bmatrix} \theta_1 \\ \theta_2 \\ \vdots \\ \theta_T \end{bmatrix}}_{pT\times 1} + \underbrace{\begin{bmatrix} \nu_1 \\ \nu_2 \\ \vdots \\ \nu_T \end{bmatrix}}_{NT\times 1} \tag{B.31}$$

or

$$y = \bar{\mathbf{X}}\Theta, \quad \nu \sim N(0, \bar{\mathbf{\Sigma}}), \quad \bar{\mathbf{\Sigma}} = \underbrace{\begin{bmatrix} \mathbf{\Sigma}_1 & 0 & \dots & 0 \\ 0 & \mathbf{\Sigma}_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \mathbf{\Sigma}_T \end{bmatrix}}_{NT \times NT}.$$

Therefore:

$$f(y|\theta, \mathbf{\Sigma}) \propto |\bar{\mathbf{\Sigma}}|^{-1/2} \exp\left(-\frac{1}{2}(y - \bar{\mathbf{X}}\Theta)' \bar{\mathbf{\Sigma}}^{-1}(y - \bar{\mathbf{X}}\Theta) \right) \tag{B.32}$$

We set the priors as follows:

$$\begin{aligned} &\theta|\mathbf{\Omega} \sim \mathcal{N}(0, \mathbf{\Omega}_0) \\ &\omega_i \sim IG\Big(\frac{\chi_0}{2}, \frac{\psi_0}{2}\Big) \\ &f_i^{-1} \sim \mathcal{N}(f_{i,0}^{-1}, \mathbf{\Upsilon}_{i,0}) \\ &\lambda_i|\phi_i \sim N(0, \mathbf{\Phi}_0) \\ &\phi_i \sim IG\Big(\frac{\beta_0}{2}, \frac{\delta_0}{2}\Big). \end{aligned} \tag{B.33}$$

The prior for λ_i deserves some additional remarks. Equation (2.8) implies that each $\lambda_{i,t}$ depends on $\lambda_{i,t-1}$, which makes the formulation of $\pi(\lambda_i|\phi_i)$ complicated. There are two alternative approaches that can be considered in this case. The first one is based on the formulation of a joint prior for $\lambda_{i,1}, \dots, \lambda_{i,T}$ accounting for the dependence across different sample periods. The second one consists of separating $\pi(\lambda_i|\phi_i)$ into T different priors, where the prior for each individual period t will be conditional on period $t-1$, thus accounting for the dependence with the previous sample period. The joint formulation would result in a joint posterior which takes a non-standard form, so that a Metropolis-Hastings step is required (see below). For the purpose of this paper, we adopt the first approach, which is in turn based on the sparse matrix methodology of Chan and Jeliazkov (2009)[32]. Notably, from Equation (2.8), any value $\lambda_{i,t}$ eventually depends on the initial value $\lambda_{i,0}$ and the shocks $v_{i,t}, t = 1, \dots, T$. Therefore, Equation (2.8) can be reformulated as:

$$GL_i = v_i, \quad i = 1, \dots, N \tag{B.34}$$

[32]The same reasoning holds also for the prior of θ. Even in this case, two alternative formulations can be considered: 1. compact formulation: $\theta|\mathbf{\Omega} \sim \mathcal{N}(0, \mathbf{\Omega}_0)$; 2. conditional formulation: $\pi(\theta|\mathbf{\Omega}) = \pi(\theta_1|\mathbf{\Omega}) \prod_{t=2}^{T} \pi(\theta_t|\mathbf{\Omega}, \theta_{t-1})$. As in the case of λ_i, we opt for the first one.

with

$$G = \begin{bmatrix} 1 & 0 & 0 & \dots & 0 \\ -\gamma & 1 & 0 & \dots & 0 \\ 0 & -\gamma & 1 & \dots & 0 \\ \vdots & & \ddots & & \vdots \\ 0 & \dots & 0 & -\gamma & 1 \end{bmatrix}, \quad L_i = \begin{bmatrix} \lambda_{i,1} \\ \lambda_{i,2} \\ \vdots \\ \lambda_{i,T} \end{bmatrix}, \quad v_i = \begin{bmatrix} \gamma\lambda_{i,0} + v_{i,1} \\ v_{i,2} \\ \vdots \\ v_{i,T} \end{bmatrix}. \tag{B.35}$$

In this case, $\lambda_{i,0}$ is the initial value of the process, which is assumed to follow a normal distribution of the form $\mathcal{N}(0, \frac{\phi_i(\omega-1)}{\gamma^2})$, where ω is a known variance parameter. This implies that:

$$\begin{aligned} var(\gamma\lambda_{i,0} + v_{i,1}) &= var(\gamma\lambda_{i,0}) + var(v_{i,1}) \\ &= \gamma^2 var(\lambda_{i,0}) + var(v_{i,1}) \\ &= \gamma^2 \frac{\phi_i(\omega - 1)}{\gamma^2} + \phi_i \\ &= \phi_i \omega. \end{aligned} \tag{B.36}$$

Following Cogley and Sargent (2005), ω is set equal to 1000 in order to get a diffuse prior for $\lambda_{i,1}$. Equation (2.8), Equation (B.35) and Equation (B.36) imply that:

$$v_i \sim \mathcal{N}(0, \phi_i I_\omega), \qquad I_\omega = \begin{bmatrix} \omega & 0 & \dots & \dots & 0 \\ 0 & 1 & \dots & \dots & 0 \\ \vdots & & \ddots & & \vdots \\ 0 & & \dots & 0 & 1 \end{bmatrix}. \tag{B.37}$$

Furthermore, Equation (B.34) implies that $L_i = G^{-1} v_i$, which, in turn, leads to:

$$L_i \sim \mathcal{N}(0, G^{-1} \phi_i I_\omega G^{-1\prime}), \tag{B.38}$$

or:

$$L_i \sim \mathcal{N}(0, \mathbf{\Phi}_0), \quad \text{with } \mathbf{\Phi}_0 = \phi_i (G' I_\omega^{-1} G)^{-1}. \tag{B.39}$$

Hence, the joint prior distribution of λ_i conditional on ϕ_i is a normal with mean 0 and covariance $\mathbf{\Phi}_0$.

Given the likelihood in Equation (B.30) and the priors in Equation (B.33), the joint posterior density is:

$$
\begin{aligned}
& f(\theta, \mathbf{\Omega}, f^{-1}, \lambda, \mathbf{\Phi}|y) \\
& \propto \prod_{t=1}^{T} |\mathbf{F}_t \mathbf{\Lambda}_t \mathbf{F}_t'|^{-1/2} \exp\Bigg(-\frac{1}{2}(y_t - \bar{\mathbf{X}}_t\theta_t)'(\mathbf{F}_t \mathbf{\Lambda}_t \mathbf{F}_t')^{-1}(y_t - \bar{\mathbf{X}}_t\theta_t)\Bigg) \\
& \times |\mathbf{\Omega}_0| \exp\Big(-\frac{1}{2}\Theta'\mathbf{\Omega}_0^{-1}\Theta\Big) \\
& \times \prod_{i=1}^{N} \omega_i^{-\frac{\chi_0}{2}-1} \exp\Big(-\frac{\psi_0}{2\omega_i}\Big) \\
& \times \prod_{i=1}^{N} \exp\Bigg[-\frac{1}{2}(f_i^{-1} - f_{i,0}^{-1})'\mathbf{\Upsilon}_{i,0}^{-1}(f_i^{-1} - f_{i,0}^{-1})\Bigg] \\
& \times |\mathbf{\Phi}_0|^{-1/2} \exp\Bigg(-\frac{1}{2}L_i'\mathbf{\Phi}_0^{-1}L_i\Bigg) \\
& \times \prod_{i=1}^{N} \phi_i^{-\frac{\beta_0}{2}-1} \exp\Big(-\frac{\delta_0}{2\phi_i}\Big).
\end{aligned}
\tag{B.40}
$$

Therefore, it is possible to derive the conditional posterior densities for each set of parameters of interest. Notably, for θ:

$$
\begin{aligned}
& \theta|(y, \mathbf{\Omega}, f^{-1}, \lambda, \mathbf{\Phi}) \sim N(\bar{\Theta}, \bar{\mathbf{\Omega}}), \\
& \text{with} \quad \bar{\mathbf{\Omega}}^{-1} = (\mathbf{\Omega}_0^{-1} + \bar{\mathbf{X}}'\bar{\mathbf{\Sigma}}^{-1}\bar{\mathbf{X}}) \\
& \text{and} \quad \bar{\Theta} = \bar{\mathbf{\Omega}}(\bar{\mathbf{X}}'\bar{\mathbf{\Sigma}}^{-1}y).
\end{aligned}
\tag{B.41}
$$

