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Low inflation and monetary policy in the euro area

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This paper presents research conducted within the Task Force on Low Inflation (LIFT). The task force is composed of economists from the European System of Central Banks (ESCB) - i.e. the 29 national central banks of the European Union (EU) and the European Central Bank. The objective of the expert team is to study issues raised by persistently low inflation from both empirical and theoretical modelling perspectives.

The research is carried out in three workstreams:

1) Drivers of Low Inflation;

2) Inflation Expectations;

3) Macroeconomic Effects of Low Inflation.

LIFT is chaired by Matteo Ciccarelli and Chiara Osbat (ECB). Workstream 1 is headed by Elena Bobeica and Marek Jarocinski (ECB) ; workstream 2 by Catherine Jardet (Banque de France) and Arnoud Stevens (National Bank of Belgium); workstream 3 by Caterina Mendicino (ECB), Sergio Santoro (Banca d'Italia) and Alessandro Notarpietro (Banca d'Italia).

The selection and refereeing process for this paper was carried out by the Chairs of the Task Force. Papers were selected based on their quality and on the relevance of the research subject to the aim of the Task Force. The authors of the selected papers were invited to revise their paper to take into consideration feedback received during the preparatory work and the referee's and Editors' comments.

The paper is released to make the research of LIFT generally available, in preliminary form, to encourage comments and suggestions prior to final publication. The views expressed in the paper are the ones of the author(s) and do not necessarily reflect those of the ECB, the ESCB, or any of the ESCB National Central Banks.

Abstract

Inflation in the euro area has been falling since mid-2013, turned negative at the end of 2014 and remained below target thereafter. This paper employs a Bayesian VAR to quantify the contribution of a set of structural shocks, identified by means of sign restrictions, to inflation and economic activity. Shocks to oil supply do not tell the full story about the disinflation that started in 2013, as both aggregate demand and monetary policy shocks also played an important role. The lower bound to policy rates turned the European Central Bank (ECB) conventional monetary policy *de facto* contractionary. A country analysis confirms that the negative effects of oil supply and monetary policy shocks on inflation was widespread, albeit with different intensity across countries. The ECB unconventional measures since 2014 contributed to raising inflation and economic activity in all the countries. All in all, our analysis confirms the appropriateness of the ECB asset purchase programme.

JEL classification codes: C32; E31; E32; E52.

Keywords: inflation; VAR models; oil supply; monetary policy; Bayesian methods.

Non-technical summary

The prolonged decline in euro-area headline inflation that started in the Spring of 2013 has fostered a wide debate on the underlying causes and on the appropriate monetary policy response. Notwithstanding the fact that the decline in inflation was a global phenomenon, also resulting from the collapse of oil prices, the euro area was characterized by two peculiar facts. First, core inflation, i.e. inflation net of energy and unprocessed food prices, declined as well to low levels and reached a minimum in early 2015. Second, inflation expectations at all horizons fell to historical lows and well below the definition of price stability of the Governing Council of the European Central Bank.

This paper relies on a Bayesian Vector AutoRegressive (BVAR) model in order to assess the drivers of euro-area inflation and economic activity. We identify several shocks hitting the economy by means of theory-consistent sign restrictions on impulse responses, namely oil supply, world demand for euro area exports, domestic demand and supply and monetary policy shocks.

The main findings can be summarized as follows. First, the shocks are able to explain the bulk of both inflation and economic activity in 2013-2015, with both domestic demand and foreign demand shocks playing a major role. Second, the fall in oil prices cannot account for the whole disinflation that started in 2013. The joint contribution of aggregate demand and monetary policy shocks was at least as relevant as oil supply shocks in driving inflation downwards, as the increase of the real short-term rate *de facto* acted as a tightening of monetary conditions. The contribution of monetary shocks was indeed negative and non-negligible in 2013 and 2014. This finding has important implications for the ECB monetary policy, as official rates were close to their effective lower bond and the asset purchase programme had not been introduced yet.

The paper also studies the role of unconventional measures adopted by the ECB during the global financial and sovereign debt crises, by considering a measure of the “shadow” interest rate which better describes the stance of monetary policy when official rates are close to their effective lower bound. In this case, the contribution of monetary policy shocks to inflation and output turns to be positive and large from the first quarter of 2015, when the ECB started purchasing government bonds within the APP.

We also explore the role played by the area-wide aggregate shocks in shaping inflation and real GDP growth developments in ten euro-area countries. We find that oil supply shocks have driven inflation to low levels in all the countries considered, although with varying intensity, thus confirming that the disinflation that started in early 2013 was a widespread phenomenon rather than the result of relative price adjustments in the aftermath of the sovereign debt crisis. The negative contribution of monetary policy shocks to inflation between 2013 and 2015 was larger in the countries hardest hit by the sovereign crisis. The unconventional measures adopted by the ECB since 2014 contributed positively to both inflation and economic activity in all the countries.

The results have important implications for monetary policy in the euro area, as they confirm the appropriateness of the asset purchase programme, which was introduced in September 2014 and the significantly expanded in January 2015 by including public securities.

1. Introduction

In Spring 2013 euro-area headline inflation began declining, reaching historically low levels at the end of 2014 (Figure 1). This downward trend characterized also other advanced economies. Three years later, inflation in the euro area remains close to zero and inflationary pressures are limited. Part of the decline reflected global factors such as the collapse of oil prices since mid-2014.[1] Domestic factors, however, may have also played a role, as suggested by developments in core inflation, i.e. inflation net of energy and unprocessed food prices, which declined to low levels and reached a minimum in early 2015. During the same period, core inflation in the U.S. remained persistently above the corresponding indicator for the euro area, notwithstanding the still negative output gap on both sides of the Atlantic. More importantly, inflation expectations at all horizons fell to historical lows in the euro area, well below the definition of price stability of the Governing Council of the European Central Bank (ECB henceforth), while they remained stable in the U.S. and close to the long-run target of the Federal Open Market Committee of the Federal Reserve.

In late 2014 the causes of the disinflation were high on the agenda of policymakers in the euro area (Draghi, 2014), as ECB policy rates were close to their effective lower bound (Figure 1).[2] The objective of this paper is to assess the drivers of inflation in the euro area, with a special focus on the 2013-2015 period. This assessment is essential for monetary policy for a number of reasons.

First, large shocks require bold policy actions. This is particularly relevant for the euro area since when the disinflation process started in the Spring of 2013, the economy was in recession, the output gap was large and negative (even up to a range between 4 and 6 per cent; Jarocinski and Lenza, 2016) and asset purchases had not been introduced yet. When oil prices collapsed in the second half of 2014, policy rates were already close to their effective lower bound and the economy was recovering at moderate pace. The persistent decline of inflation expectations signalled an increasing risk of de-anchoring from the inflation target and raised concerns about the credibility of the ECB (Cecchetti, Natoli and Sigalotti, 2015 and Łyziack and Paloviita, 2016). The risk of de-anchoring of expectations, the weakness of the recovery and the presence of the lower bound justified the introduction of the Asset Purchase Programme (APP), which was launched in

[1] The price of Brent oil fell by 64 per cent between mid-2014 and early 2016, from 80 euro per barrel to 29, close to the previous minimum reached after the 2008 bust and the bankruptcy of Lehman Brothers.

[2] "*This downward movement of inflation was primarily driven by declines in energy and food price inflation, which are two components that tend to be volatile and whose effects are typically temporary.* […] *But we also see that core inflation is low – the inflation rate that strips out these volatile and temporary components.* […] *A low reading for core inflation* […] *indicates that it is not only temporary factors that are operative: underlying demand weakness is also playing a role. Indeed, we have clear signs from survey data that weak demand is contributing to low pricing power among firms*." Opening speech by Mario Draghi at the Frankfurt European Banking Congress, Frankfurt am Main, 21 November 2014.

January 2015 and was expected to increase the size of the balance sheet of the Eurosystem up to 3 trillion of euros (Figure 1).

A second and related reason is that the central bank might not provide the necessary stimulus to the economy, as the Japanese experience during the two "lost decades" has shown. When the policy rate is close to the effective lower bound, a decline in expected inflation leads to an increase in real interest rates, which, in a context of weak aggregate demand, is *de facto* equivalent to a monetary policy tightening. Between September 2012 and December 2014 the *ex ante* real three-month interest rate in the euro area increased by 2.6 percentage points, from -2.3 per cent to 0.3, mostly reflecting the fall in inflation expectations.

Third, the transmission of shocks may change at the lower bound, with important and challenging policy implications. For example, favourable supply-side shocks could become recessionary at the relevant policy horizons. Garín, Lester and Sims (2016) consider a model in which a shock to productivity temporarily reduces the natural rate of interest and raises output. However, as the central bank cannot accommodate the shock at the lower bound, a decline in expected inflation leads to a higher real interest rate which reduces aggregate demand. The empirical analysis shows that, in contrast with the predictions of the model, positive productivity shocks are more expansionary at the lower bound compared to normal times; these shocks, instead, have a stronger negative effect on inflation, as predicted by the model. Wieland (2015) also studies the role of supply shocks at the lower bound. Focusing on the 2011 earthquake in Japan and on oil supply shocks, the author finds that these shocks are contractionary at the lower bound despite rising inflation expectations and lowering expected future nominal and real interest rates. Neri and Notarpietro (2015) show that cost-push shocks, that in normal times would lead to an increase in output, are recessionary when the policy rate is at the lower bound.

In order to assess the drivers of inflation in the euro area between 2013 and 2015, we estimate a Bayesian Vector AutoRegressive (BVAR) model and identify five shocks: oil supply, world demand for euro area exports, aggregate demand and supply and monetary policy. The identification is based on the sign restrictions approach developed by Canova and De Nicolò (2002) and Uhlig (2005) and refined by Rubio-Ramírez, Waggoner and Zha (2010). The identifying assumptions are consistent with workhorse New-Keynesian models (Smets and Wouters, 2003 and 2007) as well as open-economy models with endogenous fluctuations in oil prices in which the existence of the lower bound affect the propagation of shocks (Bodenstein, Guerrieri and Gust 2013 and Bodenstein, Guerrieri and Kilian, 2012). The determinants of oil prices and their potential endogeneity to developments in the global economy have been studied by Barsky and Kilian (2002, 2004), who launched an extensive literature on oil prices. Recently, Baumeister and Kilian (2016) provided a comprehensive historical review of the causes of the major oil price fluctuations.

The main results of our analysis can be summarised as follows. First, the five identified shocks explain the bulk of both inflation and economic activity; this is an important result given the small size of the model, with aggregate domestic demand and foreign (rest-of-the-world, RoW henceforth) demand shocks playing a major role. Second, the fall in oil prices does not tell the full story about the disinflation process started in 2013. Both aggregate demand and monetary policy shocks played an important role in pushing inflation further down as the increase of the real short-term rate *de facto* acted as a tightening of monetary conditions. This result is important for assessing the monetary stance of the ECB, as the policy rates were close to their effective lower bound and asset purchases had not been introduced yet. The contribution of monetary shocks was negative and non-negligible in 2013 and 2014 while oil supply shocks supported economic growth since mid-2014, in line with the findings in Caldara, Cavallo and Iacoviello (2016).

We corroborate these findings by addressing the role of unconventional measures adopted by the ECB during the global financial and sovereign debt crises, and in particular the APP introduced in September 2014 and substantially strengthened in January 2015. Assessing the effectiveness of unconventional measures is a non-trivial task and is the subject of an intensive and ongoing research.[3] We address this issue by using a shadow interest rate (Wu and Xia, 2015 and Krippner, 2013), which allows us to better describe monetary policy at the lower bound of policy rates. Our results are confirmed. Importantly, the contribution of monetary policy shocks to inflation and output turns positive and large from the first quarter of 2015, when the ECB started purchasing government bonds within the APP.

We also assess the contribution of the area-wide aggregate shocks to inflation and real GDP growth in ten euro-area countries. A country-level analysis is essential to shed light on the heterogeneity in the transmission of monetary policy (Ciccarelli, Maddaloni and Peydrò, 2013). We find that oil supply shocks have driven inflation to low levels in all countries, although with varying intensity, confirming that the disinflation that started in 2013 was a widespread phenomenon rather than the result of relative price adjustments in the aftermath of the sovereign debt crisis. The negative contribution of monetary policy shocks to inflation between 2013 and 2015 is larger in the countries hardest hit by the sovereign crisis. The unconventional measures adopted by the ECB since 2014 contributed positively to both inflation and economic activity in all the countries.

[3] Previous empirical studies for the euro area relied on high-frequency financial data (Altavilla, Carboni and Motto, 2015), as well as VAR methods (Lenza, Pill and Reichlin, 2010, Peersman, 2011, Giannone et al., 2012, Gambacorta, Hofmann and Peersman, 2014, Darracq-Paries and De Santis, 2015 and Boeckx, Dossche and Peersman, 2016).

Our paper is related to the existing empirical literature on the transmission of macroeconomic shocks in the euro area as a whole and in its member states. Previous analyses focused on a smaller set of shocks, such as monetary policy (Peersman and Smets, 2003, Peersman, 2004, Boivin, Giannoni and Mojon, 2009 and Barigozzi, Conti and Luciani, 2014), technology shocks (Peersman and Straub, 2009), oil price shocks (Peersman and Van Robays, 2009 and Riggi and Venditti, 2015a), financial and credit shocks (Hristov, Hülsewig and Wollmershäuser, 2012, Ciccarelli, Maddaloni and Peydrò, 2015, Darracq-Paries and De Sanctis, 2015 and Gambetti and Musso, 2016). Important exceptions are Canova and De Nicolò (2002) and Peersman (2005). The first paper identifies only domestic shocks (supply, demand and monetary policy) in the G-7 countries. The second paper identifies four shocks (oil price, supply, demand and monetary policy) in order to explain the millennium slowdown in the U.S. and the euro area. Differently from this study, we distinguish between oil supply and RoW demand shocks as drivers of oil prices, in line with the most recent literature. Besides the number of identified shocks, none of the above-mentioned contributions focused on a prolonged period low and falling inflation in which the policy rate was close to the effective lower bound, such as the period 2013-2015.

