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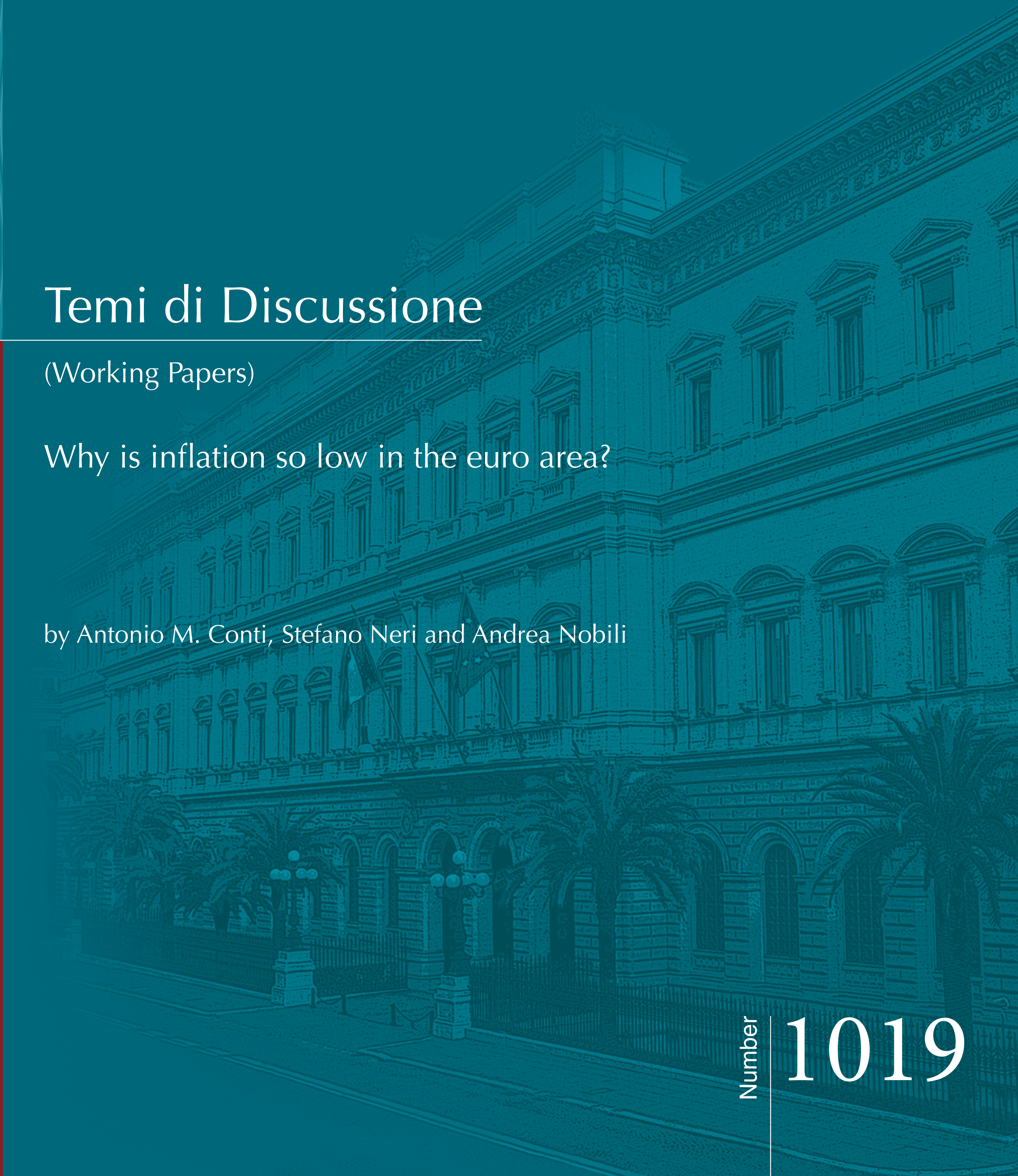

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WHY IS INFLATION SO LOW IN THE EURO AREA?

by Antonio M. Conti*, Stefano Neri* and Andrea Nobili*

Abstract

Inflation in the euro area has been falling steadily since early 2013 and at the end of 2014 turned negative. Part of the decline has been due to oil prices, but the weakness of aggregate demand has also played a significant role. This paper uses a VAR model to quantify the contribution of oil supply, aggregate demand and monetary policy shocks (identified by means of sign restrictions) on inflation in the euro area. The analysis suggests that in the last two years inflation has been driven down by all three factors, as the effective lower bound to policy rates has prevented the European Central Bank from reducing the short-term rates to support economic activity and align inflation with the definition of price stability. Remarkably, the joint contribution of monetary and demand shocks is at least as important as that of oil price developments to the deviation of inflation from its baseline. Country-by-country analysis shows that both aggregate demand and oil supply shocks have driven inflation down everywhere, albeit with varying intensity. The findings stand confirmed after a series of robustness checks.