As to the diagonal elements of $\mathbf{\Omega}$:

$$
\begin{aligned}
& \mathbf{\Omega}_i|(y, \theta, \mathbf{\Omega}_{-i}, \mathbf{\Sigma}) \sim IG(\bar{\chi}, \bar{\psi}), \\
& \text{with} \quad \bar{\chi} = \frac{\chi_0 + T}{2} \\
& \text{and} \quad \bar{\psi} = \frac{\theta_{i,1}^2/\tau + \sum_{t=2}^{T}(\theta_{i,t} - \theta_{i,t-1})^2 + \psi_0}{2}.
\end{aligned}
\tag{B.42}
$$

The non-zero elements of matrix F_t have the following conditional posterior densities:

$$
\begin{aligned}
& f_i^{-1}|(y, \theta, f_{-i}^{-1}, \lambda, \mathbf{\Phi}) \sim N(\bar{f}_i^{-1}), \bar{\mathbf{\Upsilon}}_i) \\
& \text{with} \quad \bar{\mathbf{\Upsilon}}_i = \Big(\bar{s}_i^{-1}\sum_{t=1}^{T}\nu_{-i,t}\exp(-\lambda_{i,t})\nu_{i,t}' + \bar{\mathbf{\Upsilon}}_{i0}^{-1}\Big)^{-1} \\
& \text{and} \quad \bar{f}_i^{-1} = \bar{\mathbf{\Upsilon}}_i\Big(-\bar{s}_i^{-1}\sum_{t=1}^{T}\nu_{-i,t}\exp(-\lambda_{i,t})\nu_{i,t}' + \bar{\mathbf{\Upsilon}}_{i0}^{-1}f_{i0}^{-1}\Big).
\end{aligned}
\tag{B.43}
$$

On the other hand, the conditional posterior for λ is non-standard:

$$\begin{aligned}
&\pi(\lambda_{i,t}|y, \theta, f^{-1}, \lambda_{-i,-t}, \mathbf{\Phi}) \\
&\propto \exp\Big(-\frac{1}{2}\Big\{ \bar{s}_i^{-1} \exp(-\lambda_{i,t})(\nu_{i,t} + (f_i^{-1})'\nu_{-i,t})^2 + \lambda_{i,t} \Big\}\Big) \\
&\times \exp\Big(-\frac{1}{2}\frac{(\lambda_{i,t} - \bar{\lambda}_i)^2}{\bar{\mathbf{\Phi}}}\Big) \\
&\text{with} \quad \bar{\mathbf{\Phi}} = \frac{\phi_i}{1+\gamma^2} \\
&\text{and} \quad \bar{\lambda} = \frac{\gamma}{1+\gamma^2}(\lambda_{i,t-1} + \lambda_{i,t+1}).
\end{aligned} \tag{B.44}$$

Equation (B.44) requires a Metropolis-Hastings step, with the following acceptance function:

$$\begin{aligned}
&\kappa(\lambda_{i,t}^{(m-1)}, \lambda_{i,t}^{(m)}) \\
&= \exp\Big(-\frac{1}{2}\Big\{ \exp(-\lambda_{i,t}^{(m)}) - \exp(-\lambda_{i,t}^{(m-1)}) \Big\} \bar{s}_i^{-1}(\nu_{i,t} + (f_i^{-1})'\nu_{-i,t})^2 \Big) \\
&\times \exp\Big(\{\lambda_{i,t}^{(m)} - \lambda_{i,t}^{(m-1)}\} \Big).
\end{aligned} \tag{B.45}$$

For $t = 1$ and $t = T$, Equation (B.45) needs to be slightly adapted as follows. For the first period, a candidate is drawn from $\mathcal{N}(\bar{\lambda}, \bar{\phi})$, with:

$$\bar{\lambda} = \frac{\gamma\lambda_{i,2}}{\omega^{-1} + \gamma^2} \quad \text{and} \quad \bar{\phi} = \frac{\phi_i}{\omega^{-1} + \gamma^2}. \tag{B.46}$$

The acceptance function is then given by:

$$\begin{aligned}
&\kappa(\lambda_{i,1}^{(m-1)}, \lambda_{i,1}^{(m)}) \\
&= \exp\Big(-\frac{1}{2}\Big\{ \exp(-\lambda_{i,1}^{(m)}) - \exp(-\lambda_{i,1}^{(m-1)}) \Big\} \bar{s}_i^{-1}(\nu_{i,1} + (f_i^{-1})'\nu_{-i,1})^2 \Big) \\
&\times \exp\Big(\{\lambda_{i,1}^{(m)} - \lambda_{i,1}^{(m-1)}\} \Big).
\end{aligned} \tag{B.47}$$

For the last period, the candidate is drawn from $\mathcal{N}(\bar{\lambda}, \bar{\phi})$, with:

$$\bar{\lambda} = \gamma\lambda_{i,T-1} \quad \text{and} \quad \bar{\phi} = \phi_i. \tag{B.48}$$

The acceptance function is then given by:

$$\begin{aligned}
&\kappa(\lambda_{i,T}^{(m-1)}, \lambda_{i,T}^{(m)}) \\
&= \exp\Big(-\frac{1}{2}\Big\{ \exp(-\lambda_{i,T}^{(m)}) - \exp(-\lambda_{i,T}^{(m-1)})\Big\} \bar{s}_i^{-1}(\nu_{i,T} + (f_i^{-1})'\nu_{-i,T})^2\Big) \\
&\times \exp\Big(\{\lambda_{i,T}^{(m)} - \lambda_{i,T}^{(m-1)}\}\Big).
\end{aligned} \tag{B.49}$$

Finally, the conditional posterior distribution for ϕ is:

$$\begin{aligned}
&\phi_i|(y, \theta, f^{-1}, \lambda, \phi_{-i}) \sim IG\Big(\frac{\bar{\beta}}{2}, \frac{\bar{\delta}}{2}\Big) \\
&\text{with} \quad \bar{\beta} = \beta_0 + T \\
&\text{and} \quad \bar{\delta} = \delta_0 L_i' G' L_i,
\end{aligned} \tag{B.50}$$

Gibbs sampler

The Gibbs sampling algorithm for the model consists of the following steps:

1. Determination of the initial values ($\theta^{(0)}, \mathbf{\Omega}^{(0)}, f^{-1(0)}, \lambda^{(0)}$ and $\mathbf{\Phi}^{(0)}$):
   - $\theta^{(0)}$ is given by the OLS estimate, $\hat{\theta}$ and $\mathbf{\Omega}^{(0)} = diag(\hat{\theta}\hat{\theta}')$.
   - The time-invariant OLS estimate of $\mathbf{\Sigma}_t$, $\hat{\mathbf{\Sigma}}$, is decomposed using a triangular factorization: $\hat{\mathbf{\Sigma}} = \hat{\mathbf{F}}\hat{\mathbf{\Lambda}}\hat{\mathbf{F}}'$. $\hat{\mathbf{F}}^{-1}$ is then computed and $f_i^{-1(0)}, i = 2, \ldots N$ are set as the non-zero and non-one elements of $\hat{\mathbf{F}}^{-1}$.
   - $\lambda_{i,t}^{(0)} = 0, \forall t = 1, \ldots, T$ and $\forall i = 1, \ldots, N$.
   - $\phi_i^{(0)} = 1, \forall i = 1, \ldots, N$.
2. Determination of $\bar{s}_1, \ldots, \bar{s}_N$ using the estimated $\hat{\Lambda}$.
3. Computation of $\mathbf{\Lambda}_t^{(0)}, \forall t = 1, \ldots, T$ using $\lambda_{i,t}^{(0)}$ and $\bar{s}_1, \ldots, \bar{s}_N$. Then: $\mathbf{\Sigma}_t^{(0)} = \mathbf{F}_t^{(0)}\mathbf{\Lambda}_t^{(0)}\mathbf{F}_t^{(0)\prime}, \forall t = 1, \ldots, T$.
4. At iteration m, the relevant parameters are drawn in the following order:
   - $\theta_t^{(m)}$ is drawn from Equation (B.41).
   - $\omega_i^{(m)}$ is drawn from Equation (B.42).
   - $f_i^{-1(m)}$ is drawn from Equation (B.43), where $\nu_{-i,t}^{(m)}$ and $\nu_{i,t}^{(m)}$ are computed from $\nu_t^{(m)} = y_t - X_t'\theta_t^{(m)}$. Then, $F_t^{-1(m)}$ is computed.
   - $\phi_i^{(m)}$ is drawn from Equation (B.50).
   - a candidate $\lambda_{i,t}^{(m)}, i = 1, \ldots, N, t = 1, \ldots, T$ is drawn from $\mathcal{N}(\bar{\lambda}, \bar{\mathbf{\Phi}})$ with $\bar{\lambda}$ and $\bar{\phi}$ set according to Equations (B.44), (B.46) and (B.48). The acceptance function in Equation (B.45) is then used and for $i = 1, \ldots, N$, $\lambda_{i,1}^{(m)}, \ldots, \lambda_{i,T}^{(m)}$ are stacked to

obtain $L_i^{(m)}$.

5. Computation of $\mathbf{\Lambda}_t^{(m)}$ using $\lambda^{(m)}$ and $\bar{s}_1, \dots, \bar{s}_N$.
6. Computation of $\mathbf{\Sigma}_t^{(m)}$ using $\mathbf{\Sigma}_t^{(m)} = \mathbf{F}_t^{(m)}\mathbf{\Lambda}_t^{(m)}\mathbf{F}_t^{(m)\prime}$.

Steps 4 to 6 are then repeated for each $m = 1, \dots, M$.

B.3.2 Implementation of Restrictions

The structural VAR in Equation (2.9) can be rewritten in companion form as:

$$A_{0,t}\mathbf{Y}_t = A_t^{+}\mathbf{Y}_{t-1} + \varepsilon_t, \tag{B.51}$$

where $A_t^{+} = [C_{0,t}, A_{1,t}, \dots, A_{p,t}]$ is an $N \times K$ matrix and $\mathbf{Y}_{t-1} = [\mathbf{1}, \mathbf{Y}_{t-1}, \dots, \mathbf{Y}_{t-p}]$ is an $1 \times K$ vector, with $K = T(Np+1)$. The reduced-form representation of Equation (B.51) is then:

$$\mathbf{Y}_t = B_t\mathbf{Y}_{t-1} + \mathbf{u}_t, \tag{B.52}$$

where $B_t = A_{0,t}^{-1}A_t^{+}$, $\mathbf{u}_t = A_{0,t}^{-1}\varepsilon_t$ and $E[\mathbf{u}_t\mathbf{u}_t'] = \mathbf{\Sigma}_t = A_{0,t}^{-1}H_tA_{0,t}^{-1\prime}$.

Functional Forms

Impulse Response Functions

Denote as $\tilde{\theta}_t$ the vector of structural coefficients from Equation (2.9): $\tilde{\theta}_t \equiv (A_{0,t}, A_t^{+})$. Given this, the response of the ith variable to the jth structural shock at horizon k and time t is the (i,j)th element of matrix $\mathbf{L}_{k,t}(\tilde{\theta}_t)$ which is defined recursively as:

$$\mathbf{L}_{k,t}(\tilde{\theta}_t) = \begin{cases} (A_{0,t}^{-1})' & \text{if} \quad k = 0 \\ \sum_{\ell=1}^{k}(A_{0,t}^{-1}A_{\ell,t})'\mathbf{L}_{k-\ell,t}(\tilde{\theta}_t) & \text{if} \quad 1 \leq k \leq p \\ \sum_{\ell=1}^{p}(A_{0,t}^{-1}A_{\ell,t})'\mathbf{L}_{k-\ell,t}(\tilde{\theta}_t) & \text{if} \quad p < k < \infty \end{cases} \tag{B.53}$$

Structural shocks and historical decomposition

Given $\tilde{\theta}_t$, the structural shocks at time t are:

$$\varepsilon_t(\tilde{\theta}_t) = A_{0,t}\mathbf{Y}_t - A_t^{+}\mathbf{Y}_{t-1}, \quad \text{for } t = 1, \dots, T. \tag{B.54}$$

Therefore, the cumulative contribution of the jth shock to the observed changes of the ith variable between t and $t+h$ is given by:

$$H_{i,j,t,t+h}(\tilde{\theta}_t, \varepsilon_t, \ldots, \varepsilon_{t+h}) = \sum_{\ell=0}^{h} \mathbf{e}'_{i,n}\mathbf{L}_{\ell,t}(\tilde{\theta}_t)\mathbf{e}_{j,n}\mathbf{L}_{\ell,t}(\tilde{\theta}_t)\mathbf{e}_{j,n}\mathbf{e}'_{j,n}\varepsilon_{t+h-\ell}, \quad \text{for } i \geq 1, j \leq N, h \geq 0, \tag{B.55}$$

where $\mathbf{e}_{j,n}$ is the jth column of the identity matrix I_N.

Zero and sign restrictions

We impose both sign and zero restrictions following Rubio-Ramírez et al. (2010) and Arias et al. (2018). Notably, sign restrictions can be expressed in the following functional form:

$$\Gamma(\tilde{\theta}_t) = (\mathbf{e}'_{1,N}\mathcal{F}(\tilde{\theta}_t)'\mathbf{S}'_1, \ldots, \mathbf{e}'_{N,N}\mathcal{F}(\tilde{\theta}_t)'\mathbf{S}'_N)' > \mathbf{0}. \tag{B.56}$$

We then impose restrictions on both $A_{0,t}$ and $\mathbf{L}_t(\tilde{\theta}_t)$ by appropriately setting $\mathbf{S}_j$ and $\mathcal{F}(\tilde{\theta}_t)$ in Equation (B.56)[33]. For instance, restrictions on the impulse response functions (IRFs) can be imposed by defining $\mathcal{F}(\tilde{\theta}_t)$ as vertically stacking the IRFs at the different horizons on which we want to impose restrictions and, then, $\mathbf{S}_j$ as a $s_j \times r_j$ matrix of 0s, 1s and -1s corresponding to the horizons and variables over which to impose the r_j restrictions to identify shock j. For restrictions on $A_{0,t}$, on the other hand, we set $\mathcal{F}(\tilde{\theta}_t) = \tilde{\theta}_t$ and we define $\mathbf{S}_j$ as an $s_j \times r_j$ matrix of 0s, 1s and -1s corresponding to the elements of $A_{0,t}$ that we want to restrict.

Similarly, zero restrictions can be defined as:

$$\mathbf{\Xi}(\tilde{\theta}_t) = (\mathbf{e}'_{1,N}\mathcal{F}(\tilde{\theta}_t)'\mathbf{Z}'_1, \ldots, \mathbf{e}'_{N,N}\mathcal{F}(\tilde{\theta}_t)'\mathbf{Z}'_N)' = \mathbf{0}. \tag{B.57}$$

We then impose zero restrictions on $A_{0,t}$ and $\mathbf{L}_t(\tilde{\theta}_t)$ by setting the elements of matrices $\mathbf{Z}_j$ equal to either 0 (no restriction) or 1 (zero restriction) depending on the variables and horizons we want to restrict.

In order to impose the above defined restrictions, we need extend the Gibbs sampler in Appendix B.3.1, as done by Arias et al. (2018). Notably, Equation (B.52) can be rewritten in the so-called orthogonal reduced-form parametrization as follows:

$$\mathbf{Y}_t = \mathbf{X}'_t\theta_t + \mathbf{Q}h(\mathbf{\Omega}_t)\varepsilon_t, \tag{B.58}$$

[33]Notably, $\mathcal{F}(\tilde{\theta}_t)$ can be any function satisfying the condition $\mathcal{F}(\tilde{\theta}_t\mathbf{Q}) = \mathcal{F}(\tilde{\theta}_t)\mathbf{Q}$, with $Q \in \mathcal{O}(N)$, the set of all orthogonal $N \times N$ matrices. This is always the case for IRFs.

where h is a decomposition of $\mathbf{\Sigma}_t$, such that $h(\mathbf{\Sigma}_t)'h(\mathbf{\Sigma}_t) = \mathbf{\Sigma}_t$. For the purpose of our analysis, we set h to be the Cholesky decomposition of $\mathbf{\Sigma_t}$. Moreover, $Q \in \mathcal{O}(N)$, the set of all orthogonal $N \times N$ matrices. Therefore, we define a mapping from the reduced-form parameters $(\theta_t, \mathbf{\Sigma}_t)$ to the structural parameters, $\tilde{\theta}_t$, as:

$$f_h(\tilde{\theta}_t) = \Big(\underbrace{(A_t^+ A_{0,t}^{-1})}_{\theta_t}, \underbrace{(A_{0,t}A_{0,t}')^{-1}}_{\mathbf{\Sigma}_t}, \underbrace{h((A_{0,t}A_{0,t}')^{-1})A_{0,t}}_{\mathbf{Q}} \Big). \tag{B.59}$$