This paper also relates to other contributions based on VAR models which assess the relative importance of global and domestic factors in explaining inflation dynamics in developed countries. Some papers argued that inflation is largely a global phenomenon, as the globalisation process rendered inflation more sensitive to economic developments abroad (see, for example, Ciccarelli and Mojon, 2010, Mumtaz and Surico, 2012 and Ferroni and Mojon, 2015). Bobeica and Jarocinski (2016) argue that, despite the global nature of inflation, domestic shocks can explain both the "missing disinflation" and "missing inflation" episodes in the U.S. and the euro area. This evidence is based on conditional forecasting with a medium-scale reduced-form VAR. The importance of domestic factors, however, is also confirmed by a more parsimonious structural VAR in which the identification of shocks is based on existing studies, including ours. Compared with these studies, our analysis is more oriented towards quantifying the contribution of monetary policy to the 2013-15 disinflation and assessing the impact of unconventional measures at both the euro-area and country levels.

The remainder of the paper is organized as follows. Section 2 presents the model and the identification of the shocks. Section 3 shows the impulse responses and Section 4 the historical decomposition of the key euro-area variables. Section 5 presents the cross-country analysis and Section 6 discusses a number of robustness checks. Section 7 offers some concluding remarks.

2. The Bayesian VAR

In order to carry out our analysis we adopt a VAR model estimated by means of Bayesian methods to handle the relatively scarce number of observations, since reliable euro-area data are available since mid-nineties. As the model is linear, it is not well-suited to deal with the potential non-linear effects of aggregate shocks at the lower bound of the policy rate. However, to some extent, these effects can be attributed to monetary policy shocks, as the central bank cannot offset these aggregate shocks. Moreover, the use of a shadow rate can help modelling monetary policy at the lower bound of the policy rate. In what follows we briefly describe the specification and the estimation of the VAR and the identification of the shocks.

2.1 The model

Let $\mathbf{y}_{\mathrm{t}}$ be a *n×1* vector of macroeconomic variables. Their joint dynamics is described by the following system of linear equations:

$$\mathbf{y}_t'\mathbf{A}_0 = \mathbf{c}' + \sum_{\mathrm{j}=1}^{\mathrm{p}} \mathbf{y}_{t-j}'\mathbf{A}_j + \boldsymbol{\varepsilon}_t' \qquad \boldsymbol{\varepsilon}_{\mathrm{t}} \sim i.i.d.(\mathbf{0}, \mathbf{I}_n) \qquad t = 1,2, \dots \dots T \tag{1}$$

where $\mathbf{c}$ is a *n×1* vector of constants, $\boldsymbol{\varepsilon}_{\mathrm{t}}$ is a *n×1* vector of exogenous structural shocks, $\mathbf{A}_{\mathrm{j}}$ is a *n×n* matrix of parameters for $0 \le j \le p$ with $\mathbf{A}_0$ invertible, *p* is the lag length and *T* is the sample size. Conditional on past information and initial conditions the vector $\boldsymbol{\varepsilon}_{\mathrm{t}}$ is Gaussian with zero mean and variance covariance matrix $\mathbf{I}_n$. In section 2.3 we describe how the matrix $\mathbf{A}_0$ is obtained. The model described in (1) can be also cast in a more compact form:

$$\mathbf{y}_t'\mathbf{A}_0 = \mathbf{x}_{\mathrm{t}}'\mathbf{A}_+ + \boldsymbol{\varepsilon}_{\mathrm{t}}', \qquad t = 1,2, \dots \dots T \tag{2}$$

where $\mathbf{A}_+' = [\mathbf{A}_1' \dots \mathbf{A}_{\mathrm{p}}' \;\; \mathbf{c}']$ and $\mathbf{x}_{\mathrm{t}}' = [\mathbf{y}_{\mathrm{t}-1}' \dots \mathbf{y}_{\mathrm{t-p}}' \;\; 1]$. The dimension of $\mathbf{A}_+'$ is *m×n*, where *m=np+1*. Equation (2) implies a reduced-form representation given by

$$\mathbf{y}_{\mathrm{t}}' = \mathbf{x}_{\mathrm{t}}'\mathbf{B} + \mathbf{u}_{\mathrm{t}}', t = 1,2, \dots \dots T \tag{3}$$

where $\mathbf{B} = \mathbf{A}_+\mathbf{A}_0^{-1}$, $\mathbf{u}_{\mathrm{t}}' = \boldsymbol{\varepsilon}_{\mathrm{t}}'\mathbf{A}_0^{-1}$, and $\mathbb{E}[\mathbf{u}_{\mathrm{t}}\mathbf{u}_{\mathrm{t}}'] = \boldsymbol{\Sigma} = (\mathbf{A}_0\mathbf{A}_0')^{-1}$. The matrices $\mathbf{B}$ and $\boldsymbol{\Sigma}$ are the reduced form parameters, while $\mathbf{A}_0$ and $\mathbf{A}_+$ are the structural parameters.

2.2 The data

The sample consists of quarterly observations for the period 1995:Q1 – 2015:Q3 on euro area and international variables, which help identifying both domestic and international shocks driving inflation. The data are taken from the Area Wide Model Database (AWM; Fagan, Henry and

Mestre, 2005), the ECB Statistical Data Warehouse, ECB Macroeconomic Projection Exercise database and Bloomberg.

The baseline specification includes six variables: the real oil price (the nominal oil price in U.S. dollars deflated by the euro-area consumer price index), an indicator of world demand of euro-area goods and services, real GDP, the Harmonized Index of Consumer Prices (HICP) or the core HICP (i.e. the price index net of energy, food and tobacco), the EONIA rate (assumed to be the policy rate of the ECB) and the nominal effective exchange rate of the euro against the major trade partners.[4,5] All variables, except for the interest rates, are log-transformed. When seasonal patterns are relevant, we use the seasonally adjusted time series. By estimating the VAR in levels we are implicitly allowing for the possible presence of cointegrating relations, without imposing restrictions on the long-run properties of the model (Sims, Stock and Watson, 1990).

2.3 The identification of the shocks

The identification method is based on the sign restrictions approach proposed by Canova and De Nicolò (2002) and Uhlig (2005) and refined by Rubio-Ramírez, Waggoner and Zha (2010). We focus on a set of structural shocks that are likely to be relevant for quantifying their role in driving inflation.

From a theoretical standpoint, the specification of the VAR and the restrictions to identify the shocks are based on open-economy models with endogenous oil price fluctuations (Backus and Crucini, 1998), in which domestic monetary policy responds to both domestic and foreign shocks (Bodenstein and Guerrieri, 2011 and Bodenstein, Guerrieri and Kilian, 2012) and the presence of the lower bound to the policy rate affect the transmission of these shocks by limiting the effectiveness of monetary policy (Bodenstein, Guerrieri and Gust, 2013). The restrictions on the signs of the impulse responses are reported in Table 1.[6]

The first shock is a textbook oil supply shock: an exogenous decrease in real price of oil pushes inflation down and increases both domestic and foreign output. We do not impose any restriction on the sign of the response of the short-term rate. Oil supply shocks typically pose a dilemma to policymakers as they give rise to a trade-off between the stabilization of output and inflation. We follow Peersman and Van Robays (2009) and leave the response of the euro-area

[4] Results are qualitatively similar if the Federal Funds rate and the option-implied expectation of volatility of the U.S. stock market are included as exogenous variables.

[5] The EONIA rate is affected by the excess liquidity in the euro-area banking system. The results are qualitatively similar if the rate on the main refinancing operations (MRO) is used.

[6] Bobeica and Jarocinski (2016) use similar identifying assumptions. We refrain from identifying a shock to the exchange rate since it may capture several foreign shocks, including to the U.S. monetary policy. The authors find that shocks to the exchange rate play a negligible role in explaining the dynamics of inflation.

short-term interest rate to different oil shocks unconstrained in their VAR. The authors show that conditional on oil supply shocks, the real oil price and the short-term rate co-move positively suggesting that the ECB pursues the stabilization of inflation rather than the stabilization of output. Jacquinot et al. (2009) and Forni et al. (2015) obtain similar results in the context of DSGE models, mainly as the result of the estimated parameters of the monetary policy rules.

Table 1. Sign restrictions used for identification

	Shock				
Variable	Oil supply	RoW demand	Aggregate demand	Monetary Policy	Aggregate supply
Real oil price	-	-			+
Rest-of-the-World output	+	-			
Euro-area consumer prices	-	-	-	-	-
Euro-area output	+	-	-	-	+
Euro-area short-term rate		-	-	+	
Exchange rate		+	-	+	

Note: a "+" (or "-") indicates that the impulse response of the variable in question is restricted to be positive (negative) on impact. A blank entry indicates that no restrictions is imposed; a "+" (or "-") for the (nominal effective) exchange rate implies that the structural shock leads to an appreciation (depreciation) of the euro vis-à-vis the other currencies.

A shock to RoW demand is identified as implying a positive co-movement between the RoW output and the real price of oil. The identification of this shock is important for two reasons. First, the fall in euro-area inflation and oil prices may also reflect the slowdown in global economic activity. Baumeister and Kilian (2016) and Caldara, Cavallo and Iacoviello (2016) show that the decline in oil prices since mid-2004 reflected supply-side factors, such as the growth of U.S. shale oil production and the increased oil production in other countries, as well as the decline in global economic activity. The two analyses differ in term of the relative importance of the two factors. A similar assessment applies to the collapse of oil prices in late 2008-early 2009. The second reason is that a RoW demand shock can have different effects on the real economy (Barsky and Kilian, 2004 and Kilian, 2009), and therefore call for different responses by the central bank, in particular when policy rates are at their lower bound (Bodenstein, Guerrieri and Gust, 2013 and Bodenstein, Guerrieri and Kilian, 2012). In light of this evidence, we assume that both euro-area output and the short-term interest rate decline following a negative RoW demand shock.[7] Peersman and Van

[7] Our assumption regarding the RoW demand shock are consistent with a foreign preference shock. The model developed by Bodenstein, Guerrieri and Kilian (2012) allows for several shocks that may shift the demand for and supply of oil. The identification of all these shocks goes beyond the scope of this paper. Our objective is to control for external developments which may explain inflation developments and bias the identification of domestic demand and monetary

Robays (2009), Jacquinot et al. (2009) and Forni et al. (2015) found that these restrictions are, indeed, supported by the data, at least before the global financial crisis. We also assume that a negative RoW demand shock leads to an appreciation of the exchange rate, consistently with the home bias feature in open-economy models. Since the elasticity of substitution between domestic and imported goods in the consumption basket is commonly calibrated to values larger than 1, the demand for foreign goods falls more than that of domestic goods, implying an appreciation of the exchange rate (De Paoli, 2009 and Kollmann, 2012). This restriction is important to disentangle RoW demand shocks from domestic demand shocks.[8]

The third shock we consider is a domestic aggregate demand shock: a negative shock to domestic demand decreases output, inflation and the policy rate in the euro area and leads to a depreciation of the exchange rate. These restrictions are consistent with shocks affecting directly domestic consumption and investment in New-Keynesian models (e.g. Smets and Wouters, 2007). We are aware that a domestic aggregate demand shock could be a combination of other aggregate shocks, such as credit supply or fiscal shocks, which have similar effects. We test the robustness of our results in Section 6 by including credit variables in the VAR and identifying a loan supply shock. We instead do not consider fiscal shocks as they are mainly country-specific and therefore cannot be properly identified using sign restrictions on the responses of euro-area variables.

The fourth shock we consider is a conventional monetary policy shock. In the baseline model we do not explicitly consider the role played by the several types of unconventional measures adopted by the ECB since the outbreak of the global financial crisis. However, the adoption of the EONIA as policy rate partially takes into account the additional monetary easing arising from the excess liquidity generated by the ECB unconventional measures. We further explore the role played by the unconventional monetary policy in Section 4.3. As for the monetary policy shock, an unexpected increase in the short-term interest rate reduces both output and inflation and leads to an exchange rate depreciation. We remain agnostic about the response of both real oil prices and RoW output. In the case of large economies, such as the euro area, causality in these relationships may run in both directions, implying that shocks originated in the euro area may affect the demand

shocks. However, since theory suggests that different foreign shocks may have different short-run effects on euro-area output and the policy rate, in Section 6 we carry out additional analyses to study other type of foreign shocks.

[8] Alternatively, we can consider the RoW to domestic output ratio between the as in Corsetti, Dedola and Leduc (2014) and impose an opposite sign to its response following RoW and domestic demand shocks. Experimenting with this alternative identification yields similar results to benchmark scheme.

for oil at the global level and therefore its price. We, however, prefer to remain agnostic and let the data speak by themselves, given also the scant empirical evidence for the euro area.[9]

The fifth and last shock is an aggregate supply shock originating in the euro area which drives domestic prices and output in opposite directions. Peersman and Straub (2009), for example, found an important role for technology shocks in explaining business cycle fluctuations in the euro area. The response of real oil prices is assumed to be positive, driven by the stronger reduction of domestic consumer prices compared with that of oil prices. This is sufficient to disentangle oil supply shocks from aggregate supply shocks. We do not impose restrictions on the sign of the response of the exchange rate. Although the literature is not conclusive on this point, Farrant and Peersman (2006) found that this may be the case for the euro area. However, this choice is irrelevant for our scheme, which already achieves identification of the shocks.

A key parameter in the sign restriction approach is the number of periods over which the restrictions are imposed. In this regard, Canova and Paustian (2011) show that sign restrictions imposed on the contemporaneous relationships among variables are robust to several types of model misspecification. We take on board their suggestion and impose the restrictions only on the impact responses. As for the identification of the shocks, we rely on the algorithm developed by Rubio-Ramirez, Waggoner and Zha (2010) as it is more efficient in systems of size larger than four variables and has become the standard.