JEL Classification: C32, E31, E32, E52.
Keywords: oil supply, monetary policy, inflation, VAR models, Bayesian methods.

Contents

* Bank of Italy, Economic Outlook and Monetary Policy Directorate.

Once again, a number of exogenous factors affected price developments, going from food and energy price declines, to the appreciation of the euro against the dollar since mid-2012 to May of this year, and finally to the relative price adjustment that had to happen in the stressed euro area countries. But there are increasing signals that insufficient aggregate demand is also playing an important role.

V. Constâncio, Vice-President of the ECB[1]

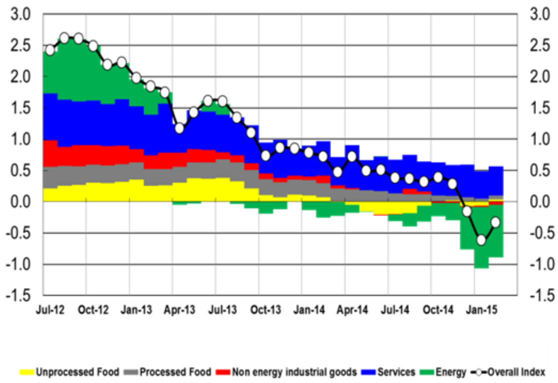
1. Introduction

Euro-area inflation fell in 2013 and 2014 and reached a negative value of -0.2% in annual terms in December 2014 (Figure 1), when core inflation was as low as 0.7%.[2] The fall in inflation since early 2013 can be only in part attributed to the fall in prices of energy goods and unprocessed food. The other components (non-energy industrial goods, processed goods and services) have also been characterised by subdued price dynamics. Part of the decline of core inflation can be explained by its increased sensitivity to the output gap, as shown by Riggi and Venditti (2015).

Inflation has been falling to historically low levels not only in the countries that have been hit the hardest by the sovereign debt crisis, but also in those less directly affected (Figure 2). In December in no country of the euro area the inflation rate was above 1 per cent; in twelve countries consumer price dynamics were negative.

Figure 1. HICP Inflation in the euro area and contribution of components

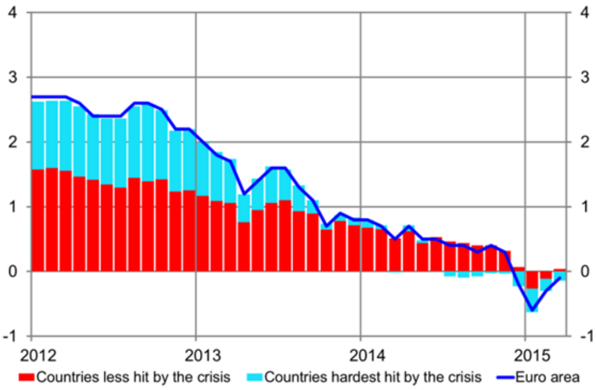
(*12-month percentage changes and percentage points*)



Source: Eurostat.
Note: based on the Harmonized Index of Consumer Prices (HICP).

Figure 2. HICP Inflation in the euro area and by group of countries

(*12-month percentage changes and percentage points*)



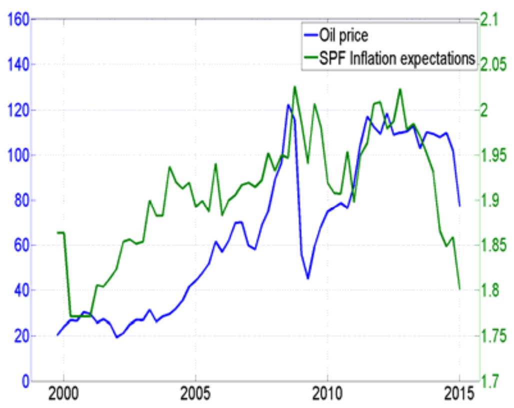
Source: Eurostat, Banca d'Italia calculations.
Note: based on the Harmonized Index of Consumer Prices (HICP).

[1] Speech by Vítor Constâncio, Vice-President of the ECB, at the 18th Annual Central Bank and Investment Authority Seminar organised by Commerzbank, Berlin, 16 October 2014.
[2] A lower value had only been reached in July 2009 (-0.6 per cent), as the result of rapidly falling oil prices.

The evidence that low inflation characterizes several sectors of economic activity and euro-area countries supports the view that weak aggregate demand has been playing a key role in keeping inflationary pressures subdued, as the opening suggests. The strength of the decline in inflation has been largely unexpected by market analysts (Miccoli and Neri, 2015).

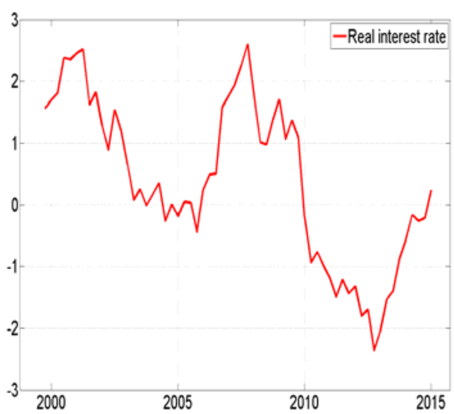
Furthermore, the current disinflationary phase is radically different from the one that characterized the 2008 and 2009 period, as the latter occurred during the most acute phase of the global financial crisis, when oil prices collapsed dramatically from the peak reached in July 2008. In that period survey-based long-term inflation expectations remained well anchored to the definition of price stability. In the current phase, instead, long-term inflation expectations, measured by the average of professional forecasters estimates, have declined persistently, reaching historical lows at 1.77 per cent (Figure 3). The decline of inflation expectations, with the ECB policy rates at their effective zero lower bound, has exerted un upward pressure on the real short-term interest rate (Figure 4). The real three-month rate, which was -2.4 per cent in the third quarter of 2012, increased sharply in the following two years, reaching 0.25 per cent at the end of 2014.

Figure 3. Oil prices and long-term inflation expectations
(*euro and percentage points*)



Source: Eurostat and ECB.
Note: Brent prices in euro. The five-year inflation expectations are taken from the Survey of Professional Forecasters of the ECB.

Figure 4. Real short-term interest rate
(*percentage points)*



Source: ECB.

In this paper we use a Bayesian VAR model to quantify the role played by oil prices, aggregate demand and monetary policy in driving inflation in the euro area, with a particular focus on the 2013-2014 period and the cross-country heterogeneity. The identification of the shocks is based on the sign restrictions approach developed by Canova and De Nicolò (2002) and Uhlig (2005) and refined by Rubio-Ramírez et al. (2010).

The baseline VAR specification and the restrictions used for the identification of the structural shocks are chosen in order to consider the main drivers of low inflation in the most recent period in the euro area. In particular, following the literature on oil price shocks (Barsky and Kilian, 2004; Kilian, 2009; Lippi and Nobili, 2012) we properly distinguish between oil supply shocks and innovations stemming from changes in the rest of the world (RoW) demand. The restrictions we impose on the impulse responses are in general consistent with the theoretical predictions of open-economy models with endogenous oil price fluctuations (Backus and Crucini, 1998, Bodenstein et al., 2011; Bodenstein and Guerrieri, 2011). We also include in the VAR a number of foreign variables in order to take into account the impact of financial tensions on the world economy and developments in U.S. monetary policy which may have affected the economy of the euro area.

Our main results are as follows. Over the whole sample, domestic and foreign demand shocks are found to be the main driver of HICP inflation. Oil supply was a relevant factor in explaining the rise of inflation in the first half of 2008, while being less important in the following disinflation. When considering to the 2013-2014 period, oil supply and aggregate demand shocks have been the major source of disinflation. Moreover, with ECB policy rates at their effective lower bound, monetary policy shocks also contributed to falling inflation. As far as individual countries are concerned, the analysis shows that in the countries most affected by the sovereign debt crisis monetary policy have played a larger role compared with the other economies Both aggregate demand and oil supply shocks, although with varying intensity across countries, have driven inflation down in all the main euro-area countries, confirming that the disinflation was a widespread phenomenon and not the consequence of relative price adjustment with the monetary union. From a quantitative point of view, the joint contribution of monetary and domestic demand shocks is at least as relevant as the one exerted by oil price developments in explaining the deviation of inflation from model baseline.

The paper relates to several contributions on oil prices and monetary policy. When evaluating the euro-area monetary policy stance it is crucial to take into account the two-way feedback between oil prices and monetary policy. Using a VAR model, Bernanke et al. (1997) show that the severity of the 1974 and 1982 recessions was the result of the direct response of the Federal Reserve to previous oil price shocks. This view has been challenged in Hamilton and Herrera (2004) which show that implementing a constant interest rate policy would have required policy changes so large to be historically unprecedented and hence unreliable because of the Lucas critique. The analysis is even more complex since the potential endogeneity of oil price fluctuations implies that the response of the central bank may depend on the source of oil shock (Kilian and Lewis, 2012).

The response of monetary policy to oil price shocks have been also investigated using dynamic stochastic general equilibrium (DSGE) models. Many papers assume oil price to be exogenous with respect to the U.S. economy (Leduc and Sill 2004 and Carlstrom and Fuerst, 2006), or they take into account the endogeneity of oil price changes while neglecting the open economy aspect of the transmission mechanism (Bodenstein et al. 2012 and Nakov and Pescatori 2010a,b). Building on the work of Backus and Crucini (1998), Bodenstein and Guerrieri (2011) propose a model to study the responses of economic activity to oil price shocks. The find evidence that non-oil trade linkages were an important transmission channel for shocks that affect oil prices in the U.S., while nominal rigidities and monetary policy are not. Bodenstein et al. (2012) use the same model to analyse the optimal monetary policy responses from a welfare point of view and to re-examine the welfare gains from global monetary policy coordination.

Our analysis makes an important contribution to the empirical literature on the transmission of shocks in the euro area (see, among others, Peersman and Smets, 2001; Boivin et al., 2009; Cecioni and Neri, 2011; Barigozzi et al., 2014). However, none of the most recent papers considers the current low inflation environment and all of them solely focus on monetary policy shocks. The closest contribution to ours is the one by Ferroni and Mojon (2014), who highlight the role of global inflation for predicting domestic prices developments. However, they end their analysis in 2013 and do not identify monetary policy shocks.[3]

Our results hold after a number of important robustness checks. In particular, we extend the analysis and identify credit supply shocks, as an unexpected tightening in the supply of lending may reduce both output and inflation. Hristov et al. (2012) and Gambetti and Musso (2014) find that credit supply shocks have been a non-negligible source of business cycle fluctuations in the euro area, in particular during the sovereign debt crisis. Finally, in spite of not identifying unconventional monetary policy shocks (differently from Peersman, 2011; Casiraghi et al. 2013; Boeckx et al., 2014), we include in the VAR as endogenous variables those capturing the unconventional measures adopted by the ECB since the beginning of the global financial crisis, namely those expanding the size of the central bank's balance sheet s. Overall, these analyses seem to validate, if not strengthen, our main results.

The remainder of the paper is organized as follows. Section 2 briefly presents the model. In Section 3 we discuss the impulse responses to the identified shocks, in Section 4 we study the drivers of inflation in the euro area. In Section 5 we extend the analysis to euro area countries and in Section 6 we present some robustness analysis. Section 7 concludes and suggests some possible directions for future research.

2. A Bayesian VAR model

In the empirical analysis we adopt a VAR model estimated by means of Bayesian methods to handle the relatively scarce number of observations, since euro-area data are available since the late nineties only. In what follows we briefly describe the specification and the estimation of the VAR and identification of the shocks.

[3] They also run the analysis for some euro area countries. However, differently from this paper, their shocks are country-specific, i.e., they estimate separate VAR for each economy.

2.1 The model

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

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

where $\mathbf{c}$ is a *n×1* vector of deterministic components containing constants, $\boldsymbol{\varepsilon}_\mathrm{t}$ *n×1* vector of exogenous structural shocks, $\mathbf{A}_\mathrm{j}$ is a *n×n* matrix of parameters for $0 \leq j \leq p$ with $\mathbf{A}_0$ invertible, *p* is the lag length, $\mathbf{z}_\mathrm{t}$ is a *r×1* vector of exogenous variables pre-multiplied by the *n×r* vector of coefficients $\boldsymbol{\gamma}$ and *T* is the sample size. The vector $\boldsymbol{\varepsilon}_\mathrm{t}$, conditional on past information and initial conditions $\mathbf{y}_{0,} \dots \mathbf{y}_{1-\mathrm{p}}$, 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 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 $\mathbf{A}_+' = [\mathbf{A}_1' \dots \mathbf{A}_\mathrm{p}' \ \boldsymbol{\gamma}' \ \mathbf{c}']$ and $\mathbf{x}_\mathrm{t}' = [\mathbf{y}_{\mathrm{t}-1}' \dots \mathbf{y}_{\mathrm{t}-\mathrm{p}}' \ \mathbf{z}_\mathrm{t}' \ \ 1]$. The dimension of $\mathbf{A}_+'$ is *m×n*, where *m=np+1*. Equation (2) implies a reduced-form representation given by

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

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 Data

The sample includes quarterly observations for the period 1995Q1 – 2014Q4. We use data for the euro area and some international variables, as we are interested in identifying both domestic and international factors that can affect inflation dynamics. The data are taken from the Area Wide Model Database (AWM, see Fagan et al., 2005), the ECB Statistical Data Warehouse, Bloomberg and the Federal Reserve of St. Louis Database (FRED). Data are seasonally adjusted.

The baseline specification includes the following six variables: the oil price in U.S. dollars, an indicator of world demand of euro-area goods and services, real GDP, the harmonized index of consumer prices (HICP) or, alternatively, the core HICP (the overall index net of energy, food and tobacco) index, the EONIA rate (assumed to be controlled by the ECB) and the exchange rate of the euro against the U.S. dollar. To take into account the U.S. monetary policy we include in the vector of exogenous variables $\mathbf{z}_t$ the effective Federal Funds rate, which can in principle affect the world business cycle and oil prices, as well the option-implied expectation of near term volatility of the U.S. stock market (known as the VIX) taken from Chicago Board Options Exchange. The VIX helps taking into account the impact of financial tensions on the world economy.

All variables, except the interest rates, are log-transformed. By estimating the VAR in levels, we are implicitly allowing for the possible presence of cointegration relations, without imposing restrictions on the long-run properties of the model (Sims et al., 1990).

2.3 Identification of the shocks

In the empirical analysis we aim at identifying a set of structural shocks affecting the euro area business cycle and analyse their effects on inflation and output and the response of monetary policy. 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 et al. (2010).

From a theoretical standpoint, the specification of our VAR builds on an open-economy model with endogenous oil price fluctuations (see Backus and Crucini, 1998, Bodenstein et al., 2011 and Bodenstein and Guerrieri, 2011), in which the domestic monetary policy can respond to both domestic and foreign shocks hitting the economy.[4] In the analysis we focus on four mutually orthogonal shocks that may be responsible for the persistent decline in inflation in the euro-area. The sign restrictions are summarised in Table 1.

Table 1. Sign restrictions used for identification

	Shock			
Variable	Oil supply	RoW demand	Aggregate demand	Monetary policy
Nominal oil price	-	-		
Rest-of-the-World output	+	-		
Euro-area output	+		-	-
Euro-area inflation	-	-	-	-
Euro-area short-term rate		-	-	+
Exchange rate		+	-	+

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

The first is a textbook "oil-supply" shock: an exogenous decrease in oil prices drives inflation down and increases output. We do not impose any a priori restriction on the sign of

[4] In the model developed by Bodenstein and Guerrieri (2011) there are two economies, one (i.e. the euro area) is a net-oil importer while the other (i.e. the "rest of the world) is a net-oil exporter. Both economies are endowed with exogenous supplies of oil, the price of which adjusts endogenously to clear the market. Nominal and real rigidities generate persistence in the transmission of the shocks. Monetary policy is modelled as a Taylor (1993) rule according to which, the central bank responds to inflation and the output gap.

the response of the short-term rate. Oil supply shocks typically pose a dilemma to policy-makers as they give raise to a trade-off between the stabilization of output and inflation.

Changes in oil prices may have different effects for the real economy depending on the source of the shock (Barsky and Kilian, 2004 and Kilian, 2009). Therefore, in order to correctly identify an oil supply shock, it is necessary to disentangle its effects from those of a "rest of the world" (RoW, hereafter) demand shock which can also lead to changes in oil prices but may have different effects on the euro-area output and inflation. A "RoW demand" shock is one implying a positive comovement between the RoW output and the oil price. These sign restrictions are consistent with both "preference" and "productivity" shocks in the RoW as in the real business cycle framework adopted by Lippi and Nobili (2012), as well as with the "foreign oil efficiency" shocks suggested by Bodenstein and Guerrieri (2011) which may capture changes in consumption patterns or production processes.

We impose a positive correlation between euro area inflation and the monetary policy rate, conditional on a shock to world demand, while we remain agnostic about the response of output since it may be different depending on whether there is a RoW productivity or preference shock (Lippi and Nobili, 2012)[5] or because there are nominal and real rigidities in the economy (Bodenstein and Guerrieri, 2011).[6] Finally, we assume that a negative (positive) shock to RoW shock leads to an appreciation (depreciation) of the exchange rate, as the foreign monetary policy eases (tightens) its stance to counteract weaker (stronger) economic conditions in the rest of the world.[7]

The third shock we consider is an "aggregate demand" shock: a negative shock to demand decreases output, inflation and the policy rate in the euro area and leads to a depreciation of the exchange rate. The sign restrictions on impulse responses are consistent with several type of shocks affecting consumption and investment (Smets and Wouters, 2007). This domestic demand shock is different from a negative RoW demand shock since it depreciates the exchange rate, whereas the foreign shock leads to an appreciation. We acknowledge that a domestic aggregate demand shock can be considered as a mixture of other aggregate shocks that have the same implication for the euro-area, such as, for example, a shock to loan supply or to fiscal policy. We test the robustness of our results in Section 4 by

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[5] In Lippi and Nobili (2012) a positive RoW productivity shock increases the total amount of resources available in the economy and consumption tends to increase in both countries. The effect on domestic production depends on the consumption substitution elasticity between home and foreign goods, being positive (negative) when the substitution elasticity is smaller (bigger) than one. A positive RoW preference shock instead increases the real cost of oil and the price of imported foreign goods, thus resulting is an unambiguous reduction of domestic production.

[6] Bodenstein and Guerrieri (2011) stressed the importance of a "foreign oil efficiency" shock. As foreign oil demand expands, the real price of oil in euro-area consumption units increases and domestic oil demand contracts. In the short run, however, this shock does not unequivocally lead to a fall in output since the presence of nominal and real rigidities may prevent both consumption and investment from adjusting immediately.

[7] Our VAR model does not include oil production and is, therefore, more parsimonious that that considered by Kilian (2009), Lippi and Nobili (2012) and Kilian and Murphy (2012) in shaping oil market developments. The practice of imposing sign restrictions on oil quantity has been challenged by Kilian and Murphy (2012) but, as shown by Lippi and Nobili (2012), it is not relevant for a proper detection of the effects on the U.S. economy.

including credit variables in the VAR and identify a loan supply shock. We do not consider fiscal shocks as they are mainly country-specific.

The fourth shock we consider is a "conventional" monetary policy shock. It is important to emphasize that we do not explicitly consider the role played by the several types of unconventional measures adopted by the ECB since the beginning of the global financial crisis (see, for example, Casiraghi et al., 2013). However, in spite of not identifying an unconventional monetary policy shock as, for example, in Peersman (2011), the adoption of the EONIA as the policy rate is somewhat capturing the additional easing induced by the excess liquidity generated by the ECB unconventional measures. In the VAR an unexpected decline in the short-term interest rates reduces both output and inflation and leads to an exchange rate depreciation. We remain agnostic about the response of both oil prices and RoW demand. In the case of large economies, such as the euro area, causality in these relationships may run in both directions, as events in the oil market and the RoW may influence the area's monetary policy in the euro area and at the same time changes in the latter may impact on the demand for oil at the global level. For example, the model in Bodenstein and Guerrieri (2011) suggests a positive comovement between the oil price and domestic output, following a monetary policy shock. We, however, prefer to remain agnostic and let the data speak by themselves, given also the scant empirical evidence for the euro area.[8]

In terms of implementation of the restrictions, a crucial assumption 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 impact.

We rely on the algorithm developed by Rubio-Ramirez et al. (2010) for the identification of the shocks, as it is more efficient in systems of size larger than four variables. The idea of their procedure can be summarized as follows.

The algorithm employs the uniform Haar prior and searches for a set of impulse responses which satisfy the sign restrictions. The algorithm is made of the following steps.

1. Take a random draw $(\mathbf{B}, \mathbf{\Sigma})$ from the posterior distribution of the reduced-form VAR parameters (inverse Wishart for the covariance matrix $\mathbf{\Sigma}$ and normal for the reduced-form coefficients $\mathbf{B}$), before any identifying assumption is imposed
2. For each couple $(\mathbf{B}, \mathbf{\Sigma})$ take a draw from the uniform distribution with respect to the Haar measure on *O(n)* (i.e., draw an orthogonal matrix $\mathbf{Q}$ from the uniform distribution with respect to the Haar measure of *O(n)*).

[8] In the case of the U.S. the assumption that oil prices are predetermined has been tested by Kilian and Vega (2011). The authors find that the price of crude oil does not respond to U.S. macroeconomic news contemporaneously and that there is no compelling evidence against the assumption of oil prices being predetermined with respect to monthly U.S. macroeconomic aggregates in the period 1983-2008.

3. The function $\widehat{h(\mathbf{B}, \mathbf{\Sigma}, \mathbf{Q})}$ will be a draw from the unrestricted posterior with respect to the prior; compute the impulse responses.
4. Keep the draw if $\mathbf{S}_{\mathrm{j}} f\left(h(\mathbf{\Sigma})^{-\mathbf{1}}\mathbf{Q}, \mathbf{B}h(\mathbf{\Sigma})^{-\mathbf{1}}\mathbf{Q}\right)\mathbf{e}_{\boldsymbol{j}} > 0$ are satisfied for $j \epsilon \mathcal{S}$, i.e. if the imposed identifying sign restrictions are respected by the IRFs, where $\mathbf{S}_{\mathrm{j}}$ is the matrix of sign restrictions and $\mathbf{e}_{\boldsymbol{j}}$ denotes the *j*-th colum of the Identity matrix.
5. Return to Step 1 until the desired number of draws from the posterior of the structural parameters conditional on the identifying sign restrictions has been achieved.

These steps are nested within a Monte Carlo algorithm (see the next section).

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 diffuse prior for the coefficients (Kadiyala and Karlsson, 1997). Let α be a vector that stacks the reduced-form coefficients in *B(L)*. We assume a normal prior for α and a diffuse one for the variance-covariance matrix of the shocks *u*. The prior distributions are:

$$\alpha \sim N(\overline{\alpha}, \overline{\overline{\Sigma}}_{\alpha})$$

$$p(\Sigma_u) \sim |\Sigma_u|^{-\frac{N+1}{2}}$$

where $\bar{c}$ and $\overline{\overline{\Sigma}}_c$ are the mean and the variance covariance matrix of the prior and *N* is the number of endogenous variables in the VAR. We impose the restrictions of the so-called Minnesota prior (Litterman, 1986) on α (Doan et al., 1984): the variables of the VAR are assumed to follow a univariate first order autoregressive process with correlated innovations, rather than unit root processes as in the original formulation. All coefficients in α are equal to zero except the first own lag of the dependent variable in each equation. The variance-covariance matrix is assumed to be diagonal: the $\bar{\sigma}_{\alpha}^{i,j,l}$ element corresponding to lag ℓ of variable *j* in equation *i* is equal to:

$$\sigma^{i,j,l} = \begin{cases} \dfrac{\phi_0}{h(l)} & \text{if } i = j, \forall l \\ \phi_0 \dfrac{\phi_1}{h(l)} \left(\dfrac{\sigma_j}{\sigma_i}\right)^2 & \text{if i} \neq j, \forall l, j \text{ endogenous} \\ \phi_0 \phi_2 & \text{if } j \text{ exogenous} \end{cases}$$

where the hyperparameter ϕ_0 represents the overall tightness of the prior; ϕ_1 the relative tightness of other variables, ϕ_2 the relative tightness of the exogenous variables and $h(\ell)$ the relative tightness of the variance of lags other than the first one (we assume that $h(\ell) = \ell$). The term $(\sigma_j / \sigