WORKING paper

BANQUE DE FRANCE
EUROSYSTÈME

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

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September 2021, WP #829

ABSTRACT

This paper 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 financial crisis. With this purpose, we first document 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 signaling channel after the "Whatever it takes" speech in July 2012. However, we also provide evidence of a great degree of heterogeneity across core and peripheral economies, as well as over time. We then adopt a time-varying SVAR with stochastic volatility to account for such heterogeneity, by identifying UMP shocks via "dynamic" sign restrictions. By means of counterfactual experiments, we provide evidence of how a different stance on the part of the ECB would have led to a significantly different economic performance of euro area economies. For instance, if the ECB had not put in place the measures adopted between 2014 and 2017, annual output growth would have been, on average, 0.67 percentage points lower in peripheral countries.

Keywords: Time-varying Bayesian SVAR, Dynamic Restrictions, Unconventional Monetary policy, Eurozone

JEL classification : C11, C32, E43, E52

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This paper is based on the second chapter of my PhD thesis. I thank Michael Bordo, John Landon-Lane,Andy Filardo, Marek Jarociński, Barbara Rossi, Livio Stracca, Massimo Ferrari, Adrian Penalver, Giulia Sestieri, Christoph Grosse Steffen, Florens Odendhal, Julia Schmidt and seminar participants at the Banque de France, the 2020 Central Bank Macroeconomic Modelling Workshop, the 61th Annual Meeting of the Italian EconomistsSociety, the 22nd INFER Annual Conference, the 9th Italian Congress of Econometrics and Empirical Economics and the 37th International Conference of the French Finance Association for useful discussion and suggestions.

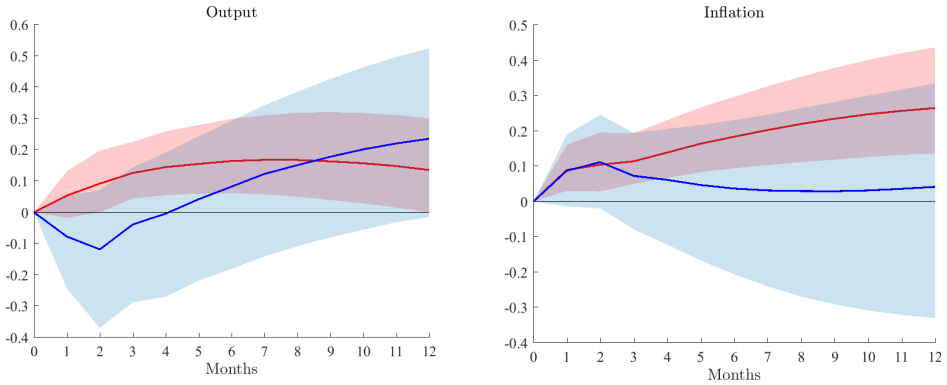
NON-TECHNICAL SUMMARY

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. As central bank balance sheets have increasingly become the most important monetary policy instrument (Gambacorta et al. (2014)), it becomes important to assess whether and how UMPs have impacted the real economy. In this regard, 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.

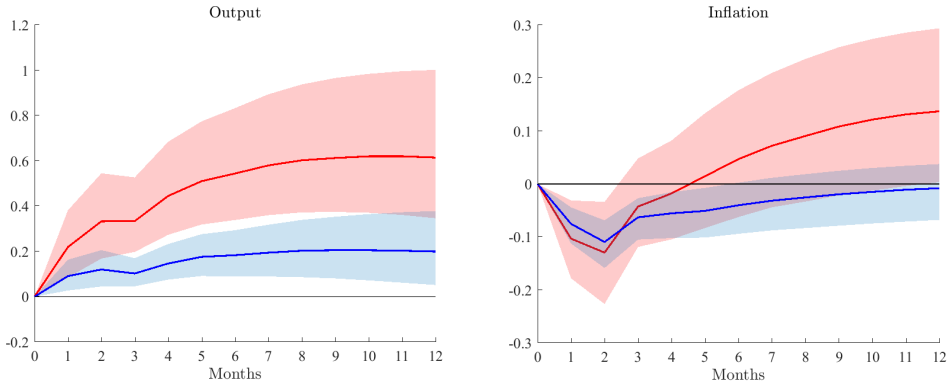
As to the transmission of UMPs to financial and economic activity, the literature has mainly focused on the interest rate channel, which, in turn, can be broken down in two main components: 1) *portfolio rebalancing*, which operates through changes in the term premia of target assets; 2) *signaling*, that relates to the ability of the central bank to shape expectations about the future path of interest rates. The present paper provides three contributions to the existing literature: i) it documents the relative importance of the portfolio rebalancing and signaling channels and assessing whether it has changed over time in the euro area (EA henceforth); ii) it produces evidence of the strong heterogeneity between core and peripheral euro area economies; iii) it shows that ECB's UMPs have sustained the economic performance of peripheral economies.

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

a) Core euro area



b) Peripheral euro area



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

Portfolio rebalancing and signaling channels are identified by decomposing the sovereign yields of core and peripheral euro area members in two main subcomponents: i) a term premium; ii) a risk-neutral or expectation component. 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 signaling channel being much stronger in the peripheral economies compared to the core countries. These dynamics have radically changes after the zero-lower bound (ZLB) kicked-in in June 2014.
We leverage on these stylized facts to identify UMP shocks in a structural Vector Autoregressive model with time-varying parameters and stochastic volatility (TVP-SVAR-SV). The structural identification is based on zero and sign restrictions which are at once group and time-contingent ("dynamic"), as they change across core and peripheral countries as well as before and after June 2014. We show that the macroeconomic impact of ECB's UMPs has significantly declined over time, above all in core economies. Moreover, the same measures are found to exert a more meaningful impact on the output of peripheral members, whereas the economic performance of core members is affected through inflation only.
Finally, we set up a counterfactual experiment to assess the impact on macroeconomic aggregates of the set of UMPs implemented by the ECB over the period 2014-2017. Results show that, absent these measures, annual output growth of peripheral economies would have been significantly lower (-0.67pps).

Une taille unique (non conventionnelle) convient-elle à tous ? Effets des politiques monétaires non conventionnelles de la BCE sur les économies de la zone euro

RÉSUMÉ

Ce document vise à évaluer l'impact macroéconomique des politiques monétaires non conventionnelles (PMNC) que la BCE a mises en place dans la zone euro après la crise financière de 2007. Dans ce but, nous documentons d'abord comment l'importance relative des principaux canaux de transmission de ces mesures a changé au fil du temps, le rééquilibrage de portefeuille ayant généralement plus d'impact que le canal de signalisation après le discours "Whatever it takes" de juillet 2012. Cependant, nous fournissons également des preuves d'un grand degré d'hétérogénéité entre les économies centrales et périphériques, ainsi que dans le temps. Nous adoptons ensuite un SVAR variable dans le temps avec une volatilité stochastique pour tenir compte de cette hétérogénéité, en identifiant les chocs PMNC via des restrictions de signe "dynamiques". Au moyen d'expériences contrefactuelles, nous démontrons comment une position différente de la BCE aurait conduit à une performance économique significativement différente des économies de la zone euro. Par exemple, si la BCE n'avait pas mis en place les mesures adoptées entre 2014 et 2017, la croissance de la production aurait été, en moyenne, inférieure de 0,67 point de pourcentage dans les pays périphériques.

Mots-clés : SVAR bayésien variant dans le temps, restrictions dynamiques, politique monétaire non conventionnelle, zone euro.

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

[1] See Buiter (2008, 2010).

[2] Appendix A 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).

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 (2020)). 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 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

[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

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 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[5].

The present paper 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)), others adopt time-varying approaches without isolating the transmission channels (Baumeister and Benati (2013), Gambetti and Musso (2017), 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)). Burriel and Galesi (2018), on the other hand, adopt a framework (Global VAR) which can account for cross-country heterogeneity and interdependecies across the euro area economies. Moreover, they run the model over different time samples, thus providing evidence of time variation in the results. However, the model is not devised to assess the different transmission mechanisms.
The remainder of the paper is structured as follows. Section 2 discusses the transmission channels of unconventional monetary policy measures, discusses their theoretical underpinning

central bank intermediation are modest in a dynamic stochastic general equilibrium (DSGE) setting. Cahn et al. (2017) and Mouabbi and Sahuc (2019) 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.

[5]These mechanisms are extensively discussed in Appendix A below.

and reviews the related literature.

Section 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 zero lower bound (ZLB) 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 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 ZLB kicked in.

In light of these results, Section 4.2.1 assesses whether a different monetary policy path would have entailed a significantly different economic performance 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. A similar exercise is then performed to assess the impact of UMPs implemented over the period 2014-2017. Results show that, absent these measures, output growth of peripheral economies would have been significantly lower (-0.67pps).

Finally, Section 5 concludes.

2 The transmission channels of UMPs

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 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[6]. These can then be interpreted as the two above mentioned channels. Notably, the non-policy bloc of the model is given by:

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

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

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 (1a), known as the (forward-looking) New Keynesian Phillips Curve, and Equation (1b), the (forward-looking) Dynamic IS Curve, are then complemented

[6]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)).

with a monetary policy rule that closes the model[7].

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 (2020)) and also the natural rate of interest, r_t^n. This is even more so in the case of UMP announcements (Nakamura and Steinsson (2018), Andrade and Ferroni (2020)).

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:

$$y_{L,t} = \frac{1}{L}\mathbb{E}_t \sum_{l=0}^{L-1} y_{1,t+l} + tp_{L,t}, \tag{2}$$

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[8].

2.1 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[9]. 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

[7] Refer to Galí (2015) for details.
[8] See Lloyd (2017).
[9] See, for instance, Vayanos and Vila (2009).

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)). However, the results of the event study in Section 3.2 around forward guidance announcements by the ECB seem not to support this possibility.

Based on Krugman et al. (1998) and Eggertsson and Woodford (2003), where the case 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[10]. 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 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[11]. Un-

[10] For a discussion, refer also to Peersman (2014).
[11] See Woodford (2003).

certainty around both monetary policy and economic performance is indeed particularly relevant as regards the effective transmission of UMPs, as highlighted by Husted et al. (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%)[12].

2.3 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, Giannone et al. (2012) focus on the monetary measures implemented by the ECB until 2011 and show that the ECB's intervention in the money market has had a signicant effect on credit markets more widely and indirectly on economic activity in the euro area. By considering also the interventions that took place after 2011, 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[13]. 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).

[12]For additional evidence on the signalling channel, see also Bhattarai et al. (2015) and Engen et al. (2015).
[13]On the international spillovers of UMPs, see Feldkircher and Huber (2016), Neely (2015) and Fratzscher et al. (2018).

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 Euro-zone, euro area economies are sorted into two groups of countries: core EA and peripheral EA members. Aggregate yield curves are then constructed accordingly[14].

3.1 Decomposition of the yield curve

On the basis of Equation (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):

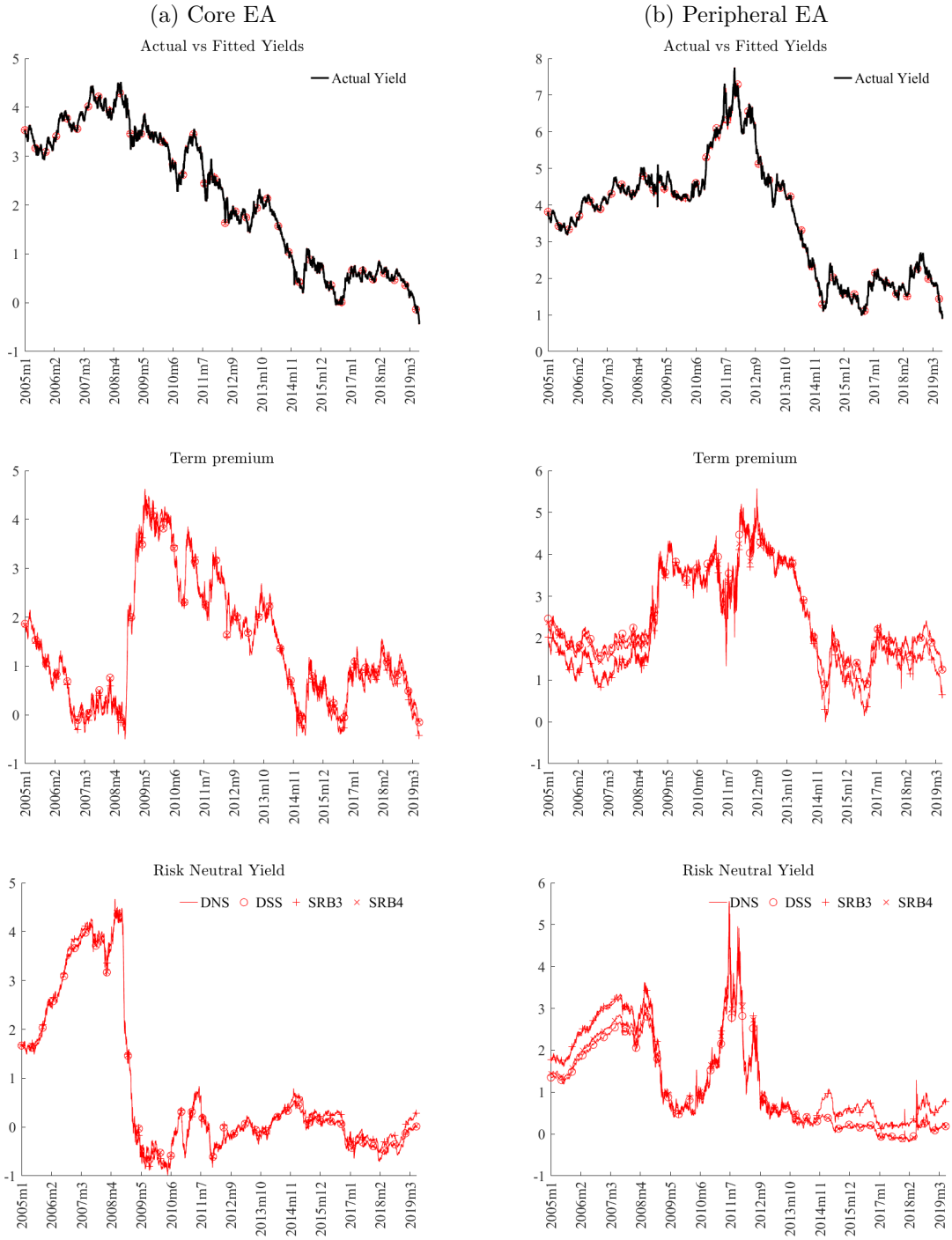
1) the Dynamic Nelson-Siegel model (DNS) à la Diebold and Li (2006);
2) the Dynamic Svensson-Söderlind (DSS), which is the 4-factor model in Diebold and Li (2006);
3) the Short-Rate Based 3 and 4-factor models (SRB3-SRB4) as in Nyholm (2018, 2020).