2.4 Inference

We set the number of lags in the VAR to four, based on the serial correlation of the residuals. As for the prior distribution, we assume a normal-Wishart prior for the reduced form coefficients and the covariance matrix of the residuals. As for the former, we impose the Minnesota prior (Doan, Litterman and Sims, 1984). The parameters of the prior distribution of the reduced form coefficients are standard: the overall degree of tightness is set to 0.5, the standard deviation of the coefficients on the own lags is set to 0.1 and the decay is linear.

The posterior distribution of the reduced-form parameters of the VAR, which is obtained by combining the (normal) likelihood of the VAR with the prior distribution, is normal conditional on the Wishart distribution for the covariance matrix of the error terms. Inference is conducted using the Gibbs sampling algorithm. For each draw from the posterior distribution of the VAR we search

[9] Peersman (2005) imposes restrictions on signs of the response of the nominal oil price to domestic shocks in the euro-area. The impulse responses suggest a significant short-run impact on oil prices.

for a rotation matrix of the Cholesky factor of the covariance matrix of the residuals until we identify the five shocks jointly.

3. Impulse responses

In this Section we present the impulse responses to the identified shocks. The results are based on 250,000 draws from the posterior distribution and 50,000 from the unit sphere.

Figure 2 shows the median (solid thick blue line) together with 0.68 probability interval (light blue shaded areas) of the posterior distribution of the responses to the identified shocks. The persistence of the responses is not unrestricted and it is solely determined by the coefficients of the reduced form of the VAR.

The first row shows the responses to an oil supply shock that lowers the real price of oil. Consumer prices decline and real GDP increases persistently, reaching a peak after two years. For the whole horizon the 0.68 probability interval is above zero, suggesting that the result is not driven only by the sign restriction but also by the persistence implied by the reduced form of the model. The negative effect on consumer prices is, instead, less persistent. World demand increases as foreign economies also experience an increase in output, which raises imports from the euro area. The median response of the short-term interest rate (note that the response is not constrained) is positive and the posterior probability that the response is larger than zero on impact is 0.7, suggesting that it is more likely that the central bank raises the policy rate in response to a negative oil supply shock. This result differs from the finding in Peersman and Van Robays (2009) and Forni et al. (2015). In Section 6.1 we explore whether this difference is due to the use of a larger sample period which includes the global financial and sovereign debt crises, when the ECB may have been more concerned about the effects on economic activity than inflation. We find that this is not the case.

The dynamic effects of a monetary policy shock that raises the short-term rate are shown in the second row from the top of Figure 2. The shock leads to a persistent decline in output and prices and to an immediate and large appreciation of the euro. The response of the price level is more sluggish compared with that of real GDP, in line with the extensive literature on the effects of monetary policy in VAR models (Christiano, Eichenbaum and Evans, 1999). The impulse responses are qualitatively similar to those in Peersman (2005).

The responses to a domestic aggregate demand shock are shown in the third row of Figure 2. Following a negative shock, real oil prices decline sharply. This result is worth emphasizing since oil prices, which are fixed in international markets, are usually considered exogenous with respect to the euro area. Peersman (2005) finds that the nominal oil price reacts significantly to aggregate demand and monetary policy shocks in the euro area over the period 1995-2002. The effects on inflation and the exchange rate are more persistent than those implied by oil supply shocks. The central bank reduces the short-term rate to offset the negative demand shock and stabilize output and inflation.

The dynamic effects of a positive supply shock are shown in the fourth row of Figure 2. The shock raises real GDP and lower consumer prices, although the magnitude of the latter effect is small. The persistence of the responses to an aggregate supply shock is much lower than in Peersman (2005), whereas that to an aggregate demand shock is similar. Real oil prices increase persistently, as output in the euro area and world demand (possibly reflecting the positive spillover of euro-area economic activity on RoW output) raise oil demand. The central bank raises the short-term rate, although marginally.

The last row of Figure 2 shows the responses to shock that reduces the RoW demand. The effect on the real price of oil is quantitatively similar to the effect induced by a shock to oil supply. Output and consumer prices decline on impact, and so does the short-term rate as the central bank aims at stabilizing output and inflation. Following a negative RoW demand shock, the adverse effect on euro-area real GDP more than compensates the positive effect stemming from the lower real price of oil and the easing of monetary policy. While both shocks have similar effects on inflation, mixing the two may bias the response of the other euro-area variables, in particular output and monetary policy.

4. The drivers of inflation and economic activity in the euro area

Having discussed the dynamic effects of the identified shocks, this section quantifies their contribution to inflation and real GDP growth in the euro area. To this end we compute the historical decomposition of variables, drawing the parameters of the VAR from their posterior distribution and using the identification scheme discussed in Section 2. We start the simulations in the first quarter of 1998 in order to remove the dependence of the results on the initial conditions. All the figures report the median of the posterior distribution of the historical decomposition, as commonly done in the literature: the figures show for each quarter of the sample the contribution of the current and past shocks to the deviations of each variable from their respective baselines, which represent the path of the variables that would arise in the absence of shocks.

4.1. The drivers of inflation

Figure 3 (panel a) shows the results for the deviations of the euro-area inflation from the baseline. The historical decomposition of inflation is constructed by taking the four-quarter differences of the decomposition of the price level.

Among the identified shocks, aggregate demand (green bars) and RoW demand shocks (light blue bars) are the main drivers of inflation in the full sample, consistently with the findings in Ferroni and Mojon (2016). These shocks explain a large part of the increase in inflation in 2008 and the subsequent decline in the following year, whereas oil supply shocks (red bars) are less important. Hamilton (2009) and Kilian (2009) show that the oil price run-up of 2007-08 was caused by strong demand rather than by declining supply. The contribution of monetary policy (blue bars) and aggregate supply (grey bars) shocks turns out to be small on average.

Unidentified shocks (yellow bars), which are not important before 2008, account for a large fraction of inflation developments in two specific periods: between mid-2011 and end-2012 and from mid-2014 onward. As for the former, part of this unexplained component may reflect the impact of higher indirect taxes (e.g. VAT and excise duties) on consumer prices. Indeed, the average impact of changes in these taxes on prices in 2012 is around 0.4 percentage points, whereas the average contribution of the unidentified shocks in the same period is around 0.6 percentage points. An alternative explanation hinges upon commodity other than energy prices. Indeed, such prices rose substantially between late 2009 and mid-2011, after having collapsed during the global financial crisis. Understanding the role of commodity other than oil prices may help accounting for a large fraction of inflation developments, but it would not alter the results regarding the other identified shocks, and in particular monetary policy and oil supply. As for the 2014-2015 period in which a large part of inflation developments is unexplained, a possible explanation is related to the fall of medium and long-term inflation expectations, which may have added further downward pressure to consumer price dynamics through second-round effects on firms pricing. For example, the average 5-year ahead inflation expectations surveyed by the ECB (Survey of Professional Forecasters) declined from 2.0 per cent in late 2013 to 1.65 in the first quarter of 2016, after having remained stable at close to 2.0 per cent since 2003.

Panel b of Figure 3 zooms on the 2013-15 period in order to assess the role played by oil supply, aggregate demand and monetary policy shocks in the disinflation. The increasing role of oil supply shocks is confirmed by the historical decomposition of the real oil price: around one third of the negative deviation from the baseline in 2014 and 2015 is accounted for by these shocks. This result is consistent with Caldara, Cavallo and Iacoviello (2016) who show that supply shocks account for an important fraction of the 2014-15 oil slump. The importance of aggregate demand shocks increased over time, reaching a maximum in the first quarter of 2015. This result is consistent with Ferroni and Mojon (2016) and Bobeica and Jarocinski (2016). Oil shocks have also become increasingly important: in the same quarter their contribution was similar to that of aggregate demand shocks.

The contribution of monetary policy shocks to inflation is always negative and reaches a maximum of -0.20 percentage points in the second quarter of 2014, before the introduction of additional monetary accommodation by the ECB through the asset purchase programmes (covered bonds and asset-backed securities) and the targeted longer-term refinancing operations (TLTROs). The sharp and persistent decline in inflation expectations, however, led to an increase in the real policy rate.

Central bankers have long accepted the view that, due to the existence of lags in the transmission mechanism of monetary policy, they should "look through" transitory developments in inflation. This view implies that central banks also look at inflationary pressures as measured by core inflation, i.e. based on the consumer price index net of energy and unprocessed food prices when setting monetary policy stance. Natal (2012) shows that in model with energy as both a consumption and a production good, monetary policy should respond strongly to core inflation while accommodating shocks to energy prices.

Based on these considerations, and despite the fact that the objective of the ECB is defined in terms of headline inflation, we replaced the overall consumer price index in the VAR with the index for core prices, estimate the model and compute the historical decomposition using the same identification of the shocks. The historical decomposition of euro-area core inflation is reported in Figure 4. A visual comparison with Figure 3 suggests that the deviations from the baseline are somehow smaller in the case of core inflation and that the VAR seems to perform slightly better in explaining its movements than those in headline inflation in the period 2008-2015.[10] Despite these differences, the results obtained with core inflation confirms those with the headline inflation.

Oil supply shocks affected core inflation in 2014 and 2015, providing evidence of significantly larger indirect effects on consumer prices than in 2008 and 2009 and also highlighting the possibility of second-round effects at work in the last part of our sample. In order to assess this

[10] In the VAR with headline inflation the ratio of the standard deviation of the contributions of the shocks to that of the deviations from the baseline is 70 per cent in the sample 1999-2007 and 66 in the remainder of the sample. The opposite is true for the model with core inflation: the ratio increases from 67 in the sample up to 2007 to 73 in the rest of the sample. These ratios are meant to provide a rough idea of the ability of the shocks to explain inflation dynamics.

possibility, we included the time series for nominal negotiated wages in the euro area in the model and identified the same five shocks. The historical decomposition of nominal wages highlighted an important role for oil supply shocks since early 2013, as falling oil prices drove inflation and nominal wages down.[11] The downward pressure to nominal wages added to the indirect effects of oil prices on core inflation, raising the risk of a persistently low inflation-low nominal wage growth.

4.2. The drivers of economic activity

After having provided a description of the factors behind inflation developments, we turn to assessing the drivers of real GDP growth. Figure 5 shows the historical decomposition for the full sample (panel a) and the 2013-2015 period (panel b). It is worth emphasizing that the five identified shocks explain a large fraction of output dynamics: the standard deviation of the sum of the identified shocks to that of the deviations from the baseline is 70 per cent. We consider this an important result given the small size of the VAR.

Aggregate demand (green bars) and RoW demand (light blue bars) shocks explain a significant fraction of real GDP growth: their contribution was particularly large during the 2008-09 recession, with each shock accounting for around 1.5 percentage points in the second quarter of 2009. Part (0.6 percentage points in the same quarter) of the contraction of economic activity was due to unfavourable oil supply shocks. This result is consistent from a qualitative point of view with the findings in Hamilton (2009), who argues that the 2007-08 oil price surge was one of the factor behind the 2009 recession in the U.S. After the recession that followed the global financial crisis, negative oil supply shocks raised real oil prices, which reached 100 euro per barrel in early 2011, and contributed negatively to real GDP growth (by half a percentage point the first quarter of 2012). Their collapse in the second half of 2014, instead, which according to the VAR was also due to favourable supply shocks, supported aggregated demand and economic activity.[12]

Monetary policy shocks provide the smallest contribution to output growth among the identified shocks; however, their contribution was negative in all the quarters in 2013 and 2014, as it is the case for inflation, possibly reflecting the limited room for manoeuvre of policy rates during this period. The existence of an effective lower bound implied that the decline of inflation expectations that accompanied the fall of consumer prices *de facto* brought about an unwarranted tightening of monetary conditions, which, *ceteris paribus*, pushed inflation and economic activity

[11] The historical decomposition of nominal negotiated wage growth is available upon request.
[12] The support of lower oil prices to aggregate demand has been recently acknowledged by President Draghi in a speech on 9 October 2012: "[…] *domestic demand is expected to remain the main driver of the recovery, and should continue to be supported by our monetary policy measures,* […] *and low oil prices.*"

further down, thus partially offsetting the benefits of lower real oil prices. A more detailed discussion on the role of monetary policy follows in the next section.

4.3. The role of monetary policy

The results of the historical decomposition have highlighted an important role for oil prices and monetary policy in driving inflation and output growth between 2013 and 2015. In this Section we focus on monetary policy and discuss the historical decomposition of the real *ex post* EONIA rate across the two disinflationary episodes: 2008-09 and 2013-15.

The two periods share some similarities, but also some important differences. The output gap was large and negative (Jarocinski and Lenza, 2016) and oil prices collapsed in both periods. However, in the first disinflationary phase, inflation expectations were on average higher and anchored to the inflation target and the ECB was able to quickly and sharply reduce the real policy rate in the aftermath of the global financial crisis by cutting policy rates by 3.25 percentage points, to 1 per cent in May 2009. The second disinflationary episode was very different. Between May 2013 and December 2015, the ECB reduced the MRO rate from 0.50 to 0.05 per cent, as policy rates were getting close to their effective lower bounds. Long-term (five-year ahead) expectations, which had remained stable at around 1.9 per cent in the 2008-09 period, declined to an unprecedented low, at 1.65 per cent, at the end of 2015. In the 2013-15 period, the combination of the sharp and unprecedented decline of inflation expectations and the lower bound to policy rates *de facto* led to an increase in real rates.

Figure 6 shows the historical decompositions of the real EONIA rate, computed as the difference between the EONIA and current inflation. Interestingly, the identified shocks explain a large fraction of the real rate between 1999 and 2015, with the only exception of the 2003-2005 period and, to a lesser extent, 2012. Consistently with the argument above, in the aftermath of the global financial crisis and the collapse of oil prices in 2008, oil supply shocks contributed to lowering the real rate whereas the shocks occurred in 2014 and 2015 led to an increase in the real rate, thus effectively tightening monetary conditions at a time in which economic activity was recovering from the 2012-13 recession.

The contribution of monetary policy shocks, which was persistently negative between 2010 and 2012, turned positive in the following years, reaching a positive contribution 0.3 percentage points in the second quarter of 2014, from a low of -0.4 in the third quarter of 2012. The joint contribution of monetary policy and oil supply shocks increased from -0.7 percentage points in early 2012 to 0.6 in the first quarter of 2015, an increase by almost 1.3 percentage points. The joint contribution of the two shocks reached 0.6 in the last quarter of 2014, second only to the contribution in the third quarter of 2007, in a quite different economic environment in the euro area. The introduction of asset purchases in late 2014 (with the covered bonds and asset-backed securities purchase programmes) and early 2015 (when the purchases of government securities was introduced) allowed the ECB to loosen substantially monetary policy. In Section 6 we take into account the effects of these measures.

The baseline specification of the VAR and the identification scheme do not allow us to fully capture the role of the wide range of unconventional measures adopted by the ECB during the global and the sovereign debt crises and more recently. Accounting for these measures is important for the interpretation of our results, in particular those regarding the drivers of inflation between 2013 and 2015. It is important to note that in the benchmark specification of the VAR the effects of some of the ECB unconventional measures are taken into account. This is the case for those measures that increased the amount of excess liquidity in the euro-area banking sector by means of refinancing operations and pushed the EONIA close to the rate on the Eurosystem deposit facility, the lower bound of the policy rates corridor.

The literature on modelling unconventional monetary policy within the VAR framework is still evolving. While the empirical VAR-based literature on assessing the impact of conventional monetary policy is large and well established (see, among the many others, Christiano, Eichenbaum and Evans, 1999 for the U.S. and Peersman and Smets, 2003 for the euro area), research on assessing the effects of unconventional monetary policy is still ongoing and far from being settled. Previous empirical studies for the euro area relied on high-frequency financial data (Altavilla, Carboni and Motto, 2015), as well as VAR methods (Lenza, Pill and Reichlin, 2010, Peersman, 2011, Giannone et al., 2012, Gambacorta, Hofmann and Peersman, 2014, Darracq-Paries and De Santis, 2015 and Boeckx, Dossche and Peersman, 2016).

Despite the challenges in quantifying the effectiveness of unconventional measures, we consider important and necessary to assess the robustness of our findings to the inclusion of variables related to the unconventional measures adopted by the ECB. To this end we consider the "shadow rate" measure proposed by Krippner (2013) and used by von Borstel, Eickmeier and Krippner (2016).[13] This measure diverges from the EONIA rate since the third quarter of 2011, which coincides with the most acute phase of the sovereign debt crisis.

[13] Shadow rates are computed by means of a nonlinear term structure model and are used to summarize the effects of unconventional monetary policy when the policy rate is at the lower bound (Wu and Xhia, 2014 and Krippner, 2013).

Figure 7 shows the historical decomposition of inflation and real GDP growth (panel a) obtained with the VAR in which the shadow rate replaces the EONIA rate. Our results and main message are confirmed: oil supply, aggregate demand and monetary policy shocks, arising from the presence of the lower bound to policy rates, all contributed to reducing inflation and keeping it at historical low levels in 2014 and 2015 (panel b). Comparison with the baseline specification of the VAR shows that when the shadow rate is employed (panel c), the contribution of monetary policy shocks to inflation and real GDP growth turns positive and large from the first quarter of 2015, right when the ECB introduced the Public Sector Purchase Programme.[14]

5. Country-level results

The previous section has shed light on the shocks that drove inflation and real GDP growth and on the role of monetary policy at the euro-area level. In this Section we assess the contribution of the identified area-wide shocks to inflation and real GDP growth in the main euro-area countries. We focus on oil supply and monetary policy shocks, as these shocks have been important drivers of inflation between 2013 and 2015, and leave out aggregate demand and aggregate supply shocks since they can have an important country dimension, in particular in those economies that are weakly synchronized with the euro-area business cycle.[15] A country-level analysis is relevant because it can shed light on the degree of cross-country heterogeneity in the transmission of euro-area aggregate shocks.

The analysis is carried out by extending the structural form of the VAR for the euro area by adding country-specific equations as follows:

$$\begin{bmatrix} y_t \\ Z_t \end{bmatrix} = \begin{bmatrix} a \\ d \end{bmatrix} + \begin{bmatrix} A(L) & 0 \\ C(L) & D(L) \end{bmatrix} \begin{bmatrix} y_{t-1} \\ Z_{t-1} \end{bmatrix} + \begin{bmatrix} A(0) & 0 \\ E(0) & F(0) \end{bmatrix} \begin{bmatrix} \varepsilon_t \\ \mu_t \end{bmatrix} \quad . \qquad (4)$$

The system in (4) is a “near-VAR”. Boeckx, Dossche and Peersman (2016) use such modelling framework to analyse the transmission channels of the ECB unconventional monetary policies in the euro area and their effects on individual member countries. This framework has been used previously by Peersman (2004) to study the heterogeneity in the effects of monetary policy across euro-area countries. A similar approach has been used recently by Cavallo and Ribba (2015) to study the transmission of monetary policy after 1999.

[14] The contribution of monetary shocks is nil in 2014:Q4, compared with a negative contribution in the baseline VAR. It is important to note that expectations of government bond purchase programme were building up since November 2014.

[15] Ferroni and Klaus (2014) find that while France, Germany and Italy are synchronized and fast converging to the euro-area aggregate cycle, the Spanish economy is weakly synchronized and adjust sluggishly.

In order for the identified structural shocks and the dynamics of the euro-area variables to remain invariant to the inclusion of the country-specific variables, we impose a block diagonal structure (Boeckx, Dossche and Peersman, 2016) and assume no feedback from the latter variables to euro-area and international variables. An alternative approach would be to estimate country-specific VAR models, each one including area-wide variables. However, in this case, the identified shocks and the corresponding dynamic effects on euro-area aggregate variables would not be identical across country VARs, making the cross-country comparison less informative.

The vector $\boldsymbol{y_t}$ includes the euro-area endogenous variables and *A(0)* is the contemporaneous impact matrix of the structural shocks $\boldsymbol{\varepsilon_t}$. The matrix *D(L)* is diagonal: in each equation the country real GDP and price level depend on the euro-area variables and on the lags of dependent variable. The vector $\boldsymbol{Z}_t$ contains the level of real GDP and consumer prices of ten euro-area member countries (Germany, France, Italy, Spain, the Netherlands, Belgium, Austria, Portugal, Ireland and Finland). We leave Greece out as the economy was severely hit by the sovereign crisis and experienced an unprecedented fiscal adjustment and a systemic banking crisis.

The model in equation (4) is estimated using the seemingly unrelated regression (SUR) method developed by Zellner (1962). We separately estimate the area-wide block and the country-specific equations. Standard likelihood ratio tests are used to determine the lag-order of the country equations, which turns out to be 2. Given the estimates of the matrices *A*, *C*, *D* and *E* we compute the historical decomposition of each country-specific variable. In practice, given the historical decomposition of euro-area, we use the country-specific equations (the lower block of the system) to project the contribution of the shocks to the aggregate variables on each country real GDP growth and inflation. Figure 8 shows the historical decomposition for the ten countries.

The contribution of oil supply shocks to inflation (left column) between 2014 and 2015 is significant in all countries although with varying intensity, ranging from the largest impact in Spain to the smallest in the Netherlands. These findings support the view that the disinflation that began in mid-2013 was not the result of a relative price (competitiveness) adjustment in the aftermath of the sovereign debt crisis but rather a widespread phenomenon partially caused by euro-area wide shocks such as oil supply and monetary policy. The negative contribution of monetary policy shocks to inflation between 2013 and 2015 is larger in the countries hit the hardest by the sovereign debt crisis (in particular Ireland and Portugal) than in the core economies (France and Germany). Ciccarelli, Maddaloni and Peydrò (2013) find evidence of heterogeneity in the responses of inflation across countries in a panel VAR model in which euro-area countries are grouped according to the degree of sovereign financial distress. Concerning the contribution of monetary policy shocks to real GDP growth (Figure 8 right column), we also find substantial heterogeneity, which has become larger during the global financial and sovereign debt crisis. However, in contrast with the findings for inflation, the contribution of monetary policy shocks to output growth is larger in the biggest countries and not in those hardest hit by the sovereign crisis.

We do not attempt to explain the heterogeneity across countries as in Ciccarelli, Maddaloni and Peydrò (2013) and Boeckx, Dossche and Peersman (2016) but rather underline that inflation was pushed down by both oil supply and monetary policy shocks in all the countries and that the latter shocks partially offset the positive impact of lower real oil prices on aggregate demand.

We also assess the heterogeneity in the effects of monetary policy across euro-area countries taking into account the role of the unconventional measures. We, therefore, perform the same econometric analysis by replacing the EONIA rate with the shadow rate and computing the corresponding contributions of monetary policy shocks to inflation and real GDP growth. Figure 9 compares these contributions (cumulated over the period 2015:Q1 – 2015:Q3) with those obtained with the model including the EONIA. The comparison highlights that monetary policy shocks contributed positively to inflation and economic activity in all the countries, suggesting a widespread beneficial effect stemming from the introduction of the APP.

However, as far as inflation is considered, the picture is somewhat different, as the countries hardest hit by the sovereign debt crisis benefitted more from the expansionary monetary policy. For example, in the case of Italy and Spain the estimated contribution of monetary policy turns positive, while it barely changes in the case of France and Germany. This heterogeneity is not evident in the case of economic activity. These results could be due to differences in the slope of the Phillips curve across countries as well as to country-specific time variation in these slopes (Riggi and Venditti, 2015b). Overall, the country analysis confirms the usefulness of introducing more monetary accommodation through the launch of the APP by the ECB in late 2014-early 2015.

6. Robustness

In this Section we test the robustness of the results along several dimensions, including the choice of the sample period and the variables and the identification of additional shocks.

6.1. Structural changes in the transmission of shocks

We first discuss the robustness of our results with respect to the choice of the sample period.[16] The data used in the empirical analysis include the period up to the introduction of the

[16] The results are not reported to save on space. They are available upon request.

euro in 1999 and the global financial and sovereign debt crises in, respectively, 2008 and 2011. These major events might have caused structural breaks in the euro-area real economy, in the functioning of financial markets and also in the transmission of aggregate shocks, including monetary policy ones. This could somewhat flaw our econometric analysis which is based on a constant parameter linear VAR. Bobeica and Jarocinski (2016), however, provided reassuring evidence in this regard. They showed that a medium-scale VAR model with constant coefficients help to solve the “missing disinflation” puzzle arising from reduced form Phillips-curve type regressions and DSGE models. Importantly, these results are robust to different identification assumptions, including those used in our paper.

Despite the reassuring evidence provided by Bobeica and Jarocinski (2016) and given the difficulties in estimating a VAR with time-varying parameters and stochastic volatility à la Primiceri (2005), we validate our results by fitting the VAR over different sample periods in order to assess the presence of structural breaks.

The introduction of the euro. The ECB started conducting the single monetary policy in January 1999 and the exchange rate were fixed among member countries at the end of 1998. The possibility that the introduction of the euro may have changed the way in which the euro-area economy responds to aggregate shocks, including monetary policy ones, has been investigated in the literature. Some contributions have found evidence of changes in the monetary transmission mechanism after 1999 (Boivin, Giannoni and Mojon, 2009, Cecioni and Neri, 2011 and Barigozzi, Conti and Luciani, 2014).

In order to test our results against the possibility of structural changes, we estimated the VAR over the 1999-2015 period without finding any major quantitative differences, neither in terms of impulse responses nor of the historical contribution of the shocks.

The global financial and sovereign debt crises. According to the benchmark model, the persistence of the response of inflation to oil supply shocks is lower than previous estimates available in the literature (e.g., Peersman and Van Robays, 2009), which may suggest a break in the conditional correlation between oil price and the euro-area aggregate variables after the global financial crisis. Baumeister and Peersman (2013) analyse the role of oil shocks in a time-varying VAR framework for both the U.S. and the euro area and find evidence of a break in the transmission of oil shocks before the breakout of the global financial. Other studies document the existence of non-linearities in the transmission of financial shocks (Balke, 2000, Prieto, Eickmeier and Marcellino, 2013 and Hartmann et al., 2013).

In light of the above considerations, we assess whether the results are altered by the inclusion of the global financial and sovereign debt crises periods in our sample. The model estimated over the periods 1995:Q1-2008:Q2 and 1995:Q1-2010:Q2 and the corresponding simulations do not highlight any major qualitative difference.[17]

6.2. The role of shocks to credit supply

A distinctive feature of the global and the sovereign debt crises was their severe impact on the banking system in several euro-area economies, with adverse effects on the supply of lending. A credit supply restriction can have substantial real effects in the euro area (Ciccarelli, Maddaloni and Peydrò, 2015 and Gerali et al., 2010), especially in the countries where private consumption and investment largely depend on bank lending. It is therefore important to assess the robustness of our results by including credit variables in the VAR and identifying credit supply shocks. This check is important for a number of reasons. First, credit markets amplify shocks originating in other sectors. Second, banks' capability to provide loans to the economy depends on their balance sheet conditions (Bernanke and Gertler, 1995 and Gertler and Karadi, 2015), which are endogenous to the state of the economy. Third, a credit supply restriction is observationally equivalent to a reduction in aggregate demand, since it may lead to a decline in output and inflation, thus inducing the central bank to adopt an accommodative monetary policy stance (Gertler and Karadi, 2015).