$h((A_{0,t}A_{0,t}')^{-1})A_{0,t}$ is then an orthogonal matrix. Moreover, the inverse of f_h is defined by:

$$f_h^{-1}(\theta_t, \mathbf{\Sigma}_t, \mathbf{Q}) = \Big(\underbrace{h(\mathbf{\Sigma}_t)^{-1}\mathbf{Q}}_{A_{0,t}}, \underbrace{(\tilde{\theta}_t h(\mathbf{\Sigma}_t)^{-1}\mathbf{Q}}_{A_t^+} \Big). \tag{B.60}$$

Therefore, given θ_t and h, each value of $\mathbf{Q}$ can be considered as a particular choice of the structural parameters. For instance, as shown in Theorem 4 in Arias et al. (2018), if $\mathbf{X}$ is an $N \times N$ matrix with elements following a standard normal distribution, and $\mathbf{X} = \mathbf{QR}$ is the QR decomposition of $\mathbf{X}$ with the diagonal of $\mathbf{R}$ normalized to be positive, then the random matrix $\mathbf{Q}$ is orthogonal and is a draw from the uniform distribution over $\mathcal{O}(N)$. This provides a prior density for $\mathbf{Q}$ that forms, together with the assumptions already made on the priors for θ_t and σ_t, a conjugate uniform-normal-inverse-Whishart prior for the orthogonal reduced-form parametrization. Therefore, **??** and **??** can be rewritten as:

Sign restrictions

$$\begin{aligned}\Gamma(\tilde{\theta}_t) &= (\mathbf{e}_{1,N}'\mathcal{F}(f_h^{-1}(\theta_t, \mathbf{\Sigma}_t, \mathbf{Q}))'\mathbf{S}_1', \dots, \mathbf{e}_{N,N}'\mathcal{F}(f_h^{-1}(\theta_t, \mathbf{\Sigma}_t, \mathbf{Q}))'\mathbf{S}_N')' \\ &= (\mathbf{e}_{1,N}'\mathbf{Q}'\mathcal{F}(f_h^{-1}(\theta_t, \mathbf{\Sigma}_t))'\mathbf{S}_1', \dots, \mathbf{e}_{N,N}'\mathbf{Q}'\mathcal{F}(f_h^{-1}(\theta_t, \mathbf{\Sigma}_t))'\mathbf{S}_N')' \quad > \mathbf{0}\end{aligned}$$

Zero restrictions

$$\begin{aligned}\Xi(\tilde{\theta}_t) &= (\mathbf{e}_{1,N}'\mathcal{F}(f_h^{-1}(\theta_t, \mathbf{\Sigma}_t, \mathbf{Q}))'\mathbf{Z}_1', \dots, \mathbf{e}_{N,N}'\mathcal{F}(f_h^{-1}(\theta_t, \mathbf{\Sigma}_t, \mathbf{Q}))'\mathbf{Z}_N')' \\ &= (\mathbf{e}_{1,N}'\mathbf{Q}'\mathcal{F}(f_h^{-1}(\theta_t, \mathbf{\Sigma}_t))'\mathbf{Z}_1', \dots, \mathbf{e}_{N,N}'\mathbf{Q}'\mathcal{F}(f_h^{-1}(\theta_t, \mathbf{\Sigma}_t))'\mathbf{Z}_N')' \quad = \mathbf{0}\end{aligned}$$

Drawing from the posterior

Given the assumptions on the conjugate prior of the orthogonal reduced-form parametrization, it is possible to make draws from the posterior satisfying a combination of sign and zero restrictions by adding to the sampler in Appendix B.3.1 the following additional steps:

7. For $1 \leq j \leq N$, $\mathbf{x}_j \in \mathbb{R}^{N+1-j-z_j}$ are drawn independently from a standard normal distribution. Then, $\mathbf{w}_j \equiv \mathbf{x}_j/||\mathbf{x}_j||$.

8. Matrix $\mathbf{Q} = [\mathbf{q}_1 \dots \mathbf{q}_N]$ is defined recursively by $\mathbf{q}_j = \mathbf{K}_j\mathbf{w}_j$ for any matrix $\mathbf{K}_j$ whose columns form an orthonormal basis for the null space of the $(j-1+z_j) \times N$ matrix

$$\mathbf{M}_j = \left[\mathbf{q}_1 \dots \mathbf{q}_{j-1}(\mathbf{Z}_j \mathcal{F}(f_h^{-1}(\theta_t, \mathbf{\Sigma}_t, I_N)))'\right]'.$$

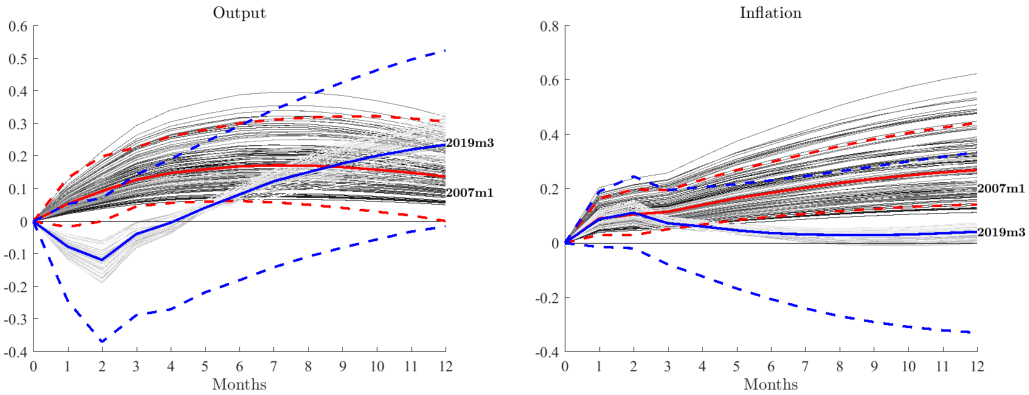
9. The structural parameters are retrieved from $(A_{0,t}, A_t^+) = f_h^{-1}(\theta_t, \mathbf{\Sigma}_t, I_N)$ and the draw is kept if it satisfies the sign restrictions, as defined in **??**, for each $j = 1, \dots, N$.

Steps 4 to 6 in Appendix B.3.1 and, then, 7 to 9 are repeated for each $m = 1, \dots, M$. In our baseline estimation, we set $M = 100000$, with a burn-in of 20000 iterations, for a total of $80000 \times T$ draws.

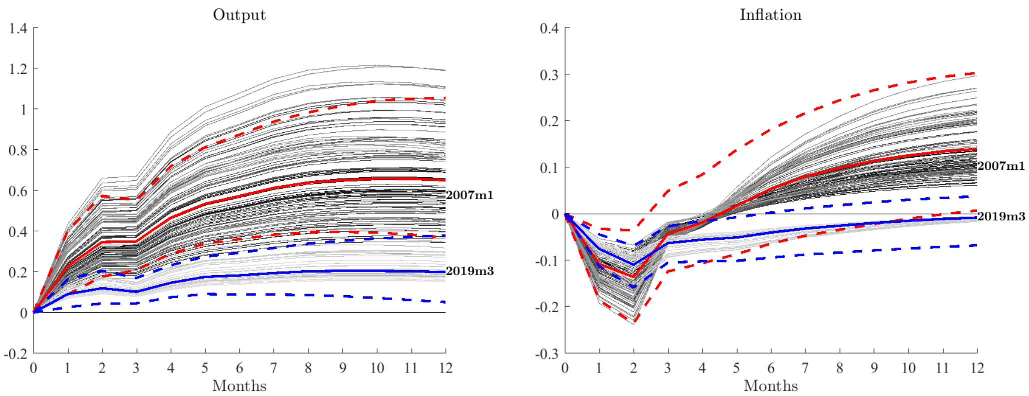
B.4 Additional charts

Figure B.1: Evolution in IRFs of output (left panels) and inflation (right panels) to a decrease in 10-year term spreads by 100bps

(a) Core EA



(b) Peripheral EA



Legend: before June 2014; after June 2014.
Notes: Dashed lines are 68% confidence bands. Lighter gray lines represent more recent periods.
Source: Author's calculations.

C Appendix to Chapter 3

C.1 Data

Table C.1 reports the variables used in our estimations, together with the sources.

The countries included in the panel local projections in Section 3.3 are reported below.

Advanced Economies

Australia, Canada, Denmark, Japan, Norway, Sweden, Switzerland, United Kingdom, United States

Emerging Markets and Developing Economies

Table C.1: Variables and sources

	Sources
Daily SVAR	
EA stress variable[1]	ECB SDW[+]
EA equity price index[2]	ECB SDW
Euro Effective Exchange Rate[3]	ECB SDW
VIX	DataStream
World Equity Price Index (excl. EA)[4]	Bloomberg
US 10-year govât bond yield	Bloomberg
EMBI+ spread (excluding Europe)[5]	Haver Analytics
Monthly Local Projections	
Industrial Production Index	DataStream
Consumer Price Index	Haver Analytics
Imports/Exports	IMF DOTS[*]

Definitions: [1] Average 10-year government bond spread of Italy and Spain against Germany; [2] Dow Jones Euro Stoxx 50 EUR Price Index; [3] Exchange rate against a basket consisting of the currencies of the main 38 EA trading partners (NEER-38); [4] FTSE World Equity price index, excluding Eurobloc; [5] Spread of the yields on emerging market debt over the entire US Treasury curve.
Sources: [+] Statistical Data Warehouse; [*] Direction of Trade Statistics
Notes: monthly series are seasonally adjusted.

Argentina, Brazil, Bulgaria, Chile, China, Czech Republic, Hungary, India, Indonesia, South Korea, Malaysia, Mexico, Peru, Philippines, Poland, Russia, South Africa, Thailand, Turkey

C.2 The Bayesian VAR

The structural VAR in Equation (3.1) can be rewritten in companion form as:

$$A_0 Y_t = A_+ \mathbf{Y}_{t-1} + \varepsilon_t, \tag{C.61}$$

where $A'_+ = [\mathbf{c}', A'_1, \ldots, A'_p]$ is an $m \times n$ matrix and $\mathbf{Y}'_{t-1} = [\mathbf{1}, Y'_{t-1}, \ldots, Y'_{t-p}]$ is an $m \times 1$ vector, with $m = Np + 1$. The reduced-form representation of Equation (C.62) is then:

$$Y_t = B\mathbf{Y}_{t-1} + u_t, \tag{C.62}$$

where $B = A_0^{-1} A_+$, $u_t = A_0^{-1}\varepsilon_t$ and $E[u_t u'_t] = \Sigma = (A_0 A'_0)^{-1}$.

C.2.1 Impulse response functions

Denote as $\mathbf{\Theta}$ the vector of structural coefficients from Equation (C.62): $\mathbf{\Theta} \equiv (A_0, A^+)$. Given this, the response of the ith variable to the jth structural shock at horizon k is the (i, j)th element of matrix $\mathbf{L}_k(\mathbf{\Theta})$ which is defined recursively as:

$$\mathbf{L}_k(\mathbf{\Theta}) = \begin{cases} (A_0^{-1})' & \text{if} \quad k = 0 \\ \sum_{\ell=1}^{k} (A_0^{-1} A_\ell)' \mathbf{L}_{k-\ell}(\mathbf{\Theta}) & \text{if} \quad 1 \leq k \leq p \\ \sum_{\ell=1}^{p} (A_0^{-1} A_\ell)' \mathbf{L}_{k-\ell}(\mathbf{\Theta}) & \text{if} \quad p < k < \infty \end{cases} \tag{C.63}$$

C.2.2 Structural shocks and historical decomposition

Given $\mathbf{\Theta}$, the structural shocks at time t are:

$$\varepsilon_t(\mathbf{\Theta}) = A_0 Y_t - A_+ \mathbf{Y_{t-1}}, \quad \text{for } t = 1, \ldots, T. \tag{C.64}$$

Therefore, the cumulative contribution of the jth shock to the observed changes of the ith variable between t and $t + h$ is given by:

$$H_{i,j,t,t+h}(\mathbf{\Theta}, \varepsilon_t, \ldots, \varepsilon_{t+h}) = \sum_{\ell=0}^{h} \mathbf{e}'_{i,n} \mathbf{L}_\ell(\mathbf{\Theta}) \mathbf{e}_{j,n} \mathbf{L}_\ell(\mathbf{\Theta}) \mathbf{e}_{j,n} \mathbf{e}'_{j,n} \varepsilon_{t+h-\ell}, \quad \text{for } i \geq 1, j \leq N, h \geq 0, \tag{C.65}$$

where $\mathbf{e}_{j,n}$ is the jth column of the identity matrix I_N.

C.3 Traditional sign restrictions

Traditional sign and zero restrictions are imposed following Rubio-Ramírez et al. (2010) and Arias et al. (2018). Notably, such restrictions can be expressed in the following functional form:

$$\Gamma(\mathbf{\Theta}) = (\mathbf{e}'_{1,n} \mathbf{F}(\mathbf{\Theta})' \mathbf{S}'_1, \ldots, \mathbf{e}'_{n,n} \mathbf{F}(\mathbf{\Theta})' \mathbf{S}'_n)' > \mathbf{0}. \tag{C.66}$$

Restrictions on both A_0 and $\mathbf{L}(\mathbf{\Theta})$ are then imposed by appropriately setting $\mathbf{S}_j$ and $\mathbf{F}(\mathbf{\Theta})$ in Equation (C.66). For instance, restrictions on the impulse response functions (IRFs) can be imposed by defining $\mathbf{F}(\mathbf{\Theta})$ as vertically stacking the IRFs at different horizons on which we want to impose restrictions and, then, $\mathbf{S}_j$ as a $s_j \times r_j$ matrix of 0s, 1s and -1s corresponding to the horizons and variables over which to impose the r_j restrictions to identify shock j. For restrictions on A_0, on the other hand, $\mathbf{F}(\mathbf{\Theta}) = \mathbf{\Theta}$ and $\mathbf{S}_j$ is an $s_j \times r_j$ matrix of 0s, 1s and -1s corresponding to the elements of A_0 that needs to be restricted.

C.3.1 Narrative restrictions

The classification and formalization of narrative sign restrictions here adopted is based on Antolín-Díaz and Rubio-Ramírez (2018).

Signs of the structural shocks

The first type of narrative restrictions concerns the signs of the structural shocks in correspondence of particular episodes occurring at known dates. Assume, for instance, that the sign of the jth shock is positive (negative) at s_j episodes at dates $t_1, \ldots, t_{s_j}$. This can be imposed in the SVAR by setting:

$$\mathbf{e}'_{j,n}\varepsilon_{t_\nu}(\boldsymbol{\Theta}) \begin{cases} > 0 \\ (< 0) \end{cases} \text{for } 1 \leq \nu \leq s_j. \tag{C.67}$$

Contributions of the structural shocks

The second class of narrative restrictions relates to the importance that a particular structural shock has at a point in time. Notably, researchers might have additional information indicating that a certain shock has been the most important contributor to the unexpected movements of the variable of interest at well-defined dates. Such information can be incorporated in the model by imposing additional restrictions on the historical decomposition.

This can be done in two ways, by specifying either: (a) that shock j was the most (least) important driver of the unexpected change in a variable during some periods; or (b) that shock j was the overwhelming (negligible) driver of the unexpected change in a variable during some periods. For case (a), the restrictions can be imposed on the historical decomposition as follows:

$$\begin{aligned} &|H_{i_\nu,j,t_\nu,t_\nu+h_\nu}(\boldsymbol{\Theta}, \varepsilon_{t_\nu}(\boldsymbol{\Theta}), \ldots, \varepsilon_{t_\nu+h}(\boldsymbol{\Theta}))| \\ &- \max_{j' \neq j} |H_{i_\nu,j',t_\nu,t_\nu+h_\nu}(\boldsymbol{\Theta}, \varepsilon_{t_\nu}(\boldsymbol{\Theta}), \ldots, \varepsilon_{t_\nu+h}(\boldsymbol{\Theta}))| \end{aligned} \begin{cases} > 0 \\ (< 0) \end{cases} \tag{C.68}$$

for $1 \leq \nu \leq s_j$. For case (b), instead, the restrictions on the historical decomposition become:

$$
\begin{aligned}
&|H_{i_\nu,j,t_\nu,t_\nu+h_\nu}(\boldsymbol{\Theta},\varepsilon_{t_\nu}(\boldsymbol{\Theta}),\ldots,\varepsilon_{t_\nu+h}(\boldsymbol{\Theta}))| \\
&-\sum_{j'\neq j}|H_{i_\nu,j',t_\nu,t_\nu+h_\nu}(\boldsymbol{\Theta},\varepsilon_{t_\nu}(\boldsymbol{\Theta}),\ldots,\varepsilon_{t_\nu+h}(\boldsymbol{\Theta}))| \quad \begin{cases} >0 \\ (<0) \end{cases}
\end{aligned} \tag{C.69}
$$

for $1 \leq \nu \leq s_j$.

C.3.2 Bayesian estimation

The estimation of the model makes use the algorithm proposed in Section III of Antolín-Díaz and Rubio-Ramírez (2018) to estimate the SVAR via Bayesian methods. Notably, the algorithm is an adaptation of the approach proposed by Rubio-Ramírez et al. (2010) and Arias et al. (2018) to take the narrative sign restrictions into account.

Given Equation (C.67), Equation (C.68) and Equation (C.69), narrative sign restrictions can be characterized as:

$$\phi(\boldsymbol{\Theta},\varepsilon^{\nu}) > \mathbf{0}, \tag{C.70}$$

where $\varepsilon^{\nu} = (\varepsilon_{t_1},\ldots,\varepsilon_{t_\nu})$ are the structural shocks constrained by the narrative sign restrictions. Differently from traditional sign restrictions, then, narrative sign restrictions depend on structural shocks as well. By Equation (C.64) above:

$$\varepsilon_t = g_h(Y_t,\mathbf{Y_{t-1}},\boldsymbol{\Theta}) \quad \text{for } 1 \leq t \leq T, \tag{C.71}$$

with $Y_t = g_h^{-1}(\varepsilon_t;\mathbf{Y_{t-1}},\boldsymbol{\Theta})$ for $1 \leq t \leq T$. Combining Equation (C.71) with Equation (C.70) leads to:

$$\tilde{\phi}(\boldsymbol{\Theta},Y^{\nu},\mathbf{Y}^{\nu}_{\mathbf{t-1}}) = \phi(\boldsymbol{\Theta},g_h(Y_{t_1},\mathbf{Y_{t_1-1}},\boldsymbol{\Theta}),\ldots,g_h(Y_{t_\nu},\mathbf{Y_{t_\nu-1}},\boldsymbol{\Theta})) > \mathbf{0} \tag{C.72}$$

where $Y^{\nu} = (Y_{t_1},\ldots,Y_{t_\nu})$ and $\mathbf{Y}^{\nu}_{\mathbf{t-1}} = (\mathbf{Y_{t_1-1}},\ldots,\mathbf{Y_{t_\nu-1}})$. Hence, Equation (C.72) is continuous on the parameters given the data and is continuous on the structural shocks given the parameters.

As in Arias et al. (2018), consider the orthogonal reduced-form parameterization of Equation (C.62), which depends on Σ, B and Q, where $Q \in \mathcal{O}(n)$, the set of all orthogonal $n \times n$ matrices. The mapping from $\boldsymbol{\Theta}$ to (B,Σ,Q) requires a decomposition of Σ, $h(\Sigma)$, satisfying: $h(\Sigma)'h(\Sigma) = \Sigma$, where h is differentiable. Usually, $h(\Sigma)$ is chosen to be the Cholesky decomposition of Σ. Therefore, the mapping between $\mathbf{\Theta}$ and (B, Σ, Q) can be defined as:

$$f_h(\mathbf{\Theta}) = \Big(\underbrace{(A_+ A_0^{-1})}_{B}, \underbrace{(A_0 A_0')^{-1}}_{\Sigma}, \underbrace{h((A_0 A_0')^{-1} A_0)}_{Q} \Big), \tag{C.73}$$

where $h((A_0 A_0')^{-1} A_0)$ is an orthogonal matrix. The inverse of f_h is then:

$$f_h^{-1}(B, \Sigma, Q) = \Big(\underbrace{h(\Sigma)^{-1} Q}_{A_0}, \underbrace{B h(\Sigma)^{-1} Q}_{A_+} \Big). \tag{C.74}$$

Using Equation (C.74), Equation (C.72) can be rewritten as:

$$\mathbf{\Phi}(B, \Sigma, Q, Y^{\nu}, \mathbf{Y}^{\nu}_{\mathbf{t-1}}) = \tilde{\phi}(f_h^{-1}(B, \Sigma, Q), Y^{\nu}, \mathbf{Y}^{\nu}_{\mathbf{t-1}}) > \mathbf{0}.$$

Posterior with traditional sign restrictions

The posterior of (B, Σ, Q) subject to traditional sign restrictions is:

$$\begin{aligned} &\pi(B, \Sigma, Q | \mathbf{Y}^T, \mathbf{\Gamma}(B, \Sigma, Q, Y^{\nu}, \mathbf{Y}^{\nu}_{\mathbf{t-1}})) \\ &= \frac{\overbrace{\pi(\mathbf{Y}^T | B, \Sigma)}^{Likelihood} \overbrace{\pi(B, \Sigma, Q | \mathbf{\Gamma}(f_h^{-1}(B, \Sigma, Q)) > \mathbf{0})}^{Prior}}{\int \pi(\mathbf{Y}^T | B, \Sigma) \pi(B, \Sigma, Q | \mathbf{\Gamma}(f_h^{-1}(B, \Sigma, Q)) > \mathbf{0}) d(B, \Sigma, Q)}, \end{aligned} \tag{C.75}$$

where $\mathbf{Y}^T = \{Y_{1-p}, \ldots, Y_0, \ldots, Y_T\}$. As the likelihood function does not depend on Q and the function characterizing the sign restrictions, $\mathbf{\Gamma}(f_h^{-1}(B, \Sigma, Q))$, does not depend on the structural shocks, traditional sign restrictions simply truncate the prior of (B, Σ, Q).

Posterior with narrative sign restrictions

The posterior of (B, Σ, Q) subject to narrative sign restrictions is:

$$\begin{aligned} &\pi(B, \Sigma, Q | \mathbf{Y}^T, \mathbf{\Phi}(B, \Sigma, Q, Y^{\nu}, \mathbf{Y}^{\nu}_{\mathbf{t-1}})) \\ &= \frac{\overbrace{\pi(\mathbf{Y}^T | B, \Sigma, Q, \mathbf{\Phi}(B, \Sigma, Q, Y^{\nu}, \mathbf{Y}^{\nu}_{\mathbf{t-1}}) > \mathbf{0}))}^{Likelihood} \overbrace{\pi(B, \Sigma, Q)}^{Prior}}{\int \pi(\mathbf{Y}^T | B, \Sigma, Q, \mathbf{\Phi}(B, \Sigma, Q, Y^{\nu}, \mathbf{Y}^{\nu}_{\mathbf{t-1}}) > \mathbf{0}) \pi(B, \Sigma, Q) d(B, \Sigma, Q)}. \end{aligned} \tag{C.76}$$

In this case, the function characterizing the narrative restrictions, $\mathbf{\Phi}(B, \Sigma, Q, Y^{\nu}, \mathbf{Y}^{\nu}_{\mathbf{t-1}})$, depends on the structural shocks, thus implying that narrative sign restrictions truncate the likelihood function.

The truncated likelihood can be rewritten as:

$$\begin{aligned}&\pi(\mathbf{Y}^T|B,\Sigma,Q,\mathbf{\Phi}(B,\Sigma,Q,Y^\nu,\mathbf{Y}^\nu_{\mathbf{t-1}})>\mathbf{0}))\\&=\frac{\left[\mathbf{\Phi}(B,\Sigma,Q,Y^\nu,\mathbf{Y}^\nu_{\mathbf{t-1}})>\mathbf{0}\right]\pi(\mathbf{Y}^T|B,\Sigma)}{\int\left[\mathbf{\Phi}(B,\Sigma,Q,Y^\nu,\mathbf{Y}^\nu_{\mathbf{t-1}})>\mathbf{0}\right]\pi(\mathbf{Y}^T|B,\Sigma)d\mathbf{Y}^T}.\end{aligned}\tag{C.77}$$

In addition, the denominator of Equation (C.77) is:

$$\begin{aligned}&\int\left[\mathbf{\Phi}(B,\Sigma,Q,Y^\nu,\mathbf{Y}^\nu_{\mathbf{t-1}})>\mathbf{0}\right]\pi(\mathbf{Y}^T|B,\Sigma)d\mathbf{Y}^T\\&=\int\left[\mathbf{\Phi}(B,\Sigma,Q,Y^\nu,\mathbf{Y}^\nu_{\mathbf{t-1}})>\mathbf{0}\right]\left(\prod_{t=1}^T\pi(Y_t|\mathbf{Y_{t-1}},B,\Sigma)\right)d(Y_1,\ldots,Y_T)\\&=\int\left[\tilde{\mathbf{\Phi}}(B,\Sigma,Q,\varepsilon^\nu)>\mathbf{0}\right]\left(\prod_{t=1}^T\frac{\pi(g_h^{-1}(\varepsilon_t;\mathbf{Y_{t-1}},f_h^{-1}(B,\Sigma,Q))|\mathbf{Y_{t-1}},B,\Sigma)}{\upsilon_{g_h}(g_h^{-1}(\varepsilon_t;\mathbf{Y_{t-1}},f_h^{-1}(B,\Sigma,Q)))}\right)d(\varepsilon_1,\ldots,\varepsilon_T)\end{aligned},$$

where $\tilde{\mathbf{\Phi}}(B,\Sigma,Q,\varepsilon^\nu)=\phi(f_h^{-1}(B,\Sigma,Q,\varepsilon^\nu)$ and υ_{g_h} is the volume of function g_h evaluated at $g_h^{-1}(\varepsilon_t;\mathbf{Y_{t-1}},f_h^{-1}(B,\Sigma,Q))$. By Equation (C.71):

$$\upsilon_{g_h}(g_h^{-1}(\varepsilon_t;\mathbf{Y_{t-1}},f_h^{-1}(B,\Sigma,Q)))=|\Sigma|^{-1/2}\quad\text{for } 1\leq t\leq T.$$

It follows that:

$$\begin{aligned}&\int\left[\tilde{\mathbf{\Phi}}(B,\Sigma,Q,\varepsilon^\nu)>\mathbf{0}\right]\left(\prod_{t=1}^T\frac{\pi(g_h^{-1}(\varepsilon_t;\mathbf{Y_{t-1}},f_h^{-1}(B,\Sigma,Q))|\mathbf{Y_{t-1}},B,\Sigma)}{\upsilon_{g_h}(g_h^{-1}(\varepsilon_t;\mathbf{Y_{t-1}},f_h^{-1}(B,\Sigma,Q)))}\right)d(\varepsilon_1,\ldots,\varepsilon_T)\\&=\int\left[\tilde{\mathbf{\Phi}}(B,\Sigma,Q,\varepsilon^\nu)>\mathbf{0}\right](\prod_{t=1}^T(\varepsilon_t)d(\varepsilon_1,\ldots,\varepsilon_T)\\&=\int\left[\tilde{\mathbf{\Phi}}(B,\Sigma,Q,\varepsilon^\nu)>\mathbf{0}\right](\prod_{s=1}^\nu(\varepsilon_{t_s})d(\varepsilon_{t_1},\ldots,\varepsilon_{t_\nu}).\end{aligned}\tag{C.78}$$

By using Equation (C.78), Equation (C.77) can be rearranged as:

$$\begin{aligned}&\pi(\mathbf{Y}^T|B,\Sigma,Q,\mathbf{\Phi}(B,\Sigma,Q,Y^\nu,\mathbf{Y}^\nu_{\mathbf{t-1}})>\mathbf{0}))\\&=\frac{\left[\mathbf{\Phi}(B,\Sigma,Q,Y^\nu,\mathbf{Y}^\nu_{\mathbf{t-1}})>\mathbf{0}\right]\pi(\mathbf{Y}^T|B,\Sigma)}{\omega(B,\Sigma,Q)},\end{aligned}\tag{C.79}$$

where $\omega(B,\Sigma,Q)=\int\left[\tilde{\mathbf{\Phi}}(B,\Sigma,Q,\varepsilon^\nu)>\mathbf{0}\right]\left(\prod_{s=1}^\nu(\varepsilon_{t_s})\right)d(\varepsilon_{t_1},\ldots,\varepsilon_{t_\nu})$.

Therefore, the truncated likelihood can be simply formulated as a weighted likelihood, with weights that are inversely proportional to the probability of satisfying the narrative restriction.

Posterior with both traditional and narrative sign restrictions

By assuming a normal-inverse-Wishart-uniform prior for (B,Σ,Q), it follows that $\pi(B,\Sigma,Q) = \pi(B,\Sigma)$. Therefore, the posterior subject to, respectively, traditional and narrative sign restrictions becomes:

Traditional sign restrictions

$$\pi(B,\Sigma,Q|\mathbf{\Gamma}(f_h^{-1}(B,\Sigma,Q)) > \mathbf{0}) \propto \left[\mathbf{\Gamma}(f_h^{-1}(B,\Sigma,Q)) > \mathbf{0}\right] \pi(\mathbf{Y^T}|B,\Sigma)\pi(B,\Sigma)$$

Narrative sign restrictions

$$\pi(B,\Sigma,Q|\mathbf{Y^T},\mathbf{\Phi}(B,\Sigma,Q,Y^\nu,\mathbf{Y^\nu_{t-1}}) > \mathbf{0}) \propto \frac{\left[\mathbf{\Phi}(B,\Sigma,Q,Y^\nu,\mathbf{Y^\nu_{t-1}}) > \mathbf{0}\right] \pi(\mathbf{Y}^T|B,\Sigma)}{\omega(B,\Sigma,Q)}\pi(B,\Sigma).$$

Consequently, the posterior of (B,Σ,Q), subject to both traditional and narrative sign restrictions, is:

$$\begin{aligned} &\pi(B,\Sigma,Q|\mathbf{\Gamma}(f_h^{-1}(B,\Sigma,Q)) > \mathbf{0}, \mathbf{\Phi}(B,\Sigma,Q,Y^\nu,\mathbf{Y^\nu_{t-1}}) > \mathbf{0}) \\ &\propto \left[\mathbf{\Gamma}(f_h^{-1}(B,\Sigma,Q)) > \mathbf{0}\right] \frac{\left[\mathbf{\Phi}(B,\Sigma,Q,Y^\nu,\mathbf{Y^\nu_{t-1}}) > \mathbf{0}\right] \pi(\mathbf{Y}^T|B,\Sigma)}{\omega(B,\Sigma,Q)}\pi(B,\Sigma). \end{aligned} \tag{C.80}$$

Algorithm to draw from the posterior

Given the normal-inverse-Wishart-uniform priors and posteriors for (B,Σ,Q), the algorithm used to independently draw from the posterior under both traditional and narrative sign restrictions consists of the following steps:

1. Independently draw (B,Σ) from the normal-inverse-Wishart posterior of the reduced-form parameters and Q from the uniform distribution over $\mathcal{O}(n)$.
2. Check whether $\mathbf{\Gamma}(f_h^{-1}(B,\Sigma,Q)) > \mathbf{0}$ and $\mathbf{\Phi}(B,\Sigma,Q,Y^\nu,\mathbf{Y^\nu_{t-1}}) > \mathbf{0}$ are satisfied.
3. If not, discard the draw. Otherwise set the importance weight of (B,Σ,Q) as follows:
   (a) Take N independent draws of ε^ν from the standard normal distribution.
   (b) Approximate $\omega(B,\Sigma,Q)$ as the proportion of N satisfying $\tilde{\mathbf{\Phi}}(B,\Sigma,Q,\varepsilon^\nu) > \mathbf{0}$ and set the importance weight to $1/\omega(B,\Sigma,Q)$.
4. Return to step 1 until the required number of draws has been reached.
5. Draw with replacement from the set of (B,Σ,Q) using the importance weights computed in step 3b.

C.4 Robustness checks

C.4.1 Sample coverage

In this section Equation (3.4) is re-estimated over a panel of countries that excludes (non-EA) EU members as of July 2019. Results, reported in Table C.2 and displayed in Figures C.1 and C.2 below, are not statistically different from what already discussed in Section 3.3.1. The analysis is then found robust to the presence of these countries in the sample.

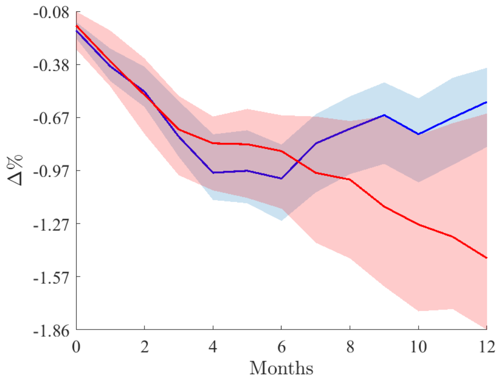
Table C.2: Maximum impact of euro area stress and global risk aversion shocks

Shock \ Variable	IP	Inflation	Exports to		Imports from	
			EA	RoW	EA	RoW
Extra-EU Advanced Economies						
EA	-1.02%	-0.27pps	-3.29%	-2.28%	-1.57%	-1.94%
	(6)*	(9)	(10)	(7)	(3)	(5)
Global	-1.46%	-0.16pps	-4.14%	-3.78%	-2.76%	-3.81%
	(12)	(10)	(12)	(12)	(12)	(11)
Extra-EU Emerging Markets						
EA	-0.48%	-0.45pps	-2.79%	-2.01%	-1.35%	-1.28%
	(2)	(9)	(10)	(3)	(3)	(5)
Global	-1.06%	-0.16pps	-3.04%	-2.91%	-2.50%	-2.38%
	(12)	(12)	(12)	(12)	(12)	(12)

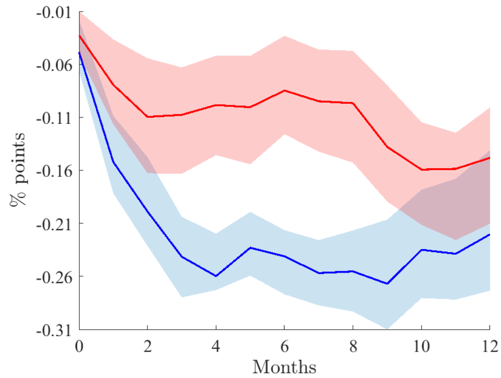
Notes: * Numbers in parentheses represent the amount of months after a shock has taken place.

Figure C.1: **Extra-EU Advanced economies** - Impulse responses to a positive one s.d. euro stress shock (blue) and a positive one s.d. global risk aversion shock (red)

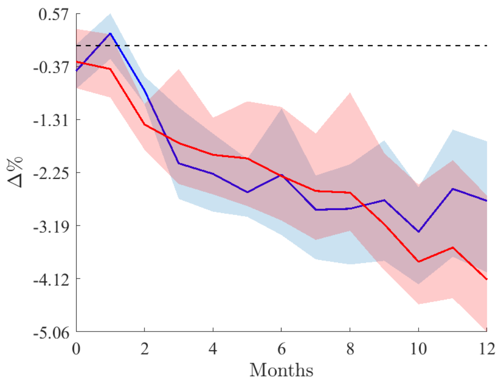
(a) Industrial production



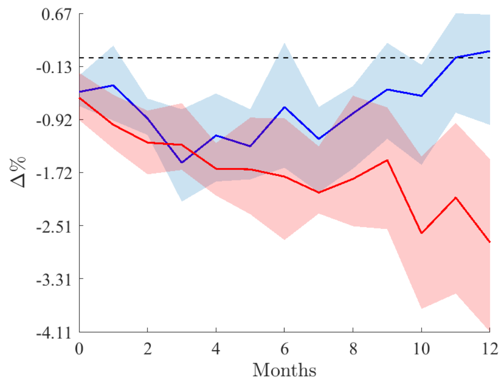
(b) Inflation



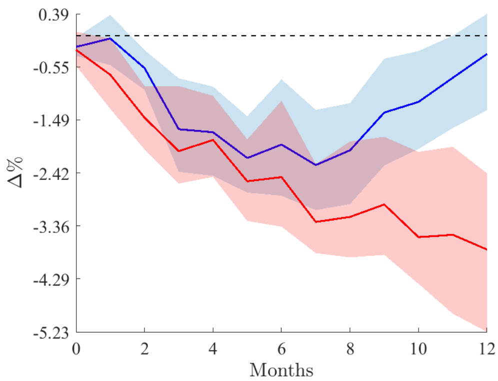
(c) Exports to euro area



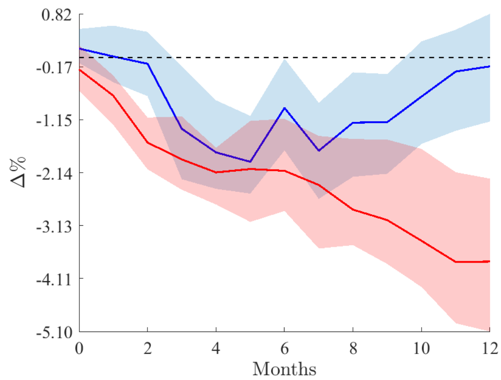
(d) Imports from euro area



(e) Exports to RoW



(f) Imports from RoW

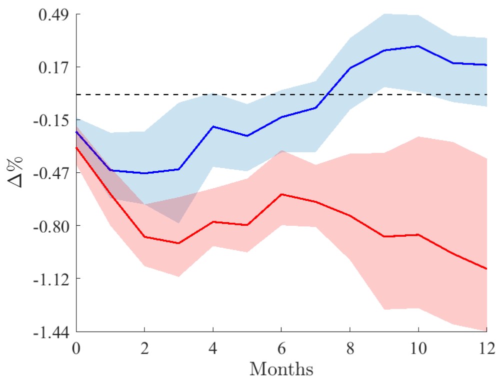


Notes: Inflation is defined as the y-o-y percentage change of the CPI. Δ%: log-change. Shaded areas are 68% confidence bands.

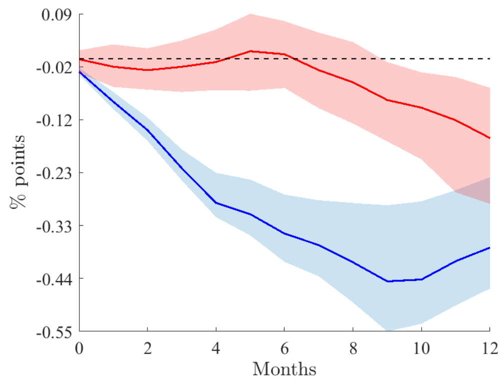
Source: Authors' calculations.

Figure C.2: **Extra-EU Emerging and developing economies** - Impulse responses to a positive one s.d.euro area stress shock (blue) and a positive one s.d. global risk aversion shock (red)

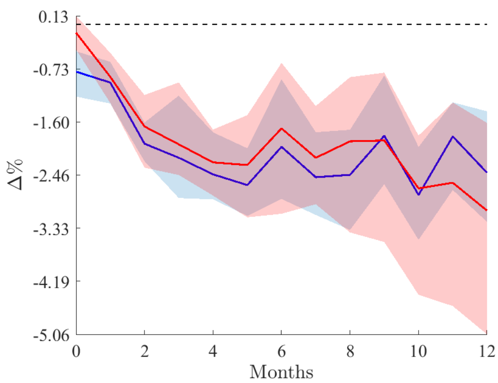
(a) Industrial production



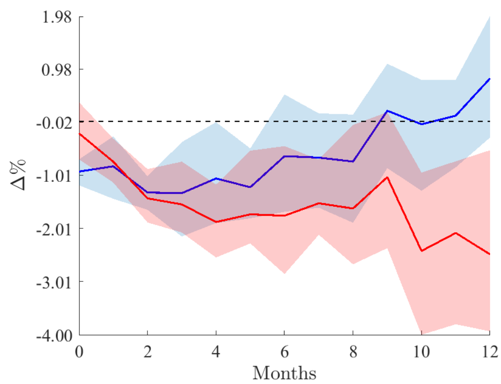
(b) Inflation



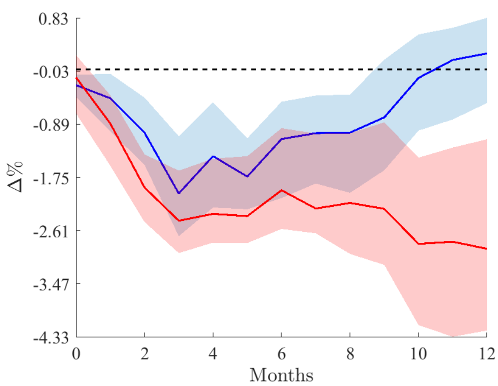
(c) Exports to euro area



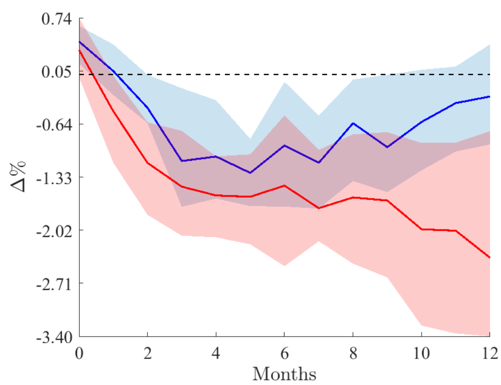
(d) Imports from euro area



(e) Exports to RoW



(f) Imports from RoW



Notes: Inflation is defined as the y-o-y percentage change of the CPI. Δ%: log-change. Shaded areas are 68% confidence bands.
Source: Authors' calculations.