Models are estimated for the government bond yields of core and peripheral EA economies at maturities from 1 to 10 years. Figure 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 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.

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

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 pre-

Figure 1: Decomposition of daily 10-year government bond yields from 3 January 2005 to 31 July 2019.



Legend: DNS; DSS SRB3; SRB4.

liminary 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. This is indeed a commonly used measure to approximate for market expectations on interest rates out to the 1-year horizon (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 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 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.

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 paper will be based on the results provided by the SRB4 model.

3.2 Proxy for UMP shocks in the euro area

The evidence on the decomposition of the yield curve in Section 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). These announcements can be classified according to the taxonomy discussed in Appendix A, 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 3 depicts the daily changes in fitted yields, term premia and risk-neutral yields for core and peripheral EA around all UMPs announcements (Figure 3a), announcements on balance sheet and credit policies (Figures 3b and 3c) and events of forward guidance on both interest rates and balance sheet policies (Figure 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 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 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.

Table 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	"Regarding non-standard monetary policy measures, [...] monthly asset purchases of EUR 80 billion are intended to run [...] in any case until the Governing Council sees a sustained adjustment in the path of inflation consistent with its inflation aim. [...] on 8 June we will start making purchases under our corporate sector purchase programme (CSPP)."
15	14/06/2018	End of APP net purchases	F+L	"[..] after September 2018[...], we will reduce the monthly pace of the net asset purchases to EUR 15 billion until the end of December 2018 and then end net purchases."
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.

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

3.2.1 Event study

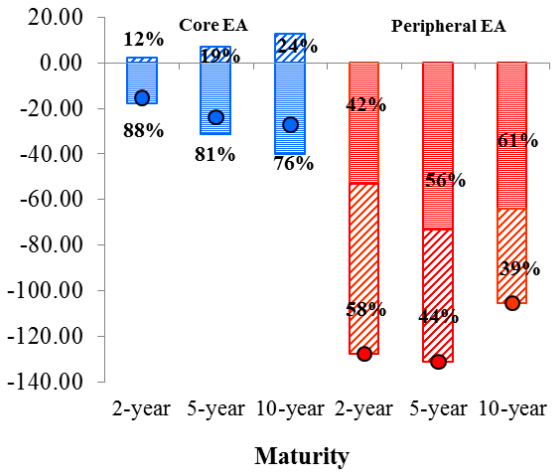
The present section complements the empirical evidence discussed so far. The changes in spreads around events, indeed, might be also affected by factors other than monetary policy. We then perform an event study for the daily changes in actual spreads, Δy_t, fitted spreads, $\Delta \hat{y}_t$, term premium spreads, ΔTP_t, and risk-neutral spreads, Δer_t for 2, 5 and 10-year government bonds on each of the 16 event dates. Notably, we run the following regression:

$$\Delta x_{n,t} = \alpha_{x,n} + \mathbf{Event}_t \beta_{x,n} + \mathbf{D}_t \gamma_{x,n} + \varepsilon_{x,n,t}, \tag{3}$$

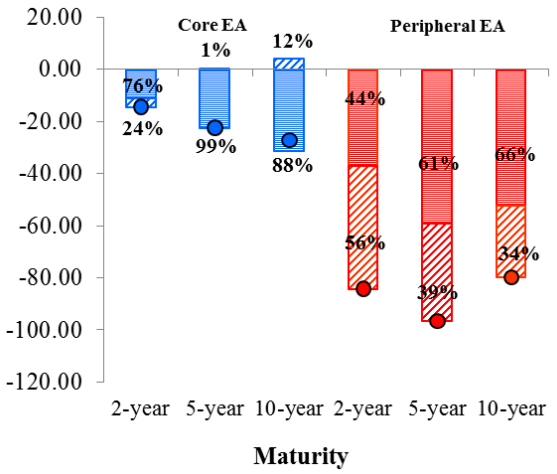
where $\Delta x_{n,t} = \{\Delta y_{n,t}, \Delta \hat{y}_{n,t}, \Delta TP_{n,t}, \Delta er_{n,t}\}$, n is the maturity and $\mathbf{Event}_t$ is a 1×16 vector of dummy variables that refer to the UMPs announcements reported in Table 2. Such dummies are set equal to 1 on the date of the announcement they are linked to and 0 otherwise. In addition, the right hand side of Equation (3) includes a $1 \times (K + P)$ matrix of control variables,

Figure 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.

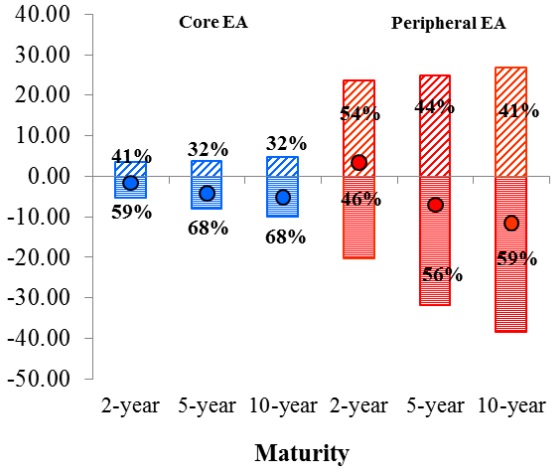
(a) All announcements



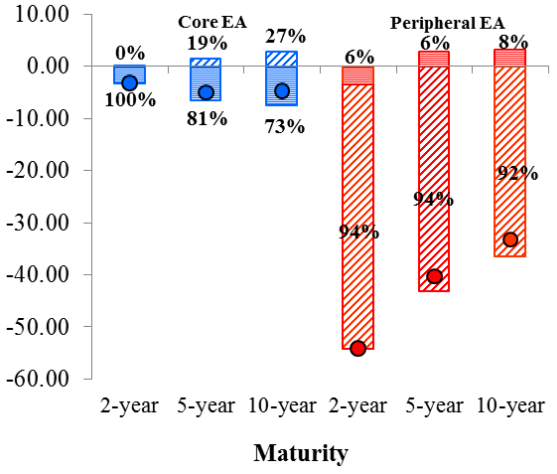
(b) Balance sheet policies



(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.

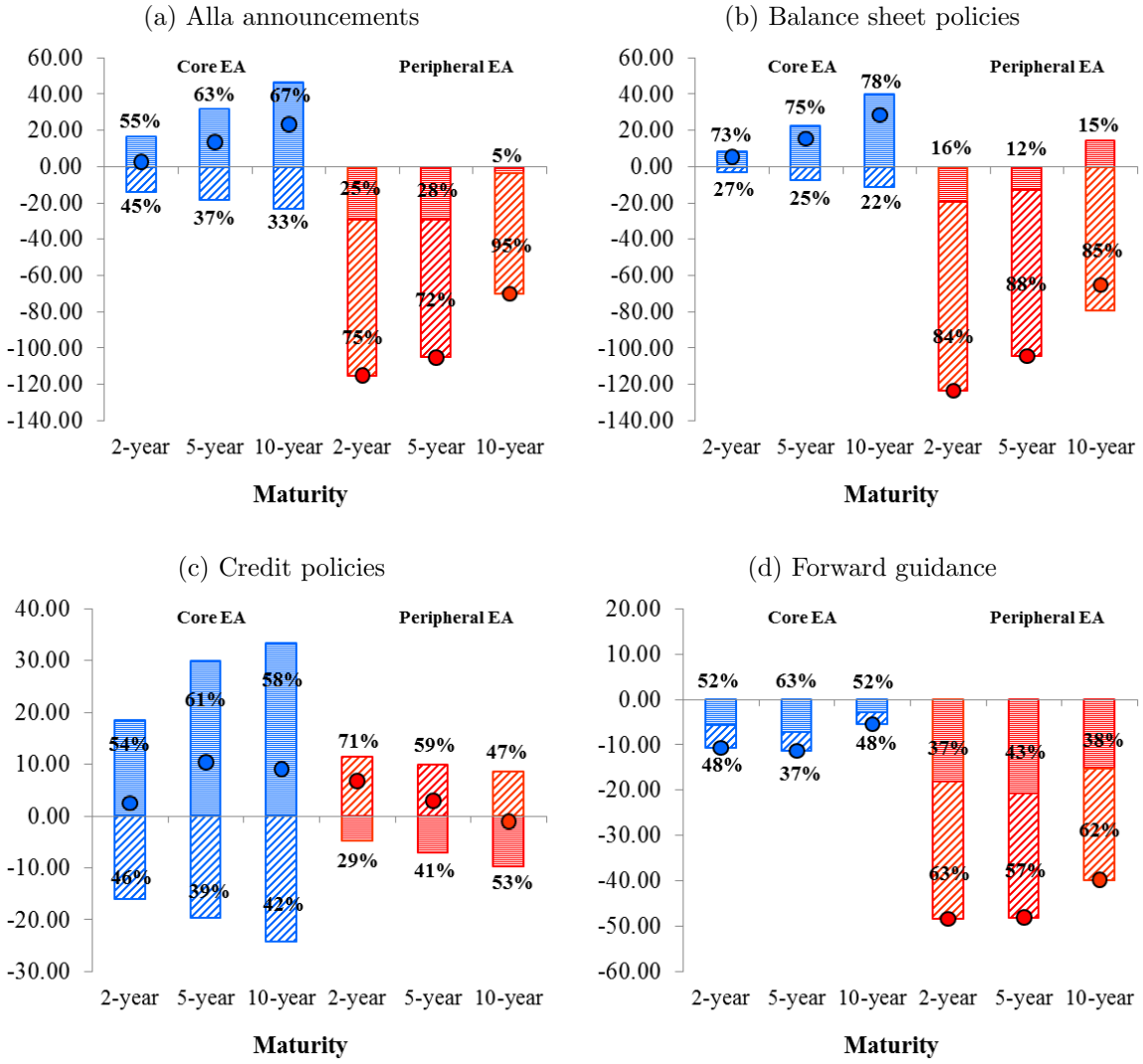
$\mathbf{D}_t$, that is partitioned as:

$$\mathbf{D}_t = \left[\mathbf{R}_t \,\middle|\, \mathbf{P}_t \right],$$

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, Ireland, Portugal and Spain, and 0 otherwise[15]. 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

[15]These events have created tensions in the government bond markets of the euro area that have often triggered interventions by the ECB (see Ioannou et al. (2020)).

Figure 3: Cumulative changes of yields, term premia and expectation components for 2, 5 and 10-year maturities for all the UMPs events.



Legend: for 2, 5 and 10-year maturities for all the UMPs events in Table 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.

Product, Unemployment Rate, Industrial Production and Consumer Confidence Index[16].

The parameter of interest in Equation (3) is the 1×16 vector $\beta_{x,n}$, whose i-th element 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

[16] 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) is also estimated using this different definition. Results are not significantly different.

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 $\mathbf{Event}_t$ has a cumulative significant impact on x at n-year maturity. Figure 4 displays the estimated coefficients for spreads and their subcomponents at 2 (Figure 4a), 5 (Figure 4b) and 10-year (Figure 4c) maturities for each single event in the set. Figure 5, on the other hand, depicts the cumulative estimates broken down by the different types of announcements[17].

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, 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 7c). 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 7b); ii) for the decrease of 2-year spreads around forward guidance events (Figure 7d).

In light of the apparent time variation in the reaction of spreads to UMPs announcements, Equation (3) is re-run by splitting the announcements sample before and after the London speech on 26 July 2012. Figure 6 reports the significant cumulative changes for all the events before (Figure 6a) and after (Figure 6b) that date. Besides a marked reduction in the level shifts for both core and peripheral EA spreads, 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[18]. This finding might be also due to the ECB's decision to implement a negative deposit rate as of June 2014 and hit the zero-lower-bound (ZLB). Splitting the announcements sample by that date leads to slightly different results, with risk-neutral spreads increasing in both core and

[17] The charts are based on the results reported in Tables C.3 to C.7 in Appendix C below.
[18] This is in line with part of the existing literature (e.g., Altavilla et al. (2015)).

peripheral EA around UMPs announcements from 2014 onward (Figure 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[19];
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.

3.2.2 Additional explaining factors

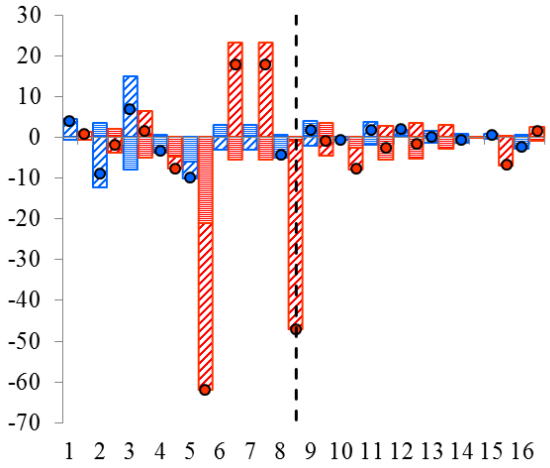
It might be argued that the decomposition of spreads by TSMs model is not suitable to account for some drivers that could contaminate the identification of the rebalancing and signalling channels. Namely, Krishnamurthy et al. (2017) identify two additional factors that can influence the behavior of spreads, especially in peripheral euro area: redenomination risk and credit risk. In order to control for these drivers, we expand Section 3.2 by including two additional variables among the regressors: i) a redenomination risk index (RDR), which is computed as the 5-year quanto CDS spreads vis-à-vis Germany; ii) the 5-year CDS spreads of the banking sector[20]. In addition, we also include an additional regressor that is aimed at capturing possible perturbations in bond markets related to uncertainty and financial stress, namely the VSTOXX index. Results are qualitatively very similar to those discussed in the previous sections, thus proving to be robust to the effect of redenomination/credit risks, as well as uncertainty and financial stress (Table C.8 and Figure 7).

[19] 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.

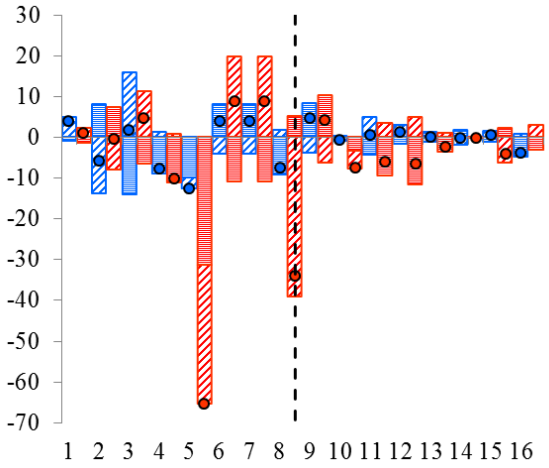
[20] Following De Santis (2019), the proxy for redenomination risk is based on quanto CDS, which are defined as the differences between the price of a sovereign CDS in local currency (euro) and the same instrument's price denominated in US dollars. For each country, we take the spread of quanto CDS against its German equivalent. Finally, we aggregate the country-level spreads via a weighted average using the shares of the general government consolidated debt as weights.

Figure 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.

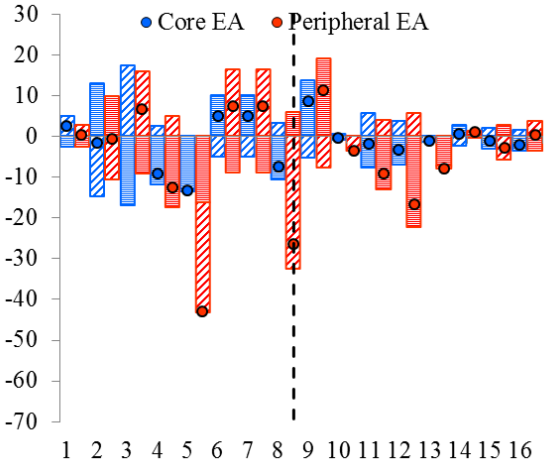
(a) 2-year spreads



(b) 5-year spreads



(c) 10-year spreads

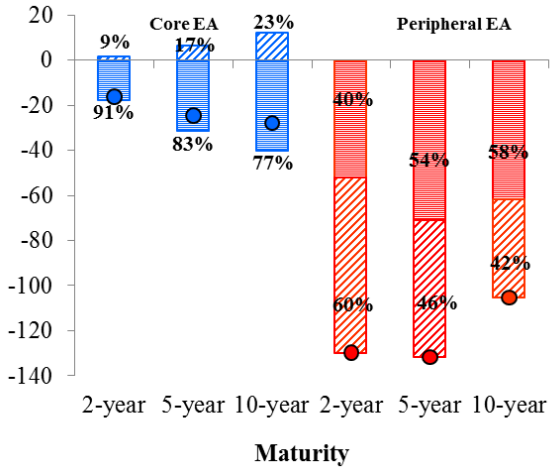


Notes: All figures are in basis points. The events are reported on the x-axis numbered as in Table 2.

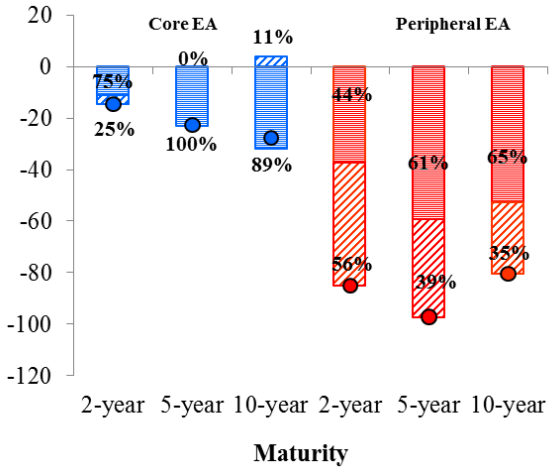
Legend: Core EA; Peripheral EA; London Speech (26 July 2012); fitted spread; term premium spread; expectation component spread.

Figure 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.

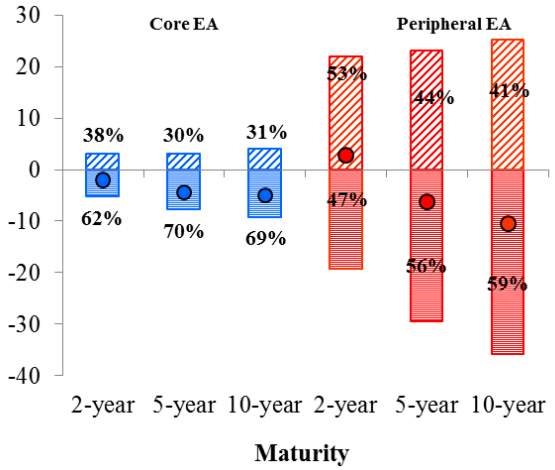
(a) All announcements



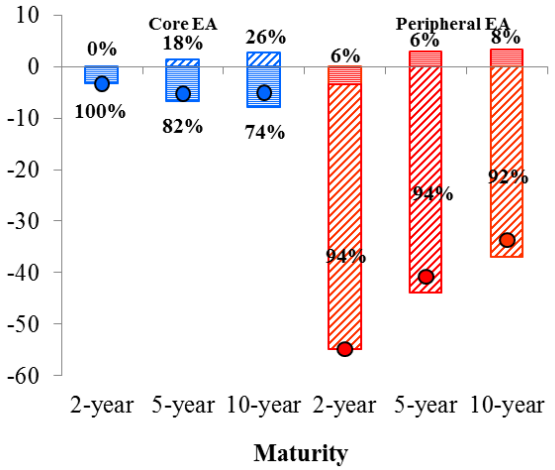
(b) Balance sheet policies



(c) Credit policies



(d) Forward guidance

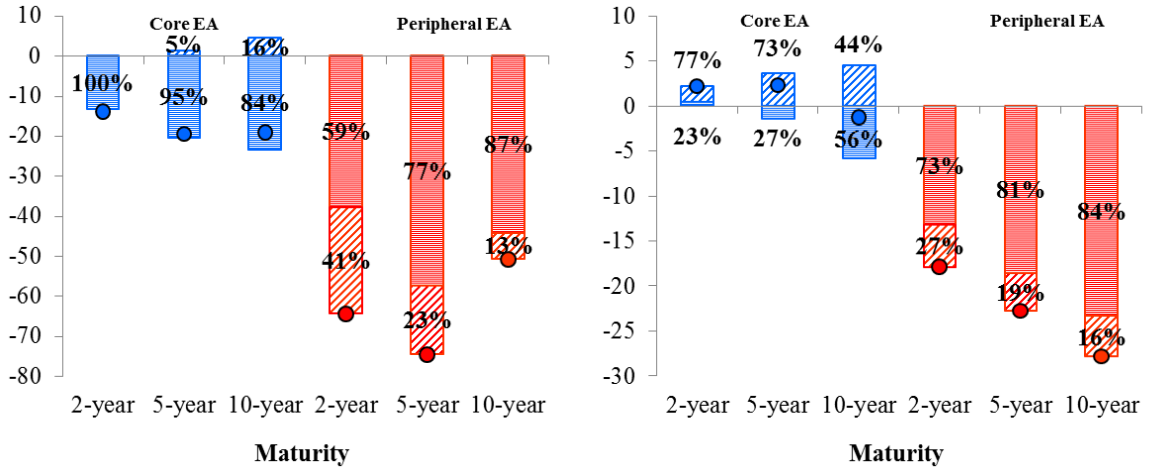


Notes: All figures are in basis points. Percentage figures indicate the share of total change due to changes in the subcomponents.
Legend: Core EA; Peripheral EA ○ fitted spread; term premium spread; expectation component spread.

Figure 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).

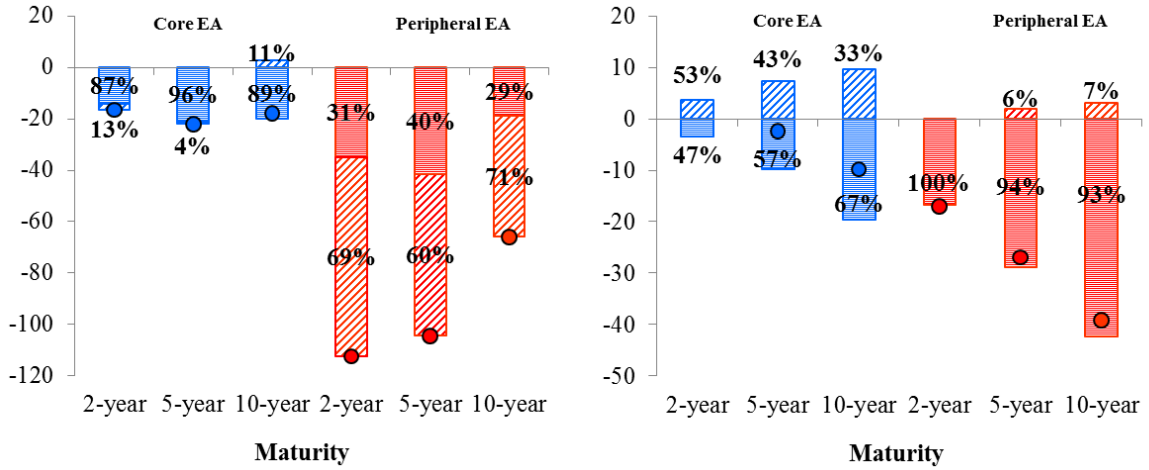
(a) Before London speech

(b) After London speech



(c) Before Negative Deposit Rate

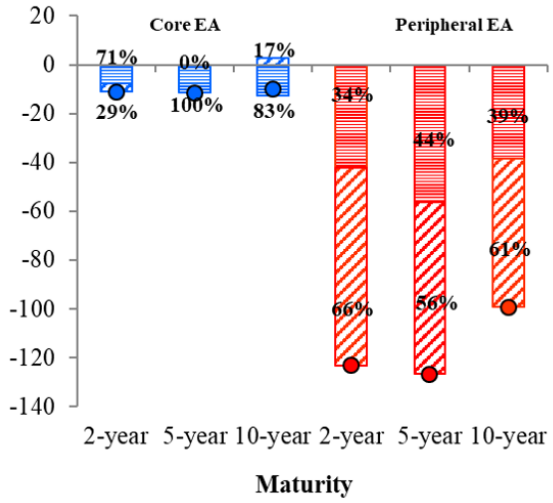
(d) After Negative Deposit Rate



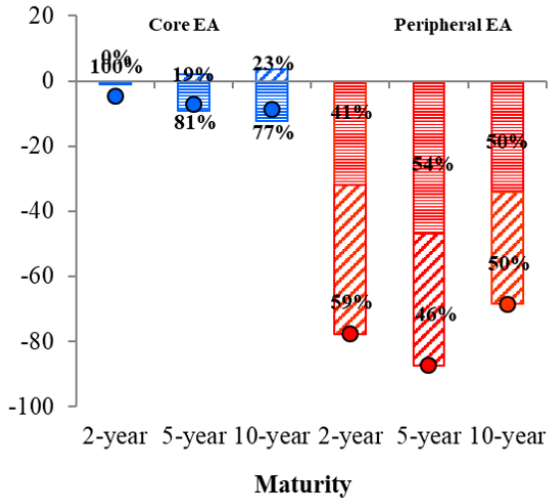
Notes: All figures are in basis points. Percentage figures indicate the share of total change due to changes in the subcomponents.
Legend: Core EA; Peripheral EA; fitted spread; term premium spread; expectation component spread.

Figure 7: 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 - **extended setup**

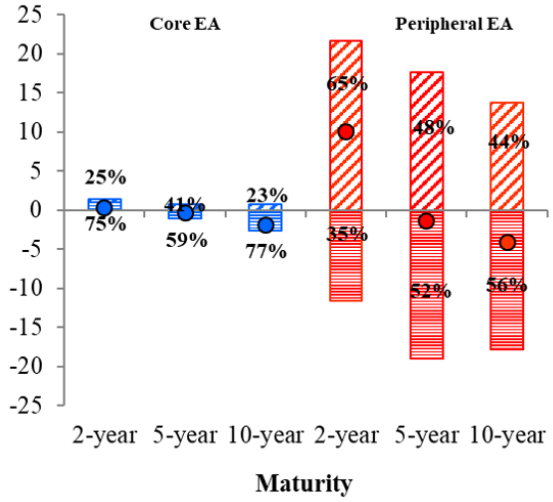
(a) All announcements



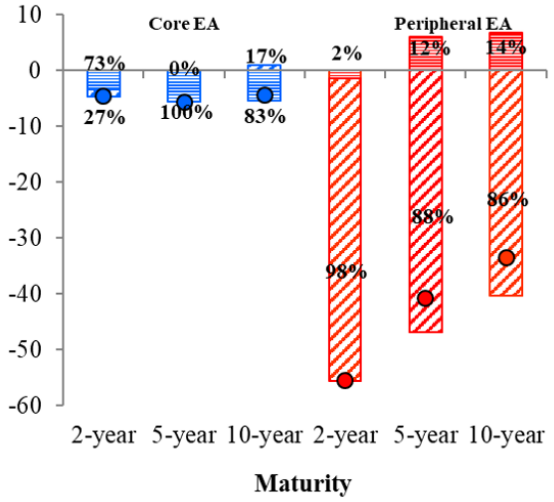
(b) Balance sheet policies



(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.

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 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[21], 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 volatility of the endogenous shocks[22].

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) 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

[21] See Cogley and Sargent (2001) and Boivin and Giannoni (2006)
[22] See Benati (2008) and Sims and Zha (2006).

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 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.

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 3, the annual growth of Industrial Production (y) and the annual HICP inflation excluding energy (π) for core and peripheral EA economies[23]. Notably, the following model is set up as in Cogley and Sargent (2005), Primiceri (2005) and Cogley et al. (2010):

$$\mathbf{Y}_t = B_{0,t} + B_{1,t}\mathbf{Y}_{t-1} + \cdots + B_{p,t}\mathbf{Y}_{t-p} + \mathbf{u}_t \equiv \mathbf{X}_t'\theta_t + \mathbf{u}_t, \tag{4}$$

where $\mathbf{Y}_t$ is the $N \times T$ vector of endogenous variables. The vector $\theta_t \equiv [B_{0,t}, B_{1,t} \dots B_{p,t}]$ and the matrix $\mathbf{X}_t \equiv [\mathbf{1}, \mathbf{Y}_{t-1} \dots \mathbf{Y}_{t-p}]$ 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:

$$\theta_t = \theta_{t-1} + \eta_t, \tag{5}$$

where $\eta_t \equiv [\eta_{1,t}, \dots, \eta_{N\cdot(1+Np),t}]'$ 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 (4) are assumed to be normally distributed, with zero mean and variance-covariance matrix $\mathbf{\Sigma}_t$ factored as:

$$\mathbf{\Sigma}_t = \mathbf{F}_t \mathbf{\Lambda}_t (\mathbf{F}_t)', \tag{6}$$

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

[23] More specifically, in Equation (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 for details.

matrix:

$$\mathbf{\Lambda}_t \equiv \begin{bmatrix} \bar{s}_1 \exp(\lambda_{1,t}) & 0 & 0 & \dots & 0 \\ 0 & \bar{s}_2 \exp(\lambda_{2,t}) & 0 & \dots & 0 \\ 0 & 0 & \bar{s}_3 \exp(\lambda_{3,t}) & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \dots & \bar{s}_N \exp(\lambda_{N,t}) \end{bmatrix},$$

$$\mathbf{F}_t \equiv \begin{bmatrix} 1 & 0 & 0 & \dots & 0 \\ f_{21,t} & 1 & 0 & \dots & 0 \\ f_{31,t} & f_{32,t} & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ f_{N1,t} & f_{N2,t} & \dots & f_{N(N-1),t} & 1 \end{bmatrix}. \tag{7}$$

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

$$\lambda_{i,t} = \gamma \lambda_{i,t-1} + \nu_{i,t}, \qquad \nu_{i,t} \sim N(0, \phi_i). \tag{8}$$

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 Section D.1 of the Appendix.

The reduced-form model in Equation (4) can be rewritten in structural form as follows:

$$A_{0,t}\mathbf{Y}_t = C_{0,t} + A_{1,t}\mathbf{Y}_{t-1} + \dots + A_{p,t}\mathbf{Y}_{t-p} + \varepsilon_t, \tag{9}$$

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 $E(\mathbf{u}_t\mathbf{u}_t') = \mathbf{\Sigma}_t = A_{0,t}^{-1} H_t A_{0,t}^{-1'}$[24]. The 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 Section D.2 of the Appendix.

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

[24]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: $\theta_t = A_{0,t}^{-1}\tilde{\theta}_t$.

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 3.2 above, there has been a stark change in the response of spreads to UMP announcements after June 2014, when the ZLB 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 Section D.2, by introducing in the model "dynamic" zero and sign restrictions, whereby the matrices $\mathbf{S}_j$ and $\mathbf{Z}_j$ in Equations (D.28) and (D.29) 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[25]. Table 3 reports the set of *contemporaneous* restrictions (i.e., on matrix $A_{0,t}$) for the different time periods.

Table 3: 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.

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-ZLB period. On the other hand, in peripheral EA the UMP shock decreases the risk-

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

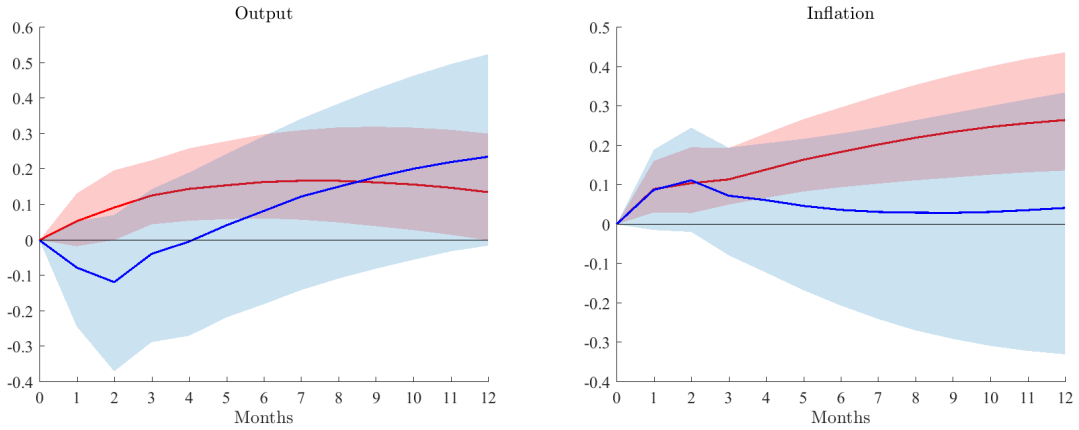
neutral spread before June 2014, while the impact on the same variable is 0 thereafter. As to the other endogenous variables, we assume that an UMP shock affects both output and inflation with a one-month delay, which accommodates the fact that UMPs are usually announced before they are implemented (Gambacorta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

4.2 Results

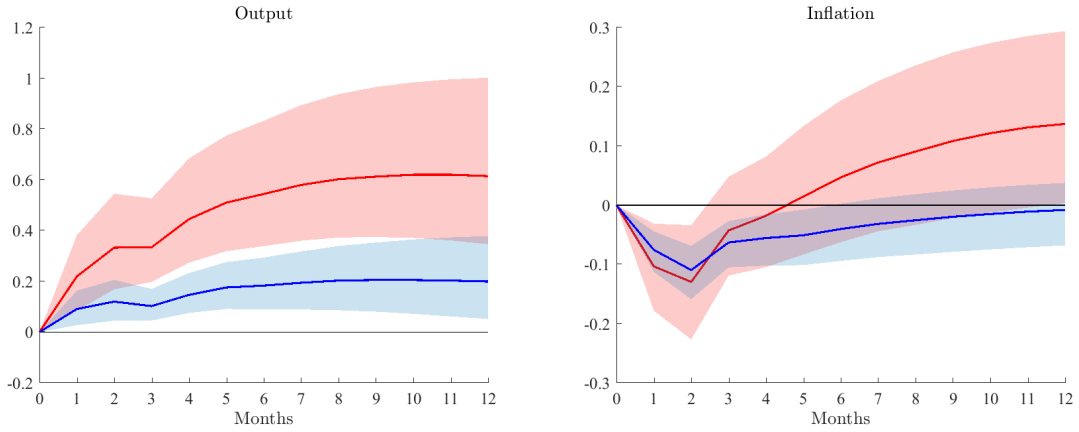
Figure 8 displays the average IRFs to a decrease in term spreads by 100bps for output and inflation in core EA (Figure 8a) and peripheral EA (Figure 8b), before and after June 2014[26].

Figure 8: Median IRFs of output (left panels) and inflation (right panels) to a decrease in term spreads by 100bps.

(a) Core EA



(b) Peripheral EA



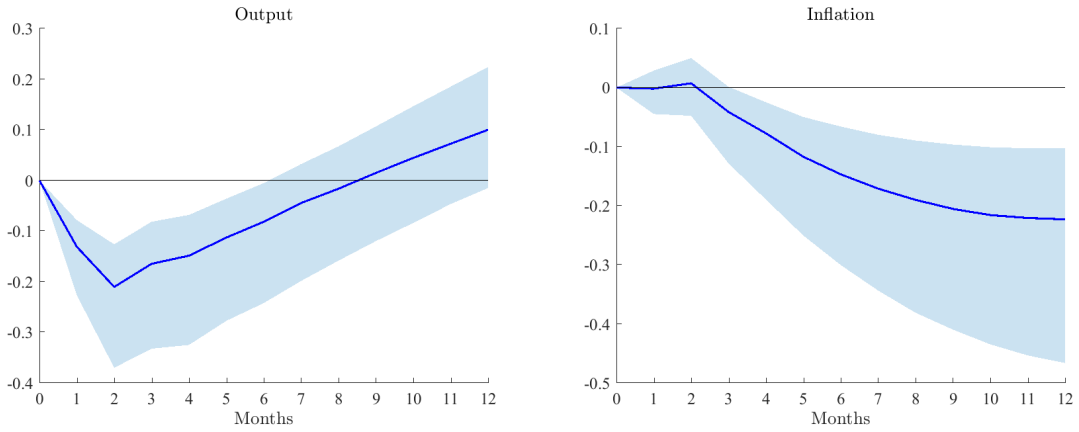
Legend: before June 2014; after June 2014.
Notes: Shaded areas are 68% confidence bands.
Source: Author's calculations.

As 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

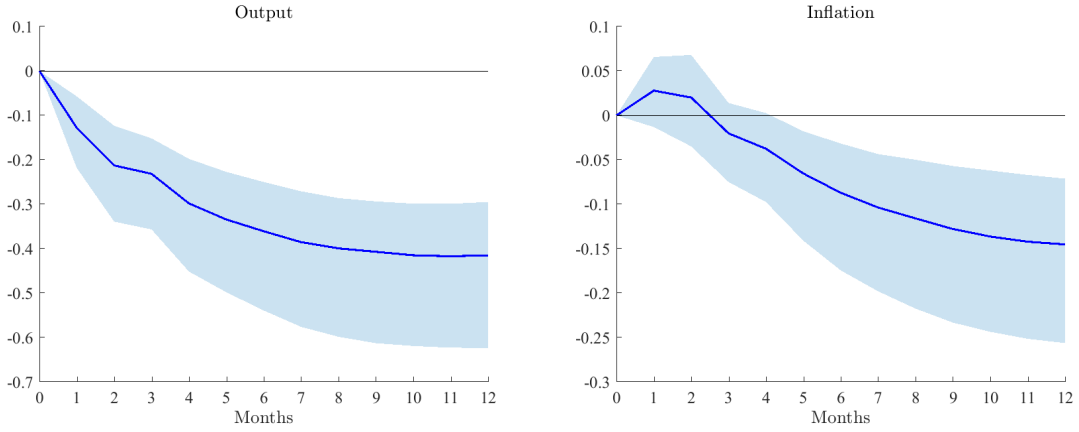
[26] Figure E.3 in Appendix E shows the complete set of median IRFs at each date in the sample

Figure 9: 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.

completely insignificant (core EA) after then (see also Table 4 and Figure 9). 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).

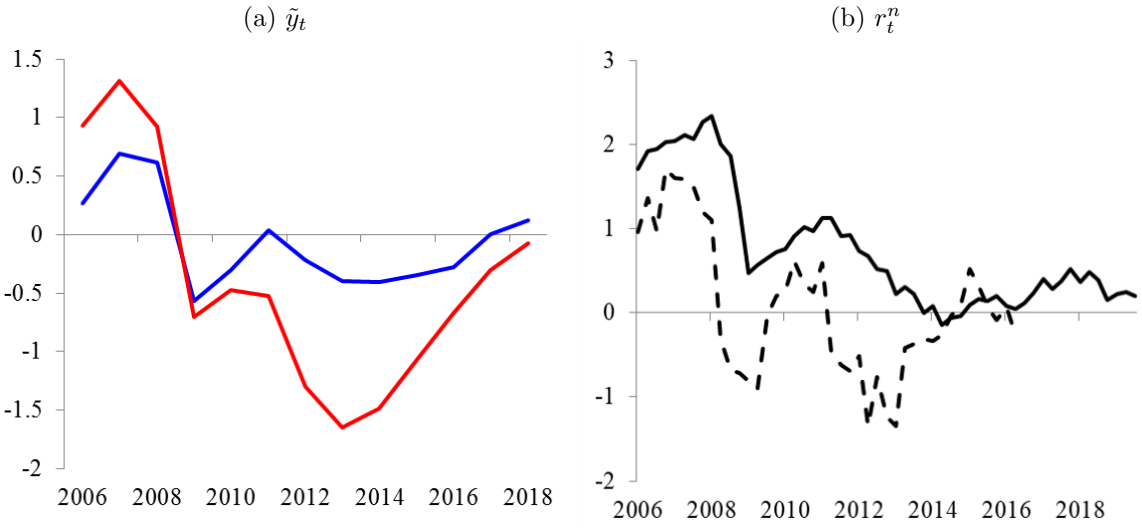
As regards peripheral EA, on the other hand, while the impact of UMPs is always significant regardless of the time period considered, there is an evident reduction in the macroeconomic response to such policies after June 2014, especially as regards output (on average, +0.14 before and +0.05 percentage points after June 2014). Conversely, the impact on inflation is counter-intuitive, in that a loosening in UMP entails a decrease in inflation over the short-run (~-0.07

Table 4: 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 10: Output gap and natural rate of interest in the euro area



Legend: Core EA; Peripheral EA. HLW; FMMR.
Notes: The output gap is expressed as percentage share of potential output. The natural rate of interest is estimated using the Holston-Laubach-Williams (HLW) model and the Fries-Méssonier-Mouabbi-Renne (FMMR) model. In the latter case, the euro area natural rate of interest is computed as the GDP-weighted average of the rates of France, Germany, Italy and Spain.
Source: IMF World Economic Outlook (WEO) Database, Holston et al. (2017), Fries et al. (2018) and author's calculations.

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 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))[27]. 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))[28]. These dynamics might be ultimately linked to a drop in the natural rate of interest. In Equation (1b), indeed, the output gap is a positive function of r_t^n. 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 (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 10a) and the estimated natural rate of interest has been close to or below zero ever since (see Figure 10b, Penalver (2017) and Brand et al. (2018)).

Additional insights are provided by the series of structural shocks, depicted in Figure 11. 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[29], 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[30].

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 different monetary policy stance since the

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

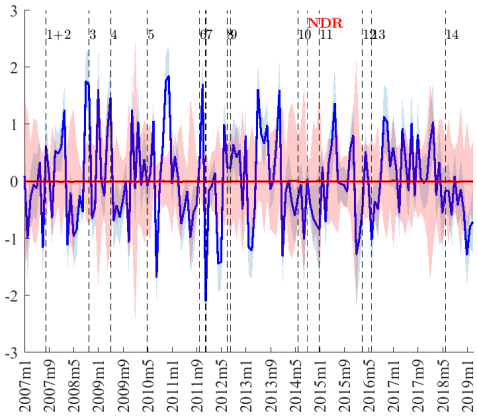
[28] Notably, in the New Keynesian framework described by Equations (1a) and (1b), $\tilde{y}_t \to 0$ implies that inflation becomes a linear function of $i_t - r_t^n$ only.

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

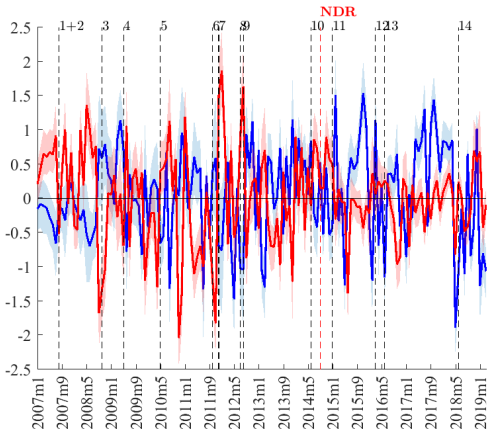
[30] It might be also argued that the drop in the effect of UMP shocks after June 2014 derives from the fact that the first part of the sample includes also the years 2008-2009, where economies were rebouncing in the aftermath of the GFC. However, results depicted in Figure 8 do not significantly change if only the period 2010-2019 is taken into consideration.

Figure 11: 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.
Source: Author's calculations.

onset of GFC.

An answer to the question might be sought for by focusing on particular episodes in the ECB's decision path. Notably, we first take into account the ECB's policy rate hikes in April and July 2011 (Figure 12). That episode is often indicated as the main example of an excessive tightening on the part of the ECB[31] and can be read through the lens of the model by looking at the reaction of the term premia and the expectation components[32]. Market participants considered the April decision as highly temporary, as indicated by the drop in longer-term OIS future rates around the announcement (Figure 12a). 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 (Figure 12b). 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. Against this background, a counterfactual analysis is run based on the following steps:

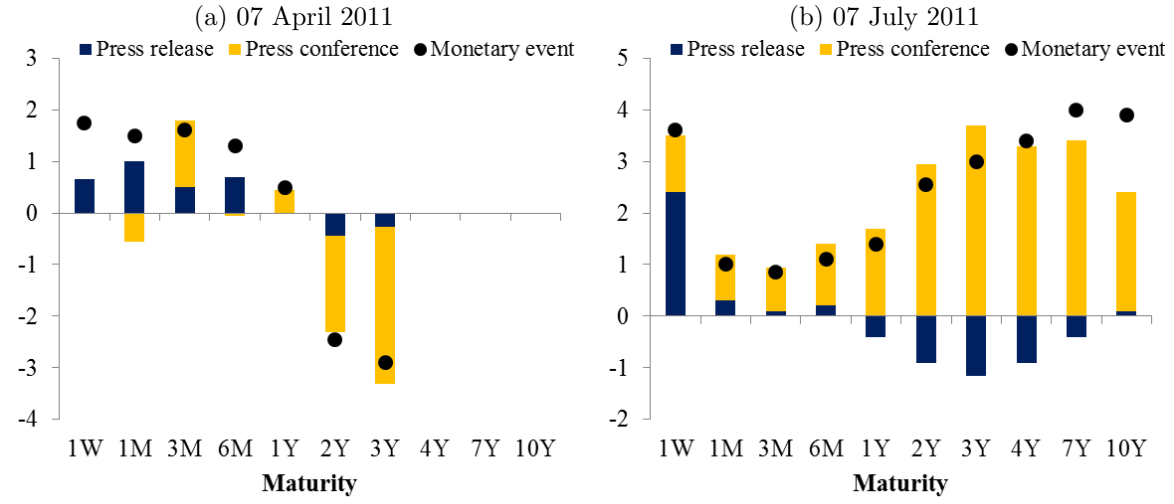
i) the historical series of structural shocks is reconstructed, conditional on the parameters of the TVP-SVAR;

ii) the shock series is then modified by applying a counter-shock on the risk-neutral spreads,

[31] 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."

[32] 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 1.

Figure 12: 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).

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[33]

Figure 13 displays the results for core (Figure 15a) and peripheral (Figure 15b) 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 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 14)[34]. 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.

It is worth assessing these findings against more recent episodes. A similar exercise is then performed by taking into account the whole of measures implemented by the ECB between

[33]The approach here proposed is devised to address Lucas critique, as explained in Baumeister and Benati (2013). A similar exercise is also performed by Lenza et al. (2010), who simulate the path of several macroeconomic variables with and without ECB's UMPs.

[34]Such difference cannot be interpreted as an impulse response function to an UMP shock, since the reported paths are conditional expectations and reflect *all the shocks* that are the most likely to generate the expectation component paths in the two scenarios, not only the UMP shock.

2014 and 2017. A part of the literature has found that such measures have helped sustain the economic performance of euro area economies. Mouabbi and Sahuc (2019), for instance, show that, absent these measures, euro area year-on-year inflation and GDP growth would have been on average about 0.61% and 1.09% below their actual levels over the period 2014Q1-2017Q2. By looking at the behaviour of spreads around the main announcements in that period, the UMP shocks can be proxied as a decrease in the 10-year term premium spreads by 10bps in core euro area economies and by 43bps in peripheral countries (see Table C.5). We then simulate the series of both output and inflation by applying a countershock on term premium spreads so that the counterfactual series is on average 10bps and 43bps higher than what observed in core and peripheral economies respectively. Figure 15 displays the counterfactual and actual simulated macroeconomic series for core and peripheral countries, whereas Figure 16 depicts the difference between the two series. Overall, absent these measures, industrial production growth and inflation would remain unchanged in core euro area, whereas industrial production would be *on average* 0.67pps lower in peripheral economies over the period 2014M1-2017M6[35].

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.

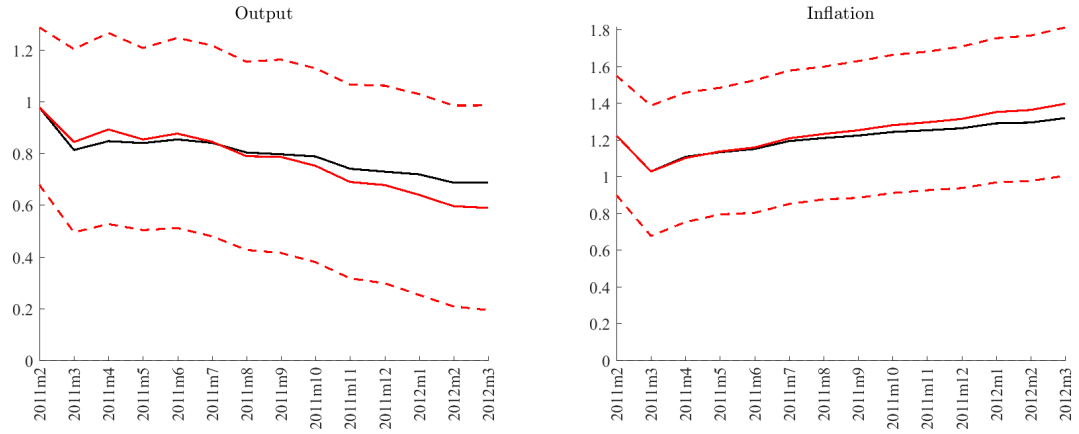
This paper contributes to the already rich literature assessing the macroeconomic impact of UMPs along the following dimensions: i) it uses the decomposition of sovereign spreads into term premium and risk-neutral spreads to isolate the portfolio and signalling channels in core and peripheral economies; 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

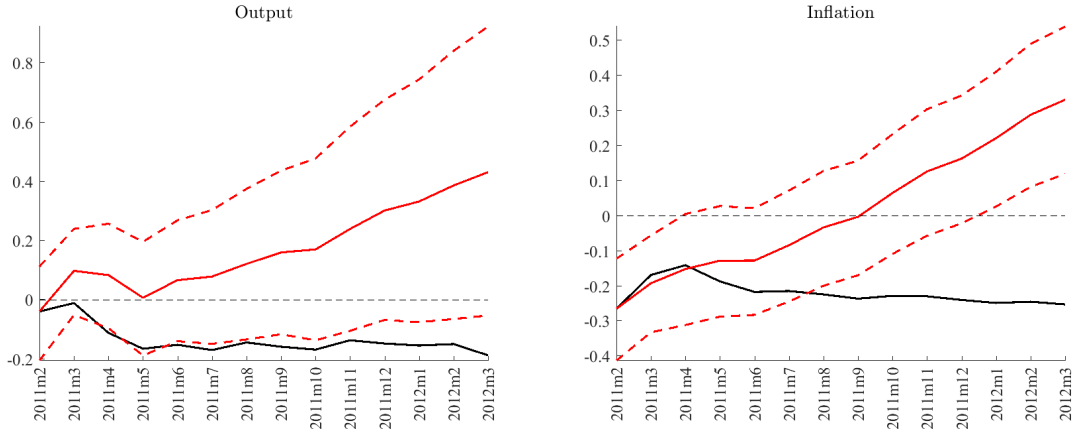
[35] Similar results are provided by Rostagno et al. (2019), who take into account the whole set of measures (credit, balance sheet, forward guidance and negative deposit rate) implemented over the period 2015-2018. While the estimates they provide for GDP growth are higher than in Mouabbi and Sahuc (2019), however the effect on inflation is much less relevant, which is somewhat closer to our results for peripheral euro area economies.

Figure 13: 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.

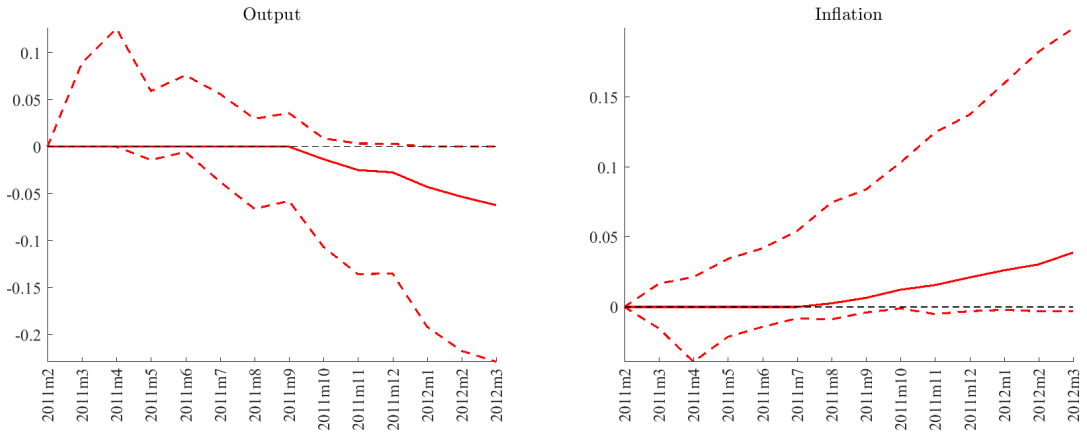
mainly driven by a shutting down of the signalling channel after the implementation of the negative deposit rate in June 2014. Results also reveal the presence of the so-called "missing inflation puzzle" in peripheral EA, where monetary loosening has been accompanied by a decrease in the inflation rate.

Finally, counterfactual analyses based on the TVP-SVAR-SV estimates show whether and how the economic performance of core and peripheral economies would have differed under a modified path of ECB's monetary policy stance. For instance, the slowdown in the peripheral EA economies would have been less pronounced, if the ECB had been more aggressive in loosening its monetary stance in 2011. Conversely, the measures implemented over the period 2014-2017 have avoided a more severe contraction in economic output in both core and peripheral countries.

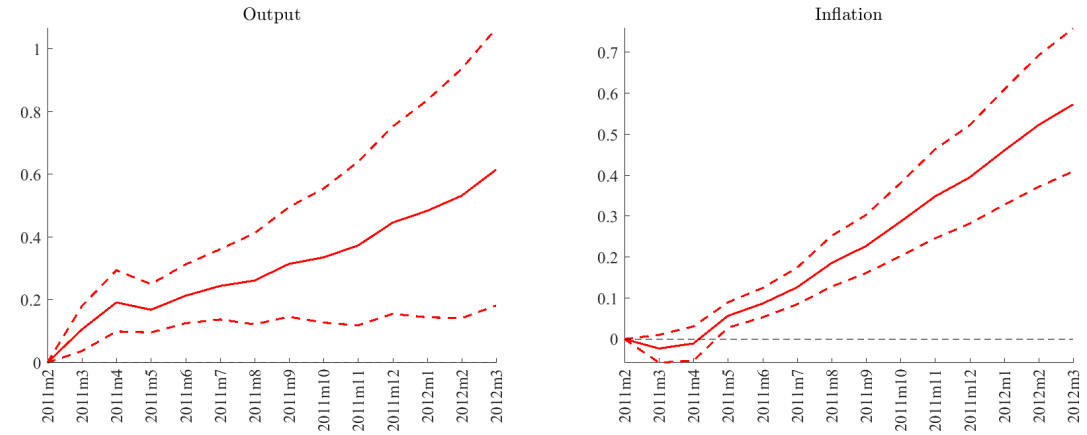
The framework adopted in this paper shows several advantages, as it can accommodate different specifications aimed at tackling research questions that can add on the findings here explained. One venue for future research might consist of evaluating how results would change

Figure 14: Counterfactual analysis for the ECB's interest hikes in 2011 - difference between the no hike and actual scenarios

(a) Core EA



(b) Peripheral EA

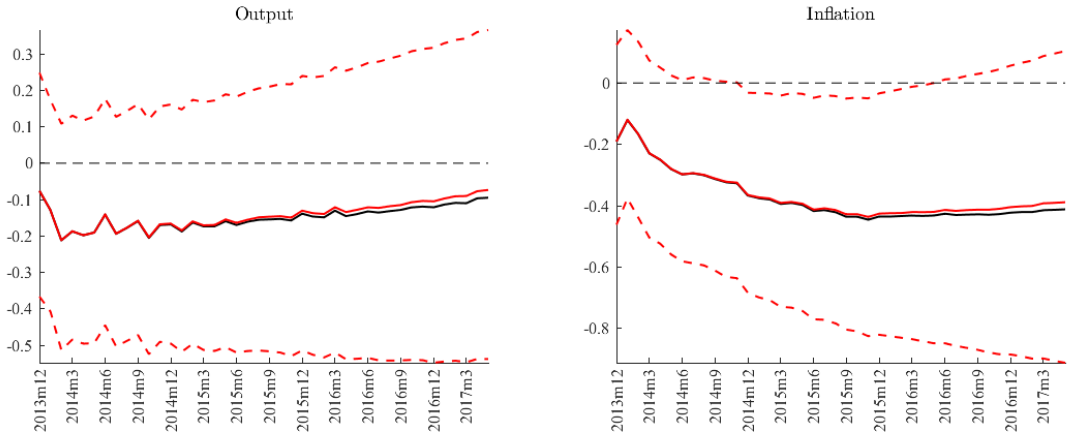


Notes: Dashed lines are 68% confidence bands.
Source: Author's calculations.

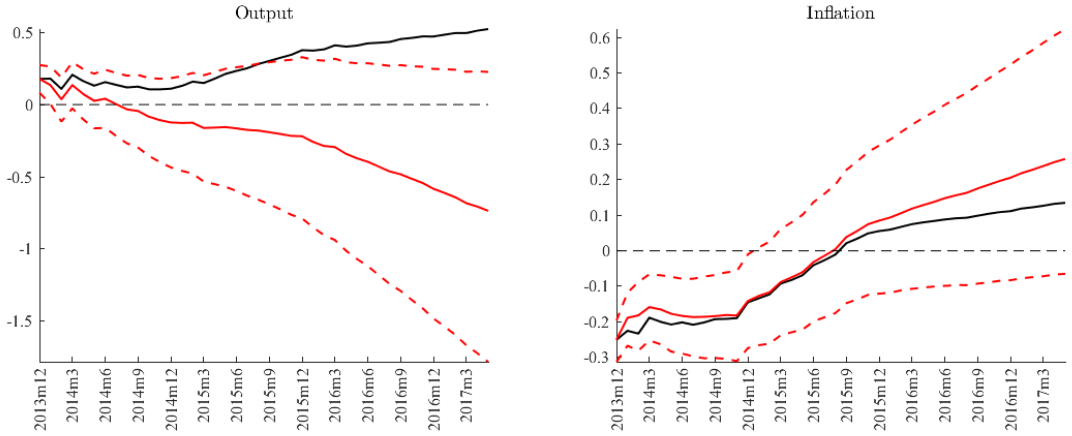
when expanding the monetary policy function to account for financial stability. A strand of literature, for instance, relates the FED's policy function to the US financial cycle (Filardo et al. (2019)). Differently from the US system, however, the euro area economy relies more heavily on bank intermediation, 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 could be investigated by expanding the TVP-SVAR-SV to include a measure of credit to the economy.

Figure 15: Counterfactual analysis for the ECB's measures in 2014-2017

(a) Core EA



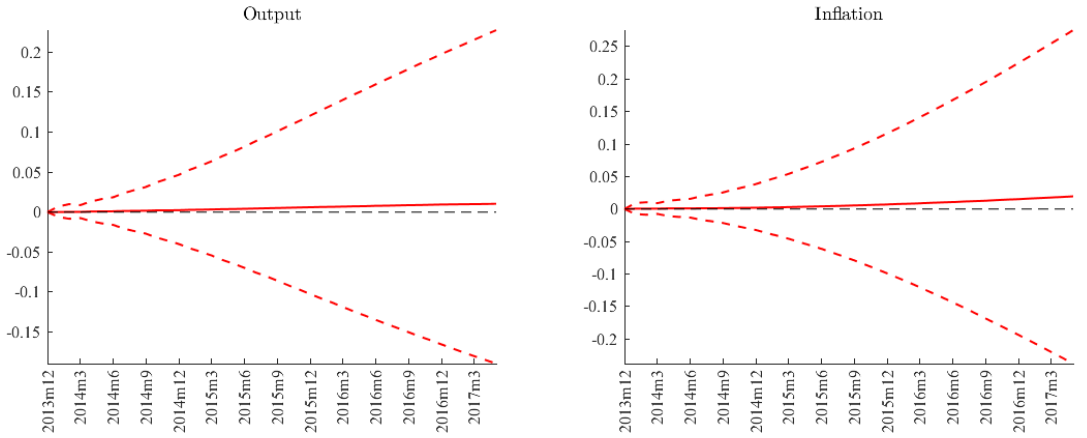
(b) Peripheral EA



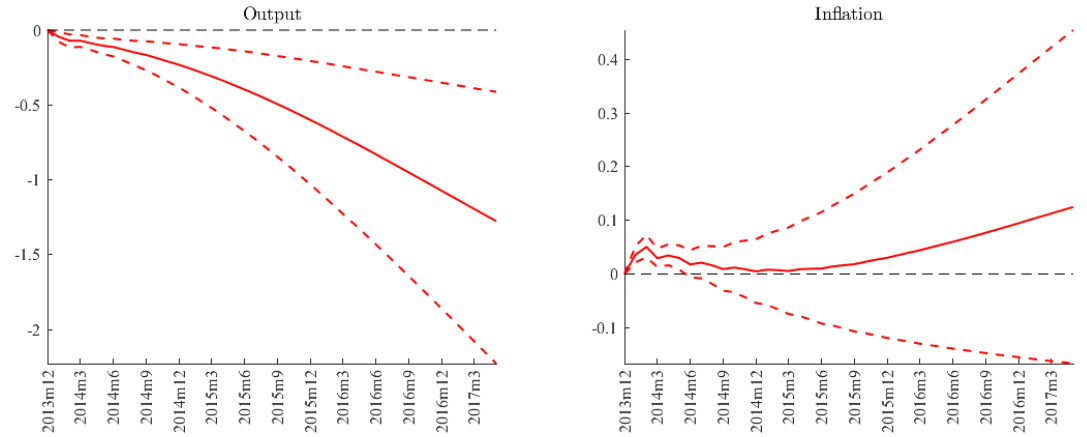
Legend: Actual; No hike.
Notes: Dashed lines are 68% confidence bands.
Source: Author's calculations.

Figure 16: Counterfactual analysis for the ECB's measures in 2014-2017 - difference between the no measures and actual scenarios

(a) Core EA



(b) Peripheral EA



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

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Appendices

A UMPs: taxonomy and international experience

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[36]. Table A.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 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.

[36] See Borio and Disyatat (2010).

Table A.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.

A.1 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 A.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)[37].

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

Table A.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."

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 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 A.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 A.1),

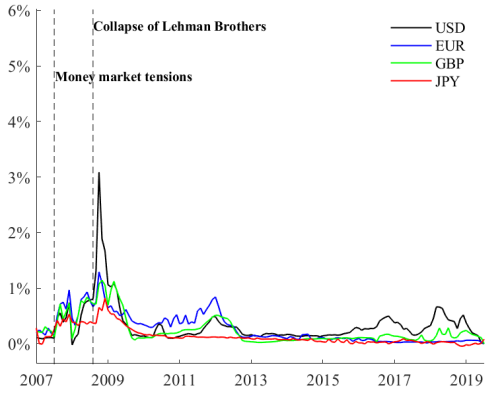
[37] The summary is based on Fawley and Neely (2013) and Borio and Zabai (2018). For more detailed accounts, refer also to Micossi (2015) (ECB) and Haldane et al. (2016) (BoE).

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.

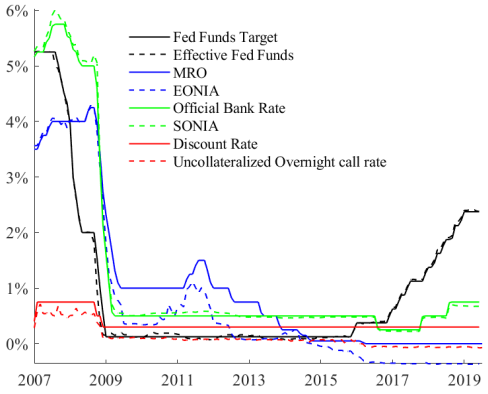
When the euro area was hit by a sovereign debt crisis in 2009, the ECB started to purchase government debt outright in order to promote financial stability in the countries under strain. As financial conditions began to normalise, asset purchases and lending schemes were deployed to boost the economic 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 A.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.

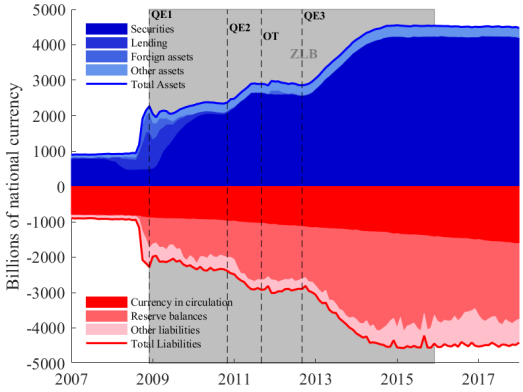
Besides these broader common trends across central banks, balance sheet policies adopted after the GFC also present some idiosyncratic features that are related to the peculiar structure of the financial system that each central bank had to cope with. Hence, in capital market-based systems like the US 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[38].

[38] 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).

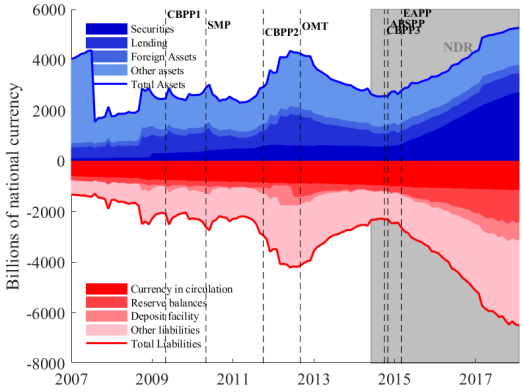
These measures have changed the size and structure of central bank balance sheets, with an increase by a factor of two in the Eurosystem and by a factor of four for the other central banks. Figure A.2 displays the balance sheets for the FED, the ECB, the BoE and the BOJ together with a timeline of the 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.

Figure A.2: Balance sheet decomposition at major central banks

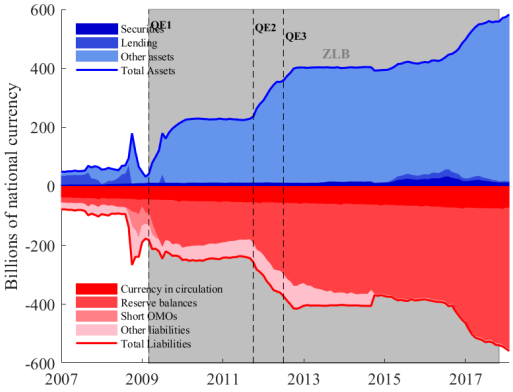
(a) Federal Reserve



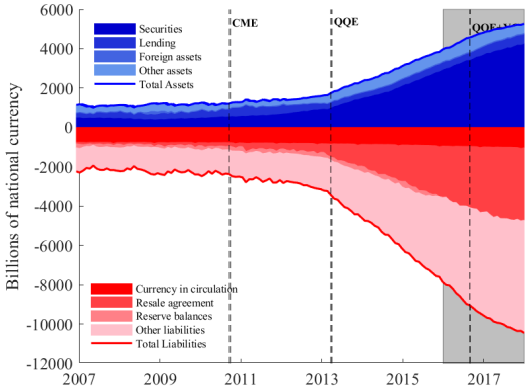
(b) Eurosystem



(c) Bank of England



(d) Bank of Japan



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.

A.2 UMPs in the Euro Area

The strategy adopted by the ECB in the aftermath of the GFC can be divided into three main phases[39]:

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 (González-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).

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[40]. Later on, the ECB announced 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

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

[40] The requirement to act on the secondary market has avoided to consider SMP as breaching Article 123 of the Treaty on the Functioning of the European Union (TFEU), which prohibits monetary financing of governments.

(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[41].

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 holdings.

B 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 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

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

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 euro area are taken from Bloomberg, while information on the UMPs and programmes announcements are taken from the ECB.

Quanto CDS spreads are computed as the difference between each country's quanto CDS price and that of Germany. As in the case of sovereign yields, aggregation is made using the shares of government debt as weights. Similarly, bank CDS spreads are constructed using averages of CDS prices across groups of relevant banks in each country. Such averages are then aggregated in the same way as for the quanto CDS spreads. The underlying CDS data, as well as those for the volatility index of the STOXX 50 (VSTOXX), are taken from Thomson Reuters.

Time-varying SVAR with SV

Besides the term and risk-neutral spreads extracted from yield curves in Section 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.

C Event study results

Tables C.3 to C.7 below report the results of the event study in Section 3.2.

Table C.3: 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 C.4: 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 C.5: 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 C.6: 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 C.7: 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.

Table C.8: Significance of cumulative changes in EA government bond fitted, term premium and risk-neutral spreads - extended setup

	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	**-11.087*** **	**-7.863*** **	**-3.224*** **	**-11.612*** **	**-11.526*** **	-0.09	**-10.023*** **	**-12.670*** **	**2.647*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.83)	(0.00)	(0.00)	(0.00)
L	**-4.782*** **	**-1.134*** **	0.20	**-7.103*** **	**-9.217*** **	**2.114*** **	**-8.619*** **	**-12.352*** **	**3.733*** **
	(0.00)	(0.00)	(0.11)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
C	**0.343*** **	**1.038*** **	**0.349*** **	**-0.345*** **	**-1.082*** **	**0.737*** **	**-1.871*** **	**-2.675*** **	**0.804*** **
	(0.00)	(0.79)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
F	**-4.642*** **	**-3.409*** **	**-1.233*** **	**-5.665*** **	**-5.613*** **	-0.05	**-4.303*** **	**-5.364*** **	**1.062*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.84)	(0.00)	(0.00)	(0.00)
					Peripheral EA				
All	**-123.191*** **	**-42.128*** **	**-81.063*** **	**-126.688*** **	**-56.166*** **	**-70.522*** **	**-99.261*** **	**-38.591*** **	**-60.670*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
L	**-77.739*** **	**-32.094*** **	**-45.645*** **	**-87.332*** **	**-47.067*** **	**-40.265*** **	**-68.561*** **	**-34.033*** **	**-34.528*** **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
C	**10.105*** **	**-11.577*** **	**21.683*** **	**-1.368** **	**-19.017*** **	**17.648*** **	**-4.081*** **	**-17.796*** **	**13.716*** **
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
F	**-55.553*** **	**-1.300** **	**-54.253*** **	**-40.798*** **	**6.100*** **	**-46.898*** **	**-33.515*** **	**6.824*** **	**-40.339*** **
	(0.00)	(0.05)	(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.

D Bayesian Estimation

D.1 MCMC algorithm

The system given by Equations (4) to (8) is estimated using Bayesian methods. Notably, assuming independence across θ, f^{-1} and λ, the posterior density can be written as:

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

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

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

The likelihood function in Equation (D.2) can also be reformulated in compact form, by setting:

$$\underbrace{\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_T \end{bmatrix}}_{NT\times 1} = \underbrace{\begin{bmatrix} \bar{\mathbf{X}}_1 & 0 & \dots & 0 \\ 0 & \bar{\mathbf{X}}_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \bar{\mathbf{X}}_T \end{bmatrix}}_{NT\times pT}\underbrace{\begin{bmatrix} \theta_1 \\ \theta_2 \\ \vdots \\ \theta_T \end{bmatrix}}_{pT\times 1} + \underbrace{\begin{bmatrix} \nu_1 \\ \nu_2 \\ \vdots \\ \nu_T \end{bmatrix}}_{NT\times 1} \tag{D.3}$$

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:

$$f(y|\theta, \mathbf{\Sigma}) \propto |\bar{\mathbf{\Sigma}}|^{-1/2}\exp\left(-\frac{1}{2}(y - \bar{\mathbf{X}}\Theta)'\bar{\mathbf{\Sigma}}^{-1}(y - \bar{\mathbf{X}}\Theta)\right) \tag{D.4}$$

We set the priors as follows:

$$\begin{aligned}
&\theta|\boldsymbol{\Omega} \sim \mathcal{N}(0, \boldsymbol{\Omega}_0) \\
&\omega_i \sim IG\Big(\frac{\chi_0}{2}, \frac{\psi_0}{2}\Big) \\
&f_i^{-1} \sim \mathcal{N}(f_{i,0}^{-1}, \boldsymbol{\Upsilon}_{i,0}) \\
&\lambda_i|\phi_i \sim N(0, \boldsymbol{\Phi}_0) \\
&\phi_i \sim IG\Big(\frac{\beta_0}{2}, \frac{\delta_0}{2}\Big).
\end{aligned} \tag{D.5}$$

The prior for λ_i deserves some additional remarks. Equation (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 $\lambda_{i,1}, \ldots, \lambda_{i,T}$ 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)[42]. Notably, from Equation (8), any value $\lambda_{i,t}$ eventually depends on the initial value $\lambda_{i,0}$ and the shocks $v_{i,t}, t = 1, \ldots, T$. Therefore, Equation (8) can be reformulated as:

$$GL_i = v_i, \quad i = 1, \ldots, N \tag{D.6}$$

with

$$G = \begin{bmatrix} 1 & 0 & 0 & \ldots & 0 \\ -\gamma & 1 & 0 & \ldots & 0 \\ 0 & -\gamma & 1 & \ldots & 0 \\ \vdots & & \ddots & & \vdots \\ 0 & \ldots & 0 & -\gamma & 1 \end{bmatrix}, \quad L_i = \begin{bmatrix} \lambda_{i,1} \\ \lambda_{i,2} \\ \vdots \\ \lambda_{i,T} \end{bmatrix}, \quad v_i = \begin{bmatrix} \gamma\lambda_{i,0} + v_{i,1} \\ v_{i,2} \\ \vdots \\ v_{i,T} \end{bmatrix}. \tag{D.7}$$

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:

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

$$
\begin{aligned}
var(\gamma\lambda_{i,0} + v_{i,1}) &= var(\gamma\lambda_{i,0}) + var(v_{i,1}) \\
&= \gamma^2 var(\lambda_{i,0}) + var(v_{i,1}) \\
&= \gamma^2 \frac{\phi_i(\omega - 1)}{\gamma^2} + \phi_i \\
&= \phi_i \omega.
\end{aligned}
\tag{D.8}
$$

Following Cogley and Sargent (2005), ω is set equal to 1000 in order to get a diffuse prior for $\lambda_{i,1}$. Equation (8), Equation (D.7) and Equation (D.8) imply that:

$$
v_i \sim \mathcal{N}(0, \phi_i I_\omega), \qquad I_\omega = \begin{bmatrix} \omega & 0 & \dots & \dots & 0 \\ 0 & 1 & \dots & \dots & 0 \\ \vdots & & \ddots & & \vdots \\ 0 & & \dots & 0 & 1 \end{bmatrix}. \tag{D.9}
$$

Furthermore, Equation (D.6) implies that $L_i = G^{-1} v_i$, which, in turn, leads to:

$$
L_i \sim \mathcal{N}(0, G^{-1} \phi_i I_\omega G^{-1\prime}), \tag{D.10}
$$

or:

$$
L_i \sim \mathcal{N}(0, \mathbf{\Phi}_0), \quad \text{with } \mathbf{\Phi}_0 = \phi_i (G' I_\omega^{-1} G)^{-1}. \tag{D.11}
$$

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 (D.2) and the priors in Equation (D.5), the joint posterior density is:

$$
\begin{aligned}
f(\theta, \mathbf{\Omega}, f^{-1}, \lambda, \mathbf{\Phi}|y) \propto & \prod_{t=1}^{T} |\mathbf{F}_t \mathbf{\Lambda}_t \mathbf{F}_t'|^{-1/2} \exp\Big(-\frac{1}{2}(y_t - \bar{\mathbf{X}}_t\theta_t)'(\mathbf{F}_t\mathbf{\Lambda}_t\mathbf{F}_t')^{-1}(y_t - \bar{\mathbf{X}}_t\theta_t)\Big) \\
& \times |\mathbf{\Omega}_0| \exp\Big(-\frac{1}{2}\Theta'\mathbf{\Omega}_0^{-1}\Theta\Big) \\
& \times \prod_{i=1}^{N} \omega_i^{-\frac{\chi_0}{2}-1} \exp\Big(-\frac{\psi_0}{2\omega_i}\Big) \\
& \times \prod_{i=1}^{N} \exp\left[-\frac{1}{2}(f_i^{-1} - f_{i,0}^{-1})'\mathbf{\Upsilon}_{i,0}^{-1}(f_i^{-1} - f_{i,0}^{-1})\right] \\
& \times |\mathbf{\Phi}_0|^{-1/2} \exp\left(-\frac{1}{2} L_i' \mathbf{\Phi}_0^{-1} L_i\right) \\
& \times \prod_{i=1}^{N} \phi_i^{-\frac{\beta_0}{2}-1} \exp\Big(-\frac{\delta_0}{2\phi_i}\Big).
\end{aligned}
\tag{D.12}
$$

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

$$
\begin{aligned}
& \theta|(y, \mathbf{\Omega}, f^{-1}, \lambda, \mathbf{\Phi}) \sim N(\bar{\Theta}, \bar{\mathbf{\Omega}}), \\
& \text{with} \quad \bar{\mathbf{\Omega}}^{-1} = (\mathbf{\Omega}_0^{-1} + \bar{\mathbf{X}}'\bar{\mathbf{\Sigma}}^{-1}\bar{\mathbf{X}}) \\
& \text{and} \quad \bar{\Theta} = \bar{\mathbf{\Omega}}(\bar{\mathbf{X}}'\bar{\mathbf{\Sigma}}^{-1}y).
\end{aligned}
\tag{D.13}
$$

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

$$
\begin{aligned}
& \mathbf{\Omega}_i|(y, \theta, \mathbf{\Omega}_{-i}, \mathbf{\Sigma}) \sim IG(\bar{\chi}, \bar{\psi}), \\
& \text{with} \quad \bar{\chi} = \frac{\chi_0 + T}{2} \\
& \text{and} \quad \bar{\psi} = \frac{\theta_{i,1}^2/\tau + \sum_{t=2}^{T}(\theta_{i,t} - \theta_{i,t-1})^2 + \psi_0}{2}.
\end{aligned}
\tag{D.14}
$$

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

$$
\begin{aligned}
& f_i^{-1}|(y, \theta, f_{-i}^{-1}, \lambda, \mathbf{\Phi}) \sim N(\bar{f}_i^{-1}), \bar{\mathbf{\Upsilon}}_i) \\
& \text{with} \quad \bar{\mathbf{\Upsilon}}_i = \Big(\bar{s}_i^{-1} \sum_{t=1}^{T} \nu_{-i,t} \exp(-\lambda_{i,t})\nu_{i,t}' + \bar{\mathbf{\Upsilon}}_{i0}^{-1}\Big)^{-1} \\
& \text{and} \quad \bar{f}_i^{-1} = \bar{\mathbf{\Upsilon}}_i\Big(-\bar{s}_i^{-1} \sum_{t=1}^{T} \nu_{-i,t} \exp(-\lambda_{i,t})\nu_{i,t}' + \bar{\mathbf{\Upsilon}}_{i0}^{-1} f_{i0}^{-1}\Big).
\end{aligned}
\tag{D.15}
$$

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

$$\begin{aligned}\pi(\lambda_{i,t}|y,\theta,f^{-1},\lambda_{-i,-t},\mathbf{\Phi}) \propto \exp\Big(-\frac{1}{2}\Big\{\bar{s}_i^{-1}\exp(-\lambda_{i,t})(\nu_{i,t}+(f_i^{-1})'\nu_{-i,t})^2+\lambda_{i,t}\Big\}\Big)\\ \times\exp\Big(-\frac{1}{2}\frac{(\lambda_{i,t}-\bar{\lambda}_i)^2}{\bar{\mathbf{\Phi}}}\Big)\\ \text{with}\quad \bar{\mathbf{\Phi}}=\frac{\phi_i}{1+\gamma^2}\\ \text{and}\quad \bar{\lambda}=\frac{\gamma}{1+\gamma^2}(\lambda_{i,t-1}+\lambda_{i,t+1}).\end{aligned} \tag{D.16}$$

Equation (D.16) requires a Metropolis-Hastings step, with the following acceptance function:

$$\begin{aligned}\kappa(\lambda_{i,t}^{(m-1)},\lambda_{i,t}^{(m)}) = \exp\Big(-\frac{1}{2}\Big\{\exp(-\lambda_{i,t}^{(m)})-\exp(-\lambda_{i,t}^{(m-1)})\Big\}\bar{s}_i^{-1}(\nu_{i,t}+(f_i^{-1})'\nu_{-i,t})^2\Big)\\ \times\exp\Big(\{\lambda_{i,t}^{(m)}-\lambda_{i,t}^{(m-1)}\}\Big).\end{aligned} \tag{D.17}$$

For $t=1$ and $t=T$, Equation (D.17) needs to be slightly adapted as follows. For the first period, a candidate is drawn from $\mathcal{N}(\bar{\lambda},\bar{\phi})$, with:

$$\bar{\lambda}=\frac{\gamma\lambda_{i,2}}{\omega^{-1}+\gamma^2}\quad\text{and}\quad\bar{\phi}=\frac{\phi_i}{\omega^{-1}+\gamma^2}. \tag{D.18}$$

The acceptance function is then given by:

$$\begin{aligned}\kappa(\lambda_{i,1}^{(m-1)},\lambda_{i,1}^{(m)}) = \exp\Big(-\frac{1}{2}\Big\{\exp(-\lambda_{i,1}^{(m)})-\exp(-\lambda_{i,1}^{(m-1)})\Big\}\bar{s}_i^{-1}(\nu_{i,1}+(f_i^{-1})'\nu_{-i,1})^2\Big)\\ \times\exp\Big(\{\lambda_{i,1}^{(m)}-\lambda_{i,1}^{(m-1)}\}\Big).\end{aligned} \tag{D.19}$$

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

$$\bar{\lambda}=\gamma\lambda_{i,T-1}\quad\text{and}\quad\bar{\phi}=\phi_i. \tag{D.20}$$

The acceptance function is then given by:

$$\begin{aligned}\kappa(\lambda_{i,T}^{(m-1)},\lambda_{i,T}^{(m)}) = \exp\Big(-\frac{1}{2}\Big\{\exp(-\lambda_{i,T}^{(m)})-\exp(-\lambda_{i,T}^{(m-1)})\Big\}\bar{s}_i^{-1}(\nu_{i,T}+(f_i^{-1})'\nu_{-i,T})^2\Big)\\ \times\exp\Big(\{\lambda_{i,T}^{(m)}-\lambda_{i,T}^{(m-1)}\}\Big).\end{aligned} \tag{D.21}$$

Finally, the conditional posterior distribution for ϕ is:

$$\begin{aligned} &\phi_i|(y,\theta,f^{-1},\lambda,\phi_{-i}) \sim IG\Big(\frac{\bar{\beta}}{2},\frac{\bar{\delta}}{2}\Big) \\ &\text{with} \quad \bar{\beta}=\beta_0+T \\ &\text{and} \quad \bar{\delta}=\delta_0 L_i' G' L_i, \end{aligned} \tag{D.22}$$

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 $f_i^{-1(0)}, i = 2,\dots N$ are set as the non-zero and non-one elements of $\hat{\mathbf{F}}^{-1}$.
   - $\lambda_{i,t}^{(0)} = 0, \forall t = 1,\dots,T$ and $\forall i = 1,\dots,N$.
   - $\phi_i^{(0)} = 1, \forall i = 1,\dots,N$.
2. Determination of $\bar{s}_1,\dots,\bar{s}_N$ using the estimated $\hat{\Lambda}$.
3. Computation of $\mathbf{\Lambda}_t^{(0)}, \forall t = 1,\dots,T$ using $\lambda_{i,t}^{(0)}$ and $\bar{s}_1,\dots,\bar{s}_N$. Then: $\mathbf{\Sigma}_t^{(0)} = \mathbf{F}_t^{(0)}\mathbf{\Lambda}_t^{(0)}\mathbf{F}_t^{(0)\prime}, \forall t = 1,\dots,T$.
4. At iteration m, the relevant parameters are drawn in the following order:
   - $\theta_t^{(m)}$ is drawn from Equation (D.13).
   - $\omega_i^{(m)}$ is drawn from Equation (D.14).
   - $f_i^{-1(m)}$ is drawn from Equation (D.15), 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 (D.22).
   - a candidate $\lambda_{i,t}^{(m)}, i = 1,\dots,N, t = 1,\dots,T$ is drawn from $\mathcal{N}(\bar{\lambda},\bar{\mathbf{\Phi}})$ with $\bar{\lambda}$ and $\bar{\phi}$ set according to Equations (D.16), (D.18) and (D.20). The acceptance function in Equation (D.17) is then used and for $i = 1,\dots,N$, $\lambda_{i,1}^{(m)},\dots,\lambda_{i,T}^{(m)}$ 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 $m = 1,\dots,M$.

D.2 Implementation of Restrictions

The structural VAR in Equation (9) can be rewritten in companion form as:

$$A_{0,t}\mathbf{Y}_t = A_t^+\mathbf{Y}_{t-1} + \varepsilon_t, \tag{D.23}$$

where $A_t^+ = [C_{0,t}, A_{1,t}, \ldots, A_{p,t}]$ is an $N \times K$ matrix and $\mathbf{Y}_{t-1} = [\mathbf{1}, \mathbf{Y}_{t-1}, \ldots, \mathbf{Y}_{t-p}]$ is an $1 \times K$ vector, with $K = T(Np+1)$. The reduced-form representation of Equation (D.23) is then:

$$\mathbf{Y}_t = B_t\mathbf{Y}_{t-1} + \mathbf{u}_t, \tag{D.24}$$

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

D.3 Functional Forms

D.3.1 Impulse Response Functions

Denote as $\tilde{\theta}_t$ the vector of structural coefficients from Equation (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:

$$\mathbf{L}_{k,t}(\tilde{\theta}_t) = \begin{cases} (A_{0,t}^{-1})' & \text{if} \quad k = 0 \\ \sum_{\ell=1}^{k}(A_{0,t}^{-1}A_{\ell,t})'\mathbf{L}_{k-\ell,t}(\tilde{\theta}_t) & \text{if} \quad 1 \le k \le p \\ \sum_{\ell=1}^{p}(A_{0,t}^{-1}A_{\ell,t})'\mathbf{L}_{k-\ell,t}(\tilde{\theta}_t) & \text{if} \quad p < k < \infty \end{cases} \tag{D.25}$$

D.3.2 Structural shocks and historical decomposition

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

$$\varepsilon_t(\tilde{\theta}_t) = A_{0,t}\mathbf{Y}_t - A_t^+\mathbf{Y}_{t-1}, \quad \text{for } t = 1, \ldots, T. \tag{D.26}$$

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

$$H_{i,j,t,t+h}(\tilde{\theta}_t, \varepsilon_t, \ldots, \varepsilon_{t+h}) = \sum_{\ell=0}^{h}\mathbf{e}_{i,n}'\mathbf{L}_{\ell,t}(\tilde{\theta}_t)\mathbf{e}_{j,n}\mathbf{L}_{\ell,t}(\tilde{\theta}_t)\mathbf{e}_{j,n}\mathbf{e}_{j,n}'\varepsilon_{t+h-\ell}, \quad \text{for } i \ge 1, j \le N, h \ge 0, \tag{D.27}$$

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

D.4 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:

$$\Gamma(\tilde{\theta}_t) = (\mathbf{e}'_{1,N}\mathscr{F}(\tilde{\theta}_t)'\mathbf{S}'_1, \dots, \mathbf{e}'_{N,N}\mathscr{F}(\tilde{\theta}_t)'\mathbf{S}'_N)' > \mathbf{0}. \tag{D.28}$$

We then impose restrictions on both $A_{0,t}$ and $\mathbf{L}_t(\tilde{\theta}_t)$ by appropriately setting $\mathbf{S}_j$ and $\mathscr{F}(\tilde{\theta}_t)$ in Equation (D.28)[43]. For instance, restrictions on the impulse response functions (IRFs) can be imposed by defining $\mathscr{F}(\tilde{\theta}_t)$ 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 $\mathscr{F}(\tilde{\theta}_t) = \tilde{\theta}_t$ 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:

$$\mathbf{\Xi}(\tilde{\theta}_t) = (\mathbf{e}'_{1,N}\mathscr{F}(\tilde{\theta}_t)'\mathbf{Z}'_1, \dots, \mathbf{e}'_{N,N}\mathscr{F}(\tilde{\theta}_t)'\mathbf{Z}'_N)' = \mathbf{0}. \tag{D.29}$$

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 Section D.1, as done by Arias et al. (2018). Notably, Equation (D.24) can be rewritten in the so-called orthogonal reduced-form parametrization as follows:

$$\mathbf{Y}_t = \mathbf{X}'_t\theta_t + \mathbf{Q}h(\mathbf{\Omega}_t)\varepsilon_t, \tag{D.30}$$

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:

$$f_h(\tilde{\theta}_t) = \Big(\underbrace{(A_t^+ A_{0,t}^{-1})}_{\theta_t}, \underbrace{(A_{0,t}A'_{0,t})^{-1}}_{\mathbf{\Sigma}_t}, \underbrace{h((A_{0,t}A'_{0,t})^{-1})A_{0,t}}_{\mathbf{Q}} \Big). \tag{D.31}$$

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

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

$$f_h^{-1}(\theta_t, \mathbf{\Sigma}_t, \mathbf{Q}) = \Big(\underbrace{h(\mathbf{\Sigma}_t)^{-1}\mathbf{Q}}_{A_{0,t}}, \underbrace{(\tilde{\theta}_t h(\mathbf{\Sigma}_t)^{-1}\mathbf{Q}}_{A_t^+} \Big). \tag{D.32}$$

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, Equation (D.28) and Equation (D.29) can be rewritten as:

Sign restrictions

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

Zero restrictions

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

D.4.1 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 Section D.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 $\mathbf{Q} = [\mathbf{q}_1 \ldots \mathbf{q}_N]$ 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

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

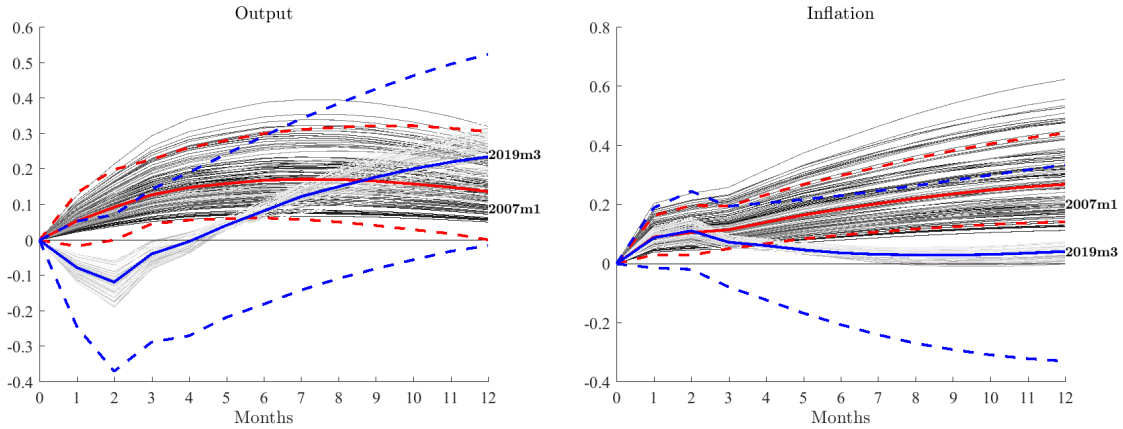
9. The structural parameters are retrieved from $(A_{0,t}, A_t^+) = f_h^{-1}(\theta_t, \mathbf{\Sigma}_t, I_N)$ and the draw is kept if it satisfies the sign restrictions, as defined in Equation (D.28), for each $j = 1, \ldots, N$.

Steps 4 to 6 in Section D.1 and, then, 7 to 9 are repeated for each $m = 1, \ldots, M$. In the baseline estimation, $M = 100000$, with a burn-in of 20000 iterations, for a total of $80000 \times T$ draws.

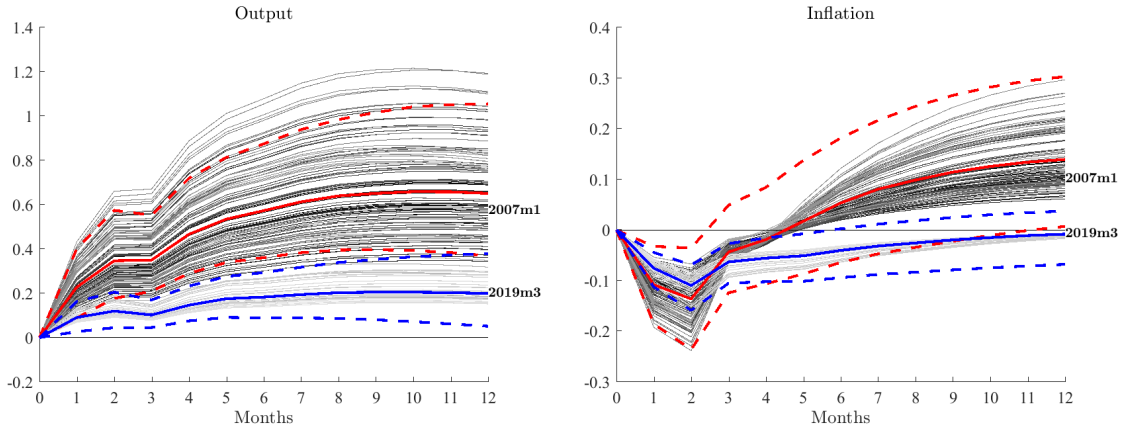
E Additional charts

Figure E.3: Evolution in IRFs of output (left panels) and inflation (right panels) to a decrease in 10-year term premium spreads by 10bps

(a) Core EA



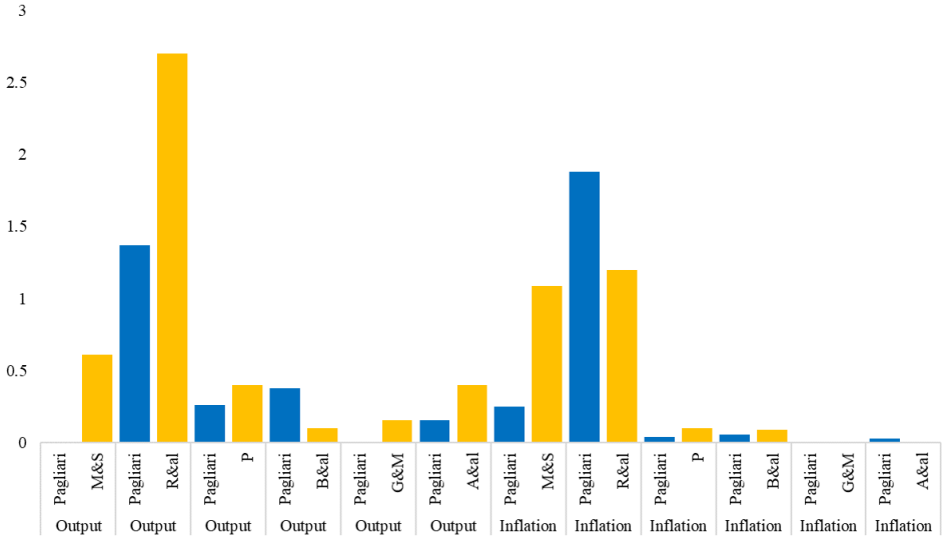
(b) Peripheral EA



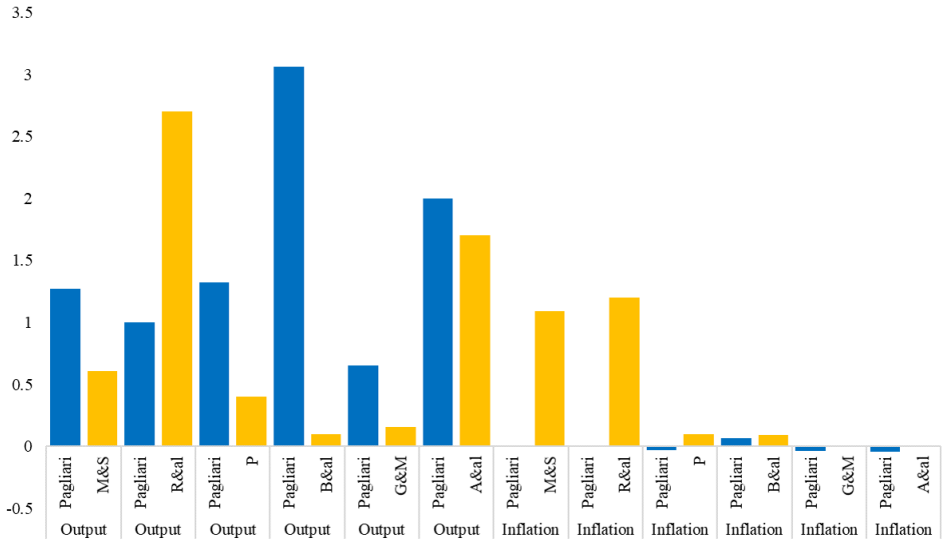
Legend: before June 2014; after June 2014.
Notes: Dashed lines are 68% confidence bands. Lighter gray lines represent more recent periods.
Source: Author's calculations.

Figure E.4: Graphical comparison of macroeconomic impact of UMPs across papers

(a) Core EA



(b) Peripheral EA



Legend: Pagliari (2021); other papers.
Notes: Cumulative effects over reference periods. Other papers - M&S = Mouabbi and Sahuc (2019); R&al = Rostagno et al. (2019); P = Peersman (2011) ; B&al = Boeckx et al. (2017); G&M = Gambetti and Musso (2017); A&al = Altavilla et al. (2016).
Source: Author's calculations.