In order to capture the effects of exogenous changes in credit supply, we include in the VAR the cost of new loans to the non-financial private sector and the corresponding credit volumes.[18] We identify an adverse loan supply shock as the one implying an increase in the cost of credit, a decline in lending volumes, real GDP, and the EONIA rate and a depreciation of the exchange rate. A loan supply shock is disentangled from an aggregate demand shock since the response of the cost of credit is opposite in sign: the loan rate increases after a tightening in lending standards, whereas it declines after a negative demand shock. The restrictions on the sign of the responses of the policy rate and the exchange rate ensures that the credit supply shock is also disentangled from monetary policy and RoW shocks, respectively. Abbate, Eickmeier and Prieto (2016) and Gambetti

[17] The stability of the impulse responses across periods is in line with the findings in Canova, Ferroni and Matthes (2015), who study the consequences of using time-invariant models when the data generating process features parameter variations for estimation, the identification of shocks and inference. The authors find that structural time-invariant VAR models can capture well the key qualitative features of the variables (impact, shape and persistence).

[18] The variables are defined as weighted average, with the time-varying weights given by the shares of loans granted in each quarter to non-financial corporations and households to the total amount of outstanding loans to the private sector.

and Musso (2016) argue that theory does not provide clear guidance on the effects of credit supply shocks on inflation. For this reason, we leave the response of inflation unconstrained.[19]

Figure 10 shows the impulse responses to an adverse credit supply shock. They are qualitatively similar to those in Gambetti and Musso (2016). Although the posterior distribution of the response of the price level is wide, the median response is negative.[20] Real GDP declines significantly and persistently, mirroring the strong contraction of lending volumes. Monetary policy becomes expansionary to support the economy. Figure 11 shows the historical decomposition of real GDP growth and inflation: the contribution of credit supply shocks is in general larger for the former than for the latter. Credit supply shocks contributed to raising inflation in 2012 and to the downward trend occurred in the following two years. This may suggest a supply side cost-channel according to which an increase in firms' interest expenses on working capital implies a higher marginal cost of production and output prices (Ravenna and Walsh, 2006 and Gilchrist et al, 2016). Credit supply shocks exerted a negative contribution on real GDP in the most acute phase of the global financial crisis and during the sovereign debt crisis.

Compared to the benchmark case, the identification of credit supply shocks tends to crowd-out aggregate supply shocks, and to a lesser extent aggregate demand shocks in 2015. The negative contribution of monetary policy to both inflation and output is confirmed.

6.3. Accounting for sovereign spreads

Another important challenge to our analysis is the sovereign debt crisis which hit the euro area between mid-2011 and the summer of 2012 and exerted significant macroeconomic effects on both individual countries and the euro area as a whole (Neri and Ropele, 2015). For this reason, it is important to test our results against the inclusion of a measure of the sovereign debt tensions.

To account for the increase in sovereign risk premia, we add to the model the GDP-weighted average of the sovereign spreads between the 10-year yields on the government bonds of the countries most affected by the sovereign crisis (Greece, Ireland, Portugal, Spain and Italy) and on the German bund. We refrain from identifying a shock to the sovereign spread and concentrate on taking into account the reduced-form dynamic relationships between this variable, on the one hand, and real GDP and consumer prices, on the other. In the same vein, we do not restrict the sign

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[19] Gambetti and Musso (2016) identify loan supply shocks with sign restrictions in a VAR framework with time-varying parameters and stochastic volatilities. This approach has the advantage that the impulse responses can vary over time, which allow to assess the effects of shocks to credit supply occurring in periods of financial distress. Employing their framework would be computationally challenging in our eight variable VAR.

[20] This finding is in line with most of the empirical evidence on the effects of credit shocks. However, Abbate, Eickmeier and Prieto (2016) show that these shocks to credit markets generate a negative co-movement between prices and economic activity in the U.S. Imposing such restriction does not affect our results.

of the responses of the sovereign spread to both foreign and domestic shocks. The results regarding the contribution of the identified shocks to inflation and real GDP growth are robust to this alternative specification, also if we replace the EONIA with the shadow rate.

6.4. Additional insights on the role of oil shocks

In this Section we provide additional insights regarding the identification of oil supply shocks and its implications for our results. The first issue we address concerns the response of monetary policy to oil supply shocks. In our identification we do not impose a restriction on sign of the response of the policy rate after an oil supply shocks. The posterior distribution of the impulse responses does not allow use to reach a sharp conclusion on the response of the ECB to oil supply shocks. Peersman and Van Robays (2009) and Forni et al. (2015), instead, show that the ECB reduces its policy rate to stabilize inflation around its objective following oil supply shocks.

As shown in the Section 6.1, the difference between our results and those in Peersman and Van Robays (2009) and Forni et al. (2015) cannot be due to our use of a longer sample period which includes the global financial and sovereign debt crises, two periods in which the ECB may have been very concerned about developments in economic activity. However, the literature on sign restrictions suggests that the response of the unconstrained variables may be blurred and affected by few draws of the algorithm when the variance of the shock is small (Paustian, 2007). To check for this possibility, we implemented an identification scheme in which the policy rate declines following a positive oil supply shock, consistently with the empirical evidence above. The results do not change, as expected, since this additional restriction does not affect the identification of aggregate demand and monetary policy shocks.

A second issue regards the role of other shocks hitting the oil market that are not identified and which may also have implications, in particular, for our results. A decline in the RoW output may be caused by negative productivity shocks in the rest of the world economy. Bodenstein, Guerrieri and Kilian, 2012, for example, show that a negative foreign productivity shock induces a decline in both the real oil price and domestic inflation but may lead to an increase in domestic output and to a tightening of monetary policy. We test this possibility by imposing that the RoW shock increase euro-area output rather than leaving it unrestricted as in the baseline model. The historical decomposition shows some role for foreign productivity shocks in explaining euro-area inflation, although only in 2015. However, the contributions of euro-area shocks are unaffected.

The third issue we address is the possibility that the identified oil supply shocks also capture the effects of oil-specific demand shocks. Kilian (2009) argues that the global demand for oil does not depend only on global growth but also on how intensively oil is used in production. The model developed by Bodenstein and Guerrieri (2011) and used by Bodenstein, Guerrieri and Kilian (2012) and Bodenstein, Guerrieri and Gust (2013) does include shocks to foreign oil intensity. While these shocks can be useful to interpret oil price developments between 2003 and mid-2008, there is substantial agreement that the bulk of oil price movements in 2014 and 2015 was due to supply-side factors (Caldara, Cavallo and Iacoviello, 2016) and, to some extent, by developments in global economic activity (Baumeister and Kilian, 2016). Based on these considerations, our results for the most recent period could be only marginally affected by excluding oil-specific demand shocks.[21] In any case, the identification of an oil-specific demand shock should not affect our results regarding the role of oil supply, aggregate demand and monetary policy shocks in driving inflation and economic activity in the euro area as oil-specific shocks are by construction orthogonal to them.

7. Concluding remarks

Inflation in the euro area reached historical lows in late 2014. Since then, it has remained at very low levels, raising concerns about the credibility of the ECB monetary policy. While falling oil prices certainly played a key role, euro-area specific factors have also been at work.

This paper has shown that oil supply, monetary policy and aggregate demand shocks have all been important drivers of the inflation between 2013 and 2015. The effective lower bound to the policy rate prevented the ECB from providing the necessary stimulus to aggregate demand: the disinflation coupled with the lower bound led *de facto* to an unwanted tightening of monetary conditions. The paper has also documented substantial heterogeneity in the transmission of common shocks to inflation and economic activity all euro-area countries. Our findings provide support and justification to the adoption of the asset purchase programme by the ECB.

Further research could assess the implications of shocks to inflation expectations and changes in their formation mechanism for monetary policy and the dynamics of inflation. This line of research has become increasingly important since late 2014 as several commentators have raised concerns regarding the credibility of the ECB and the anchoring of inflation expectations to the inflation target. The difficulties experienced by the Bank of Japan in anchoring inflation expectations also provide further support to this line of research.

[21] Oil-specific demand shocks can be disentangled from oil supply shocks by including oil production in the model and assuming an opposite sign in its response to the two shocks (Lippi and Nobili, 2012 and Kilian and Murphy, 2012). This choice, however, poses some econometric issues. Baumeister and Hamilton (2015) and Caldara, Cavallo and Iacoviello (2016) address them by combining sign restrictions with bounds on the elasticities of oil supply and demand. Disentangling oil supply shocks from oil-specific demand shocks is beyond the scope of our analysis.

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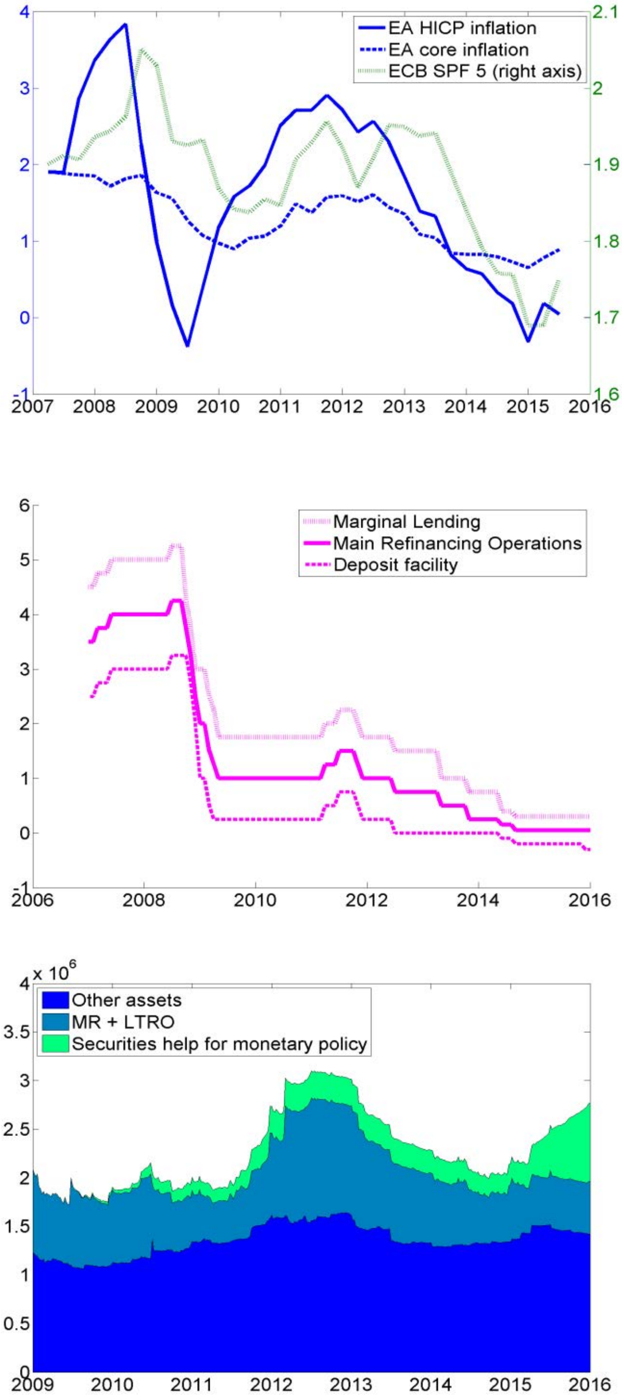
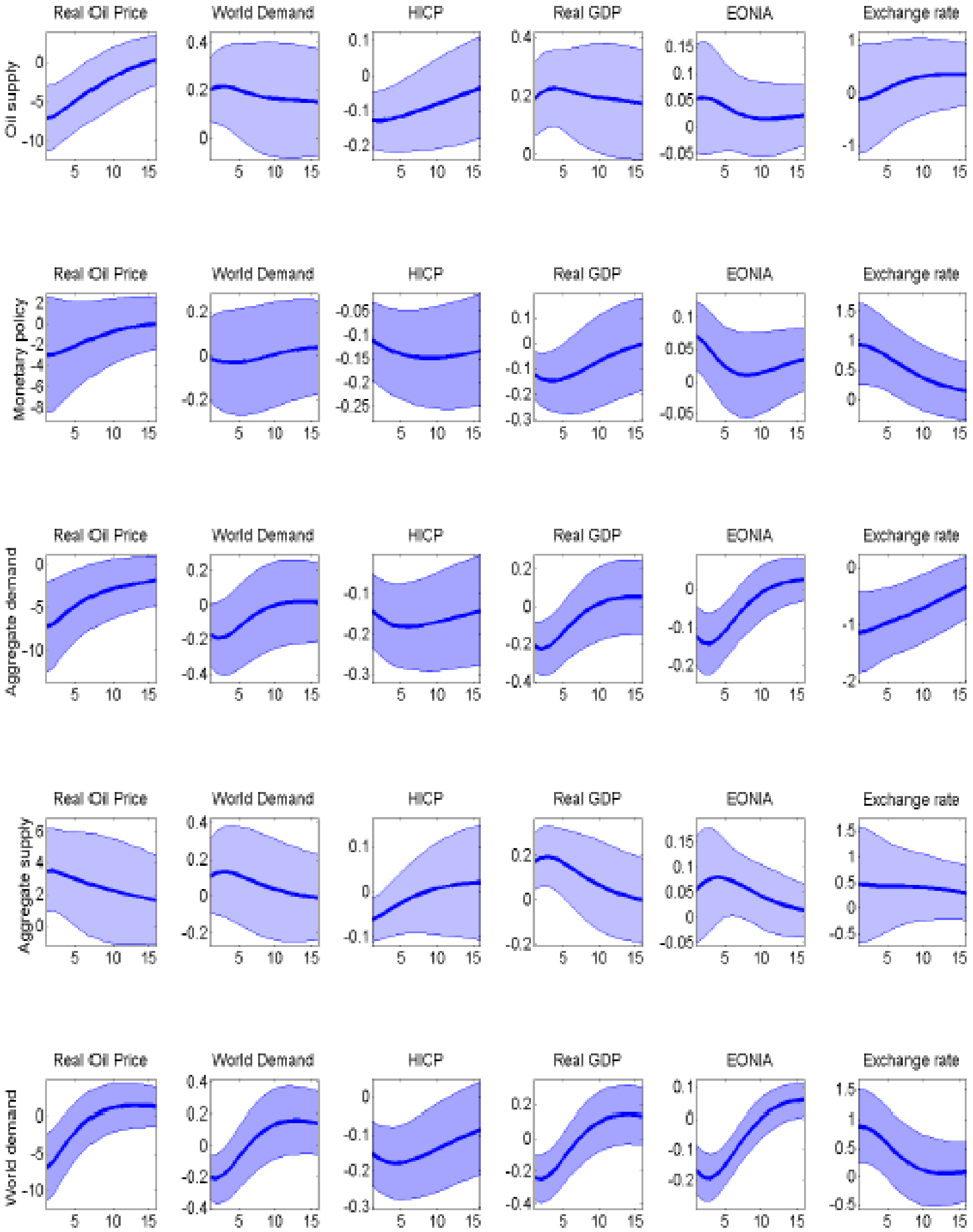
Figure 1: Inflation, inflation expectations and monetary policy in the euro area



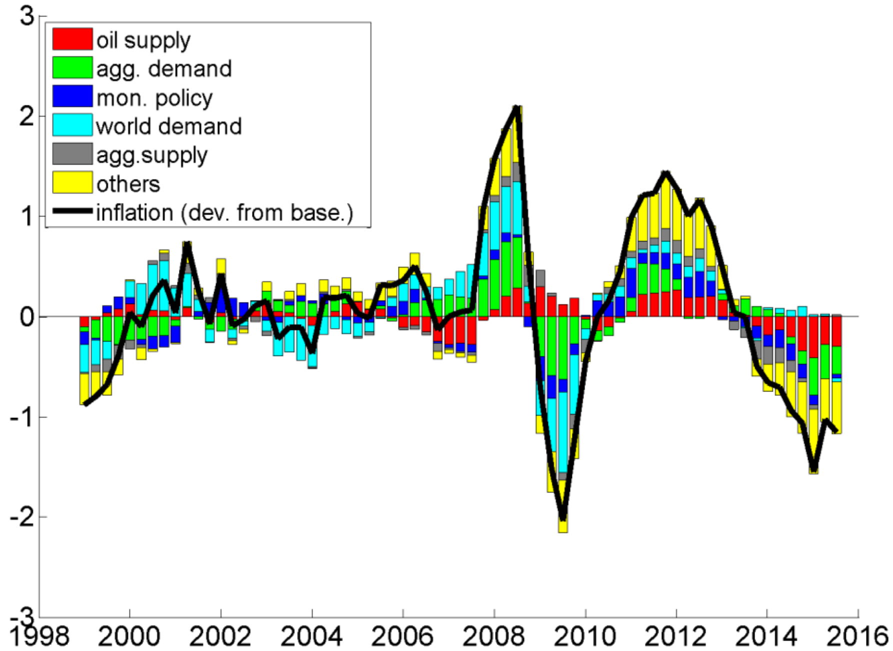
*Notes***:** panel (a): the blue solid line is the actual annual change in the euro-area HICP for the period 2006:Q1 – 2015:Q3. The blue dashed line is the actual y-o-y change in the euro-area HICP excluding energy, food and tobacco (core inflation) for the period 2006:Q1 – 2015:Q3. The green line represents euro-area HICP inflation 5-years expectations of Survey of Professional Forecasters (SPF). Panel (b): the magenta solid line is the MRO rate of the ECB, while the dotted magenta line is the marginal lending rate and the magenta dashed line is the deposit facility rate. Panel (c): the green shaded area is the volume of securities help for monetary policy, the light blue shaded area is the sum of Main Refinancing (MRO) and Long Term Refinancing Operations (LTRO), while the dark blue shaded area represents other ECB assets.

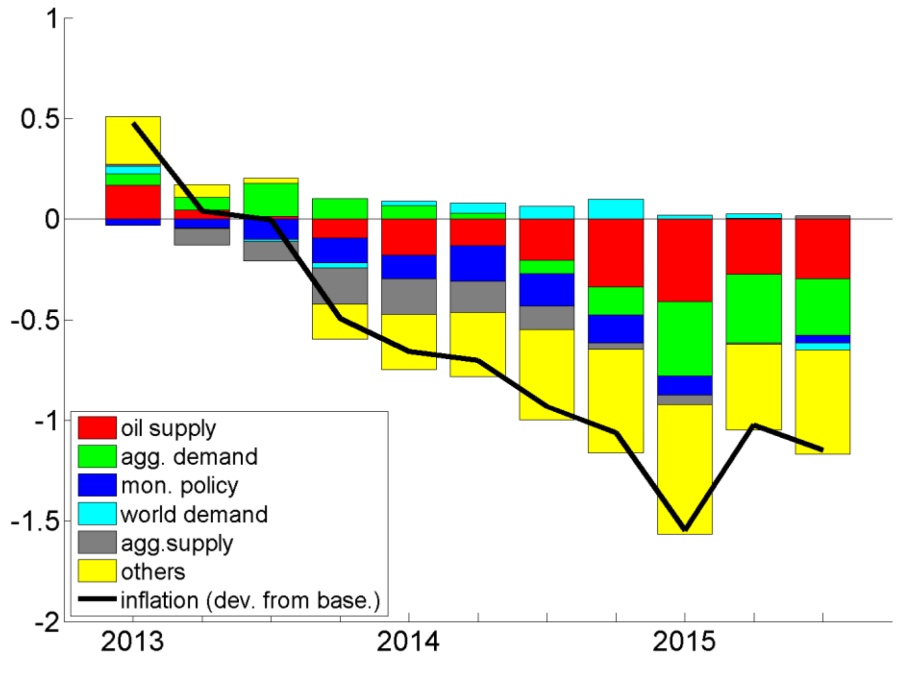
Figure 2: Impulse responses to the five shocks in the baseline specification



Notes: percentage deviation from baseline. Thick blue line: median of the posterior distribution; light blue shaded area: 0.68 probability interval of the posterior distribution.

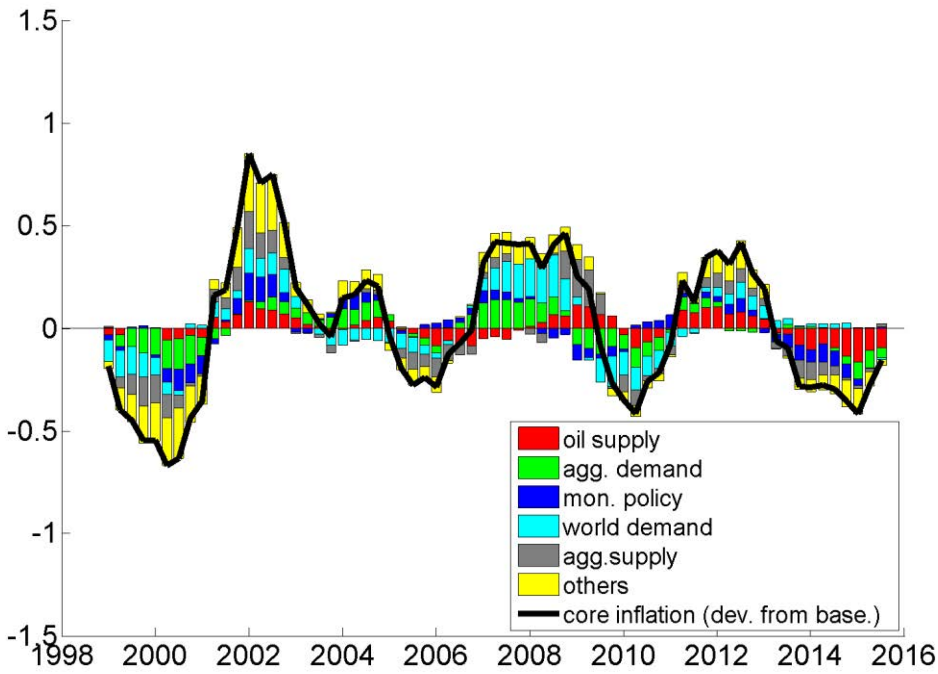
Figure 3: Historical decomposition of euro area HICP inflation

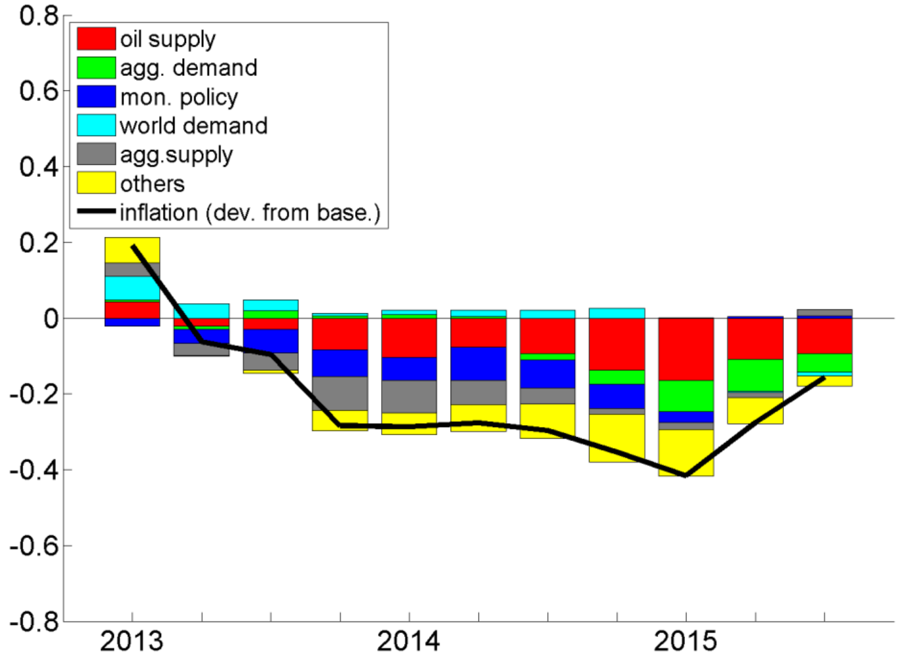




Notes: panel (a) and (b): the black solid line is actual y-o-y change in the euro-area HICP. The coloured stacked bars represent the (median of the posterior) contribution of the identified structural shocks to euro-area HICP y-o-y inflation.

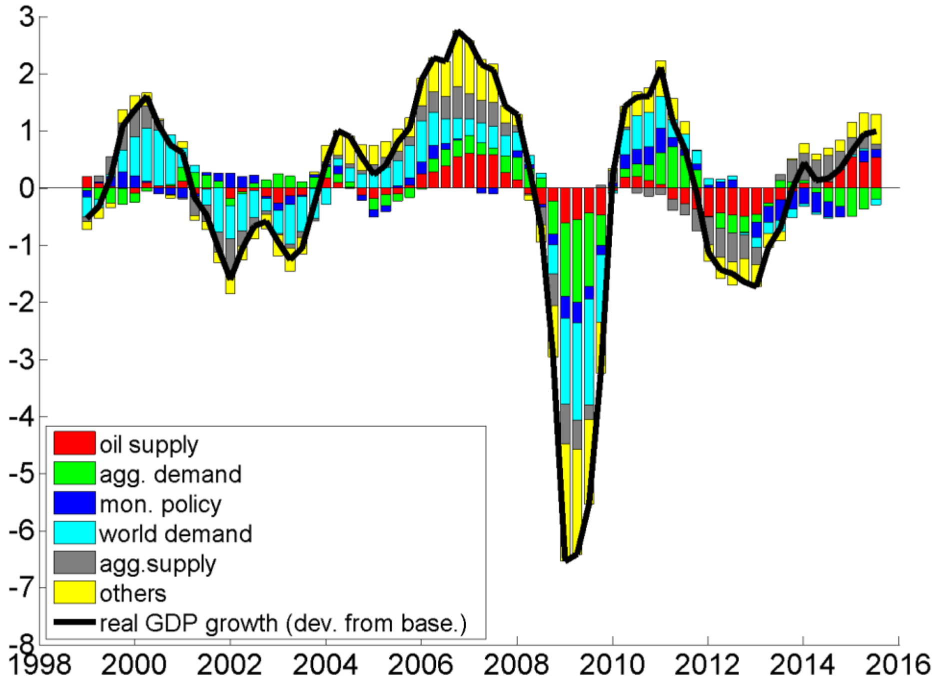
Figure 4: Historical decomposition of euro area core inflation

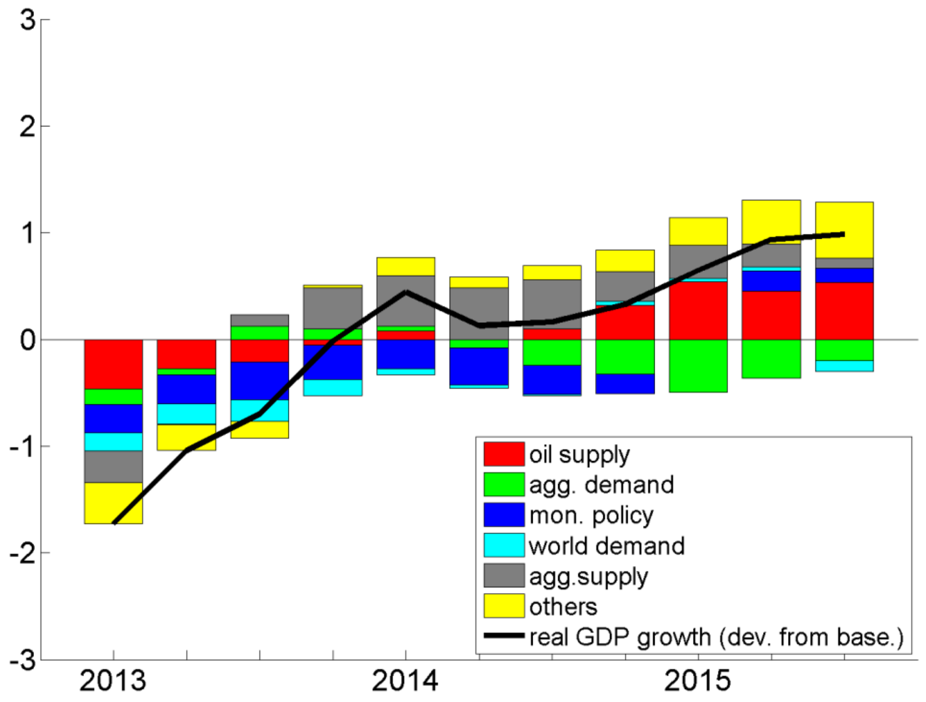




Notes: panel (a) and (b): the black solid line is actual y-o-y change in the euro-area core HICP excluding energy, food and tobacco. The coloured stacked bars represent the (median of the posterior) contribution of the identified structural shocks to y-o-y core inflation.

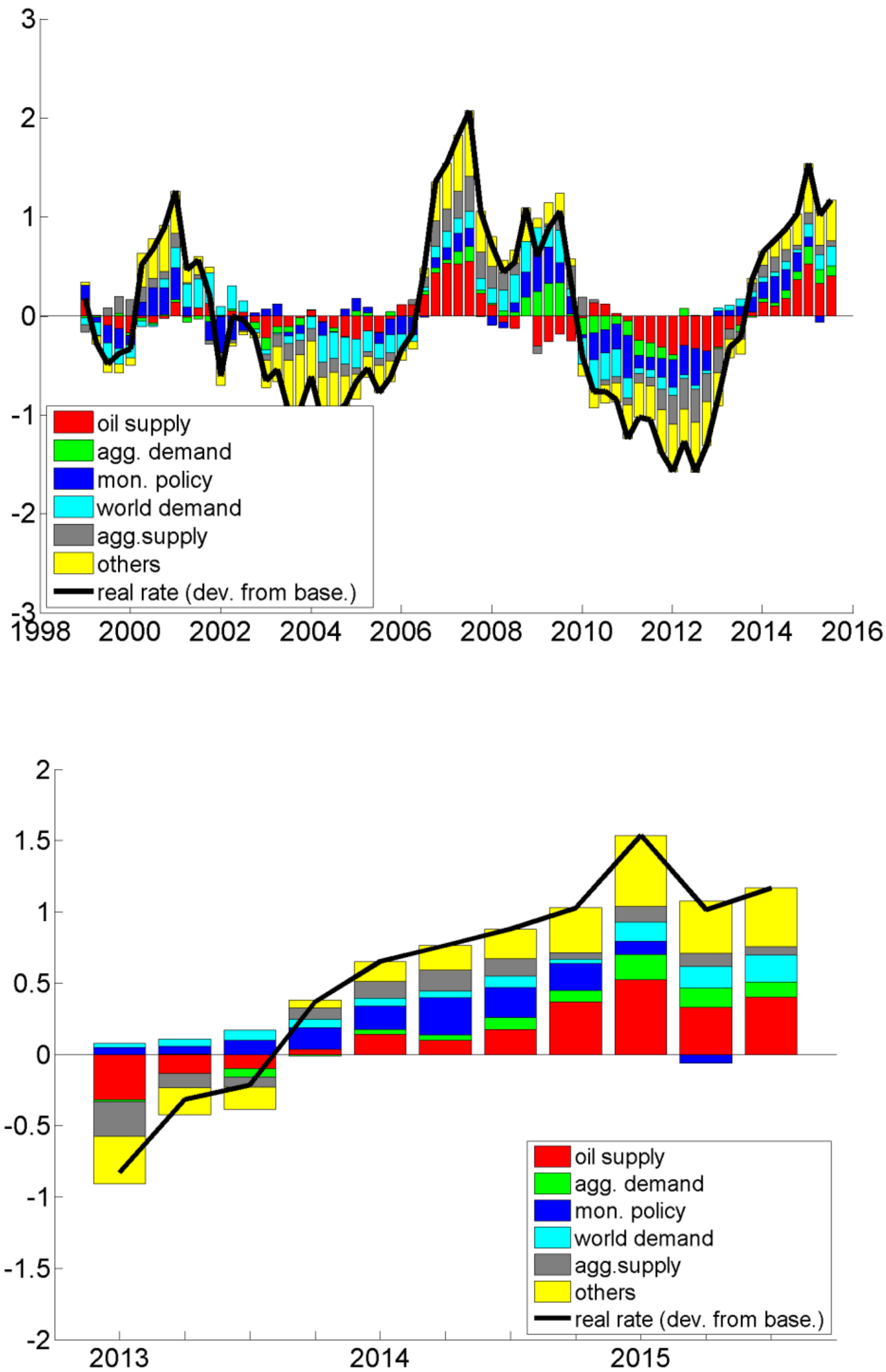
Figure 5: Historical decomposition of euro area real GDP growth





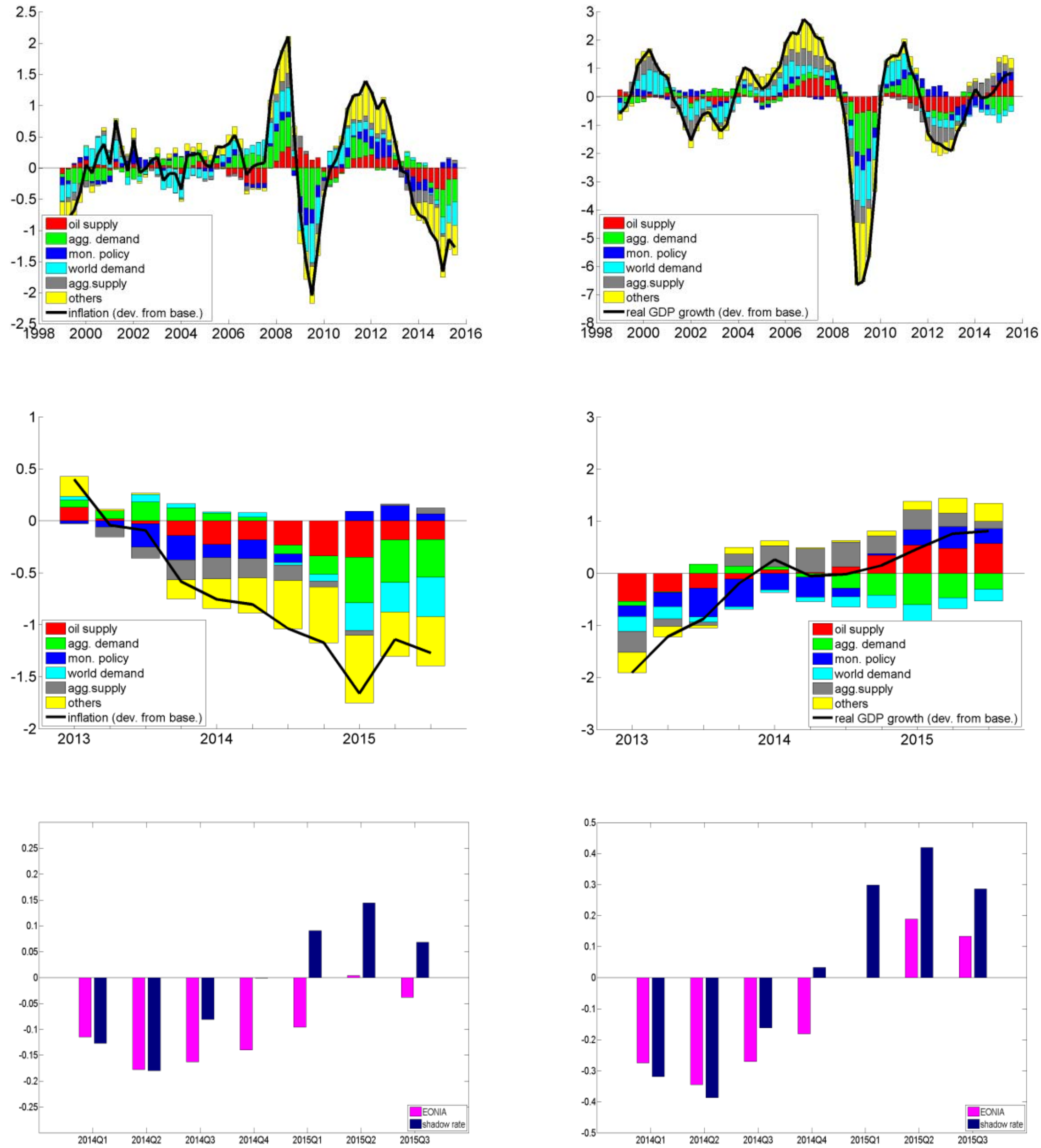
Notes: panel (a) and (b): the black solid line is actual y-o-y change in the euro-area real GDP. The coloured stacked bars represent the (median of the posterior) contribution of the identified structural shocks to y-o-y real GDP growth.

Figure 6: Historical decomposition of euro area real interest rate



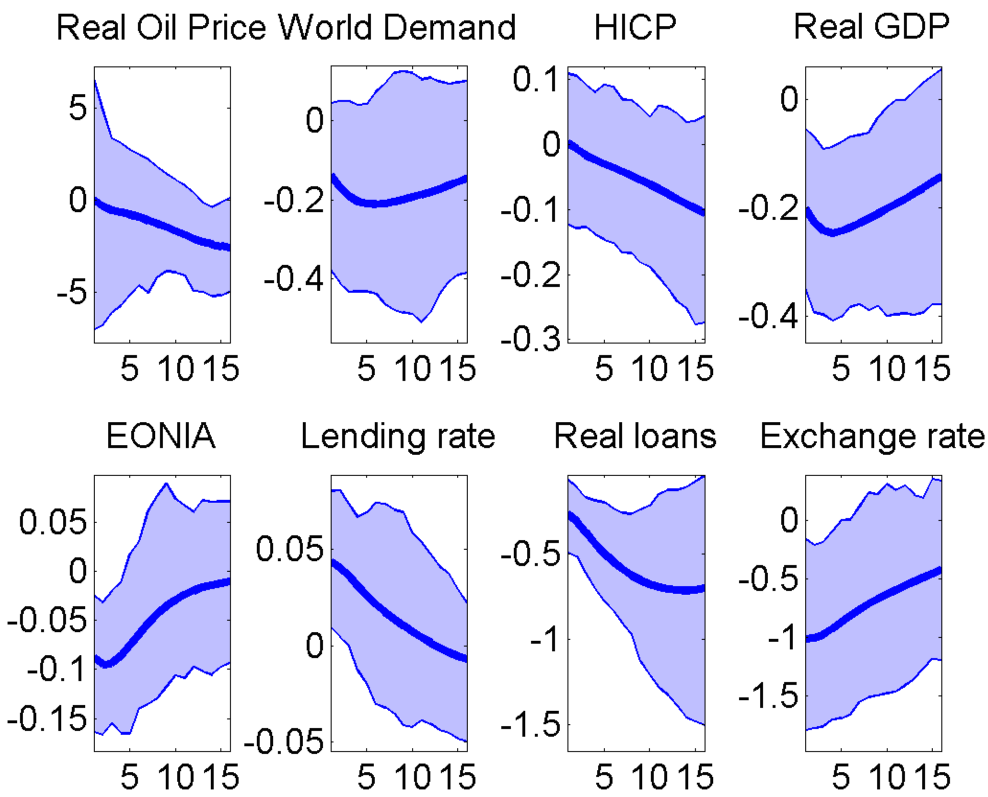
Notes: panel (a) and (b): the black solid line is deviation of real interest rate from its baseline. The coloured stacked bars represent the (median of the posterior) contribution of the identified structural shocks to the deviation of real interest rate, defined as the difference between the EONIA and the realized HICP inflation rate, from its baseline.

Figure 7. Historical decomposition of euro area HICP inflation and real GDP growth: the role of unconventional monetary policy



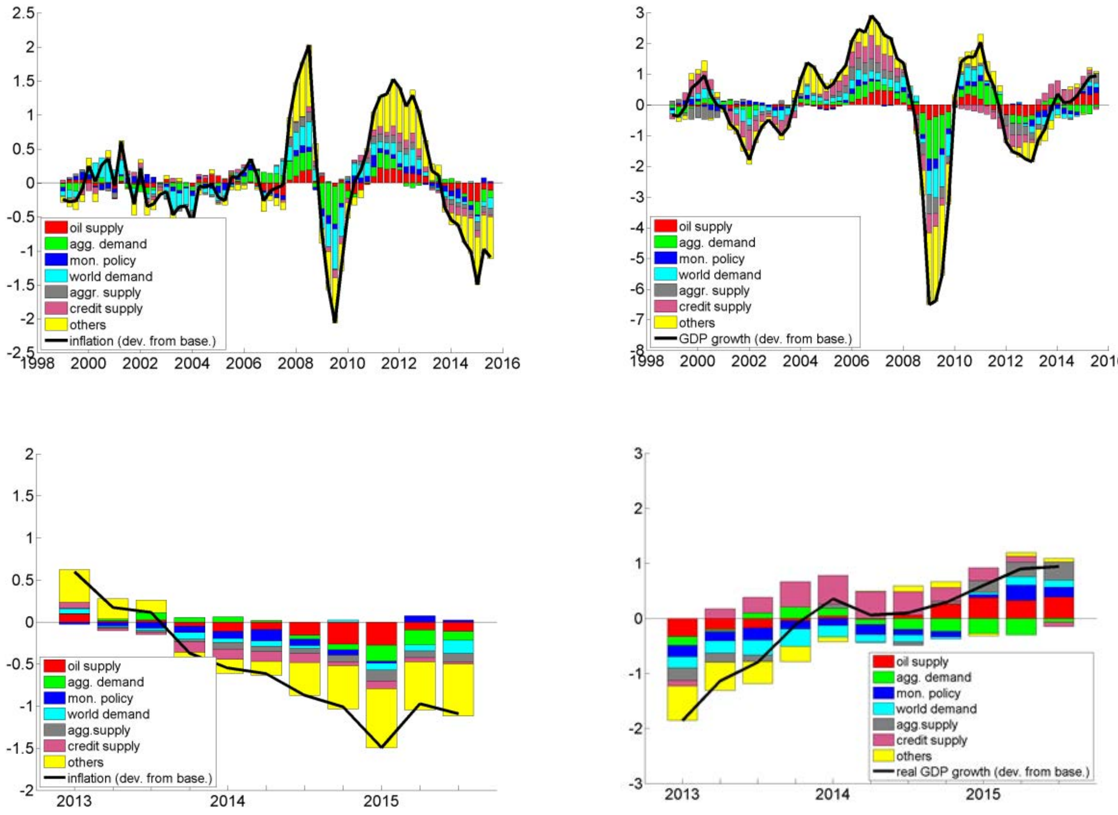
Notes: panel (a) and (c): the black solid line is actual y-o-y change in the euro-area HICP. The coloured stacked bars represent the (median of the posterior) contribution of the identified structural shocks to euro-area HICP y-o-y inflation. Panel (b) and (d): the black solid line is actual y-o-y change in the euro-area HICP. The coloured stacked bars represent the (median of the posterior) contribution of the identified structural shocks to euro-area HICP y-o-y inflation. Panel (e) and (f): the magenta bars are the contribution of monetary policy shocks to inflation (real GDP growth) when using the EONIA as policy rate, whereas the navy blue bars are the contribution of monetary policy shocks to inflation (real GDP growth) when using the shadow rate to capture the effects of unconventional monetary policy. The time horizon is 2014:Q1-2015:Q3.

Figure 8. Impulse responses to an adverse credit supply shock



Notes: percentage deviation from baseline. Thick blue line: median of the posterior distribution; light blue shaded area: 0.68 probability interval of the posterior distribution.

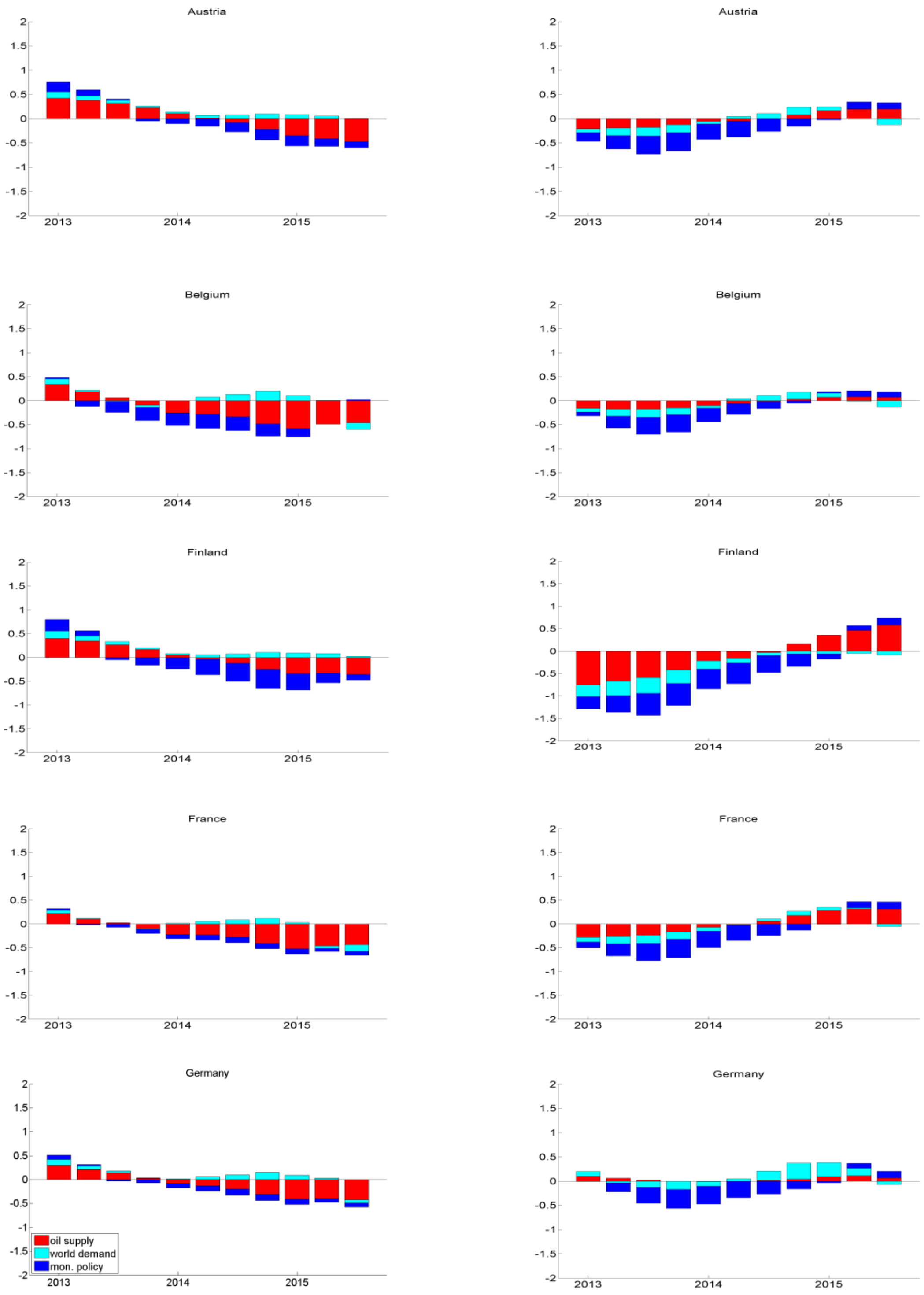
Figure 9. Historical decomposition of euro area inflation and real GDP growth: identifying credit supply shocks



Notes: in panels a to c the black solid line is actual y-o-y change in the euro-area HICP. The coloured stacked bars represent the (median of the posterior) contribution of the identified structural shocks to y-o-y inflation. Panel b-d: the black solid line is actual y-o-y change in the real euro-area GDP growth. The coloured stacked bars represent the (median of the posterior) contribution of the identified structural shocks to y-o-y GDP growth.

Figure 10. Historical decomposition: euro area countries

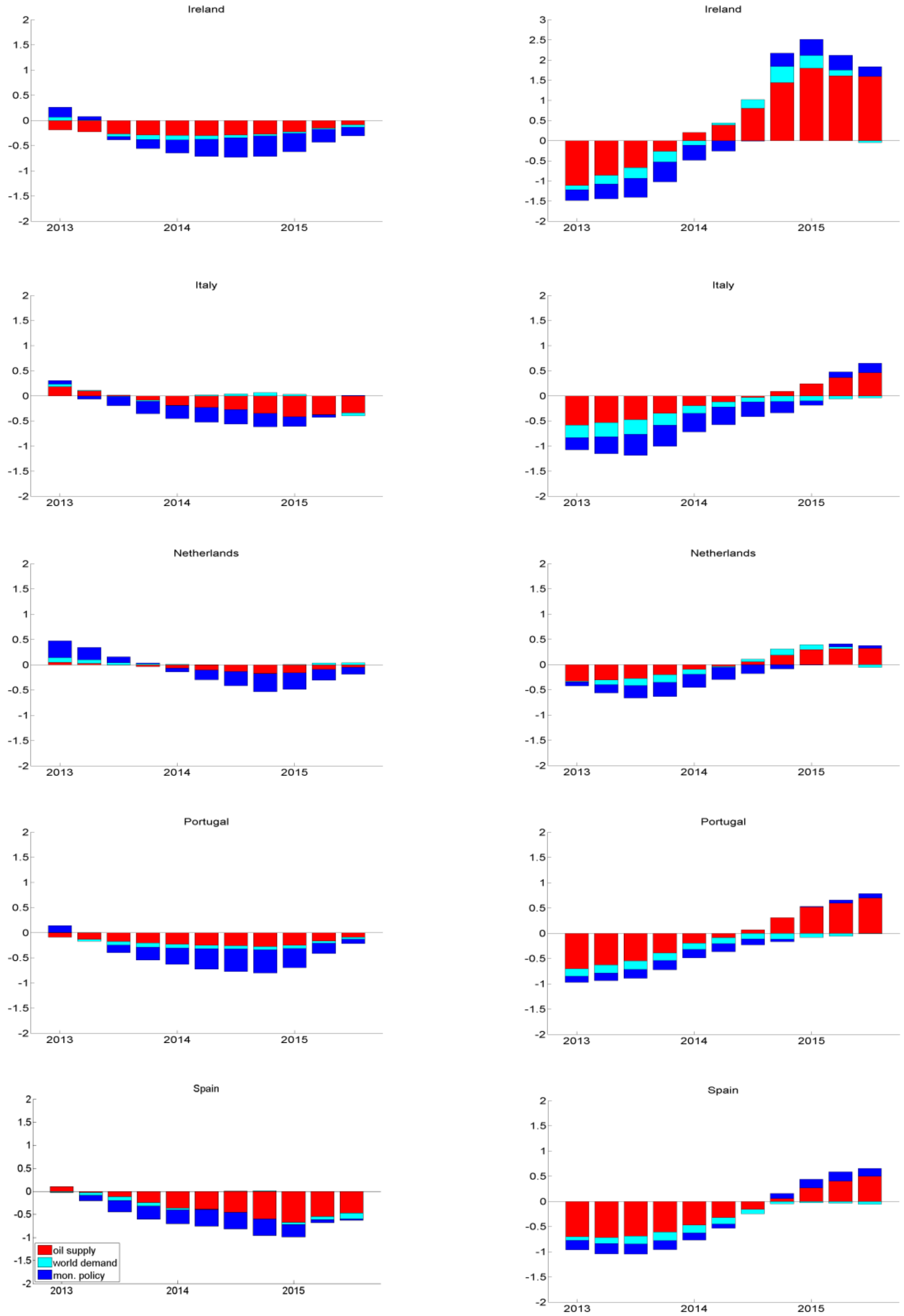
a. Inflation **b. Real GDP growth**



Notes: in all the panels the coloured stacked bars represent the (median of the posterior) contribution of the identified structural shocks to y-o-y inflation (left column) and y-o-y GDP growth (right column).

Figure 10. Historical decomposition, euro area countries (cont'd)

a. Inflation **b. Real GDP growth**

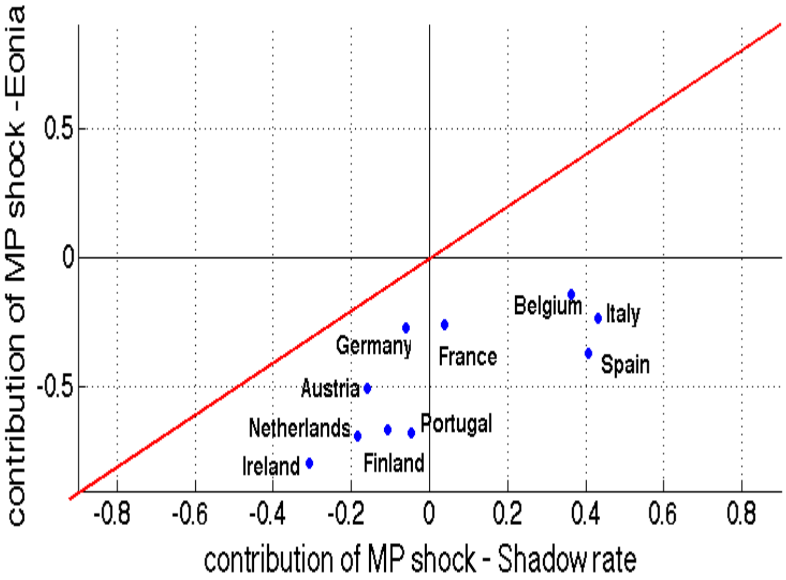


Notes: in all the panels the coloured stacked bars represent the (median of the posterior) contribution of the identified structural shocks to y-o-y inflation (left column) and y-o-y GDP growth (right column).

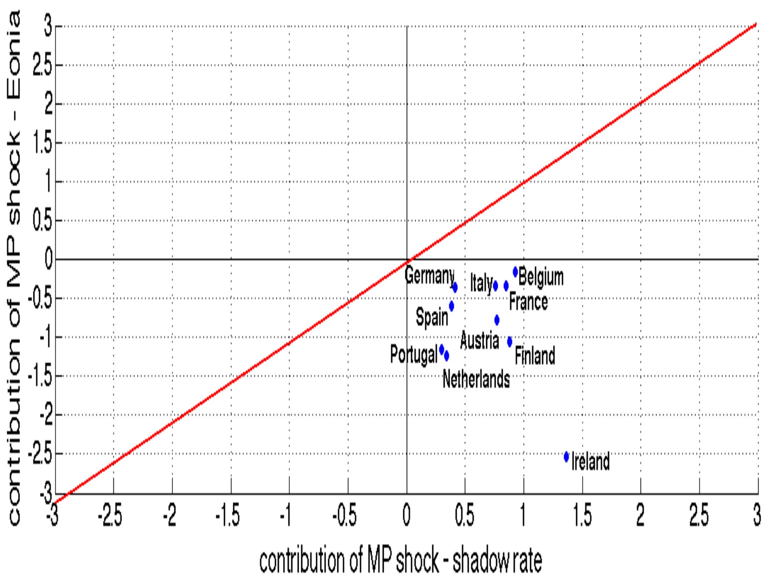
Figure 11. Heterogeneity in contribution of monetary policy:

EONIA vs. shadow rate

a. Inflation



b. Real GDP growth



Notes: the blue dots represent the sum of the contribution of monetary policy shocks to inflation (panel a) and real y-o-y GDP growth (panel b) over the period 2015:Q1-2015:Q3. The red line is the 45-degree line.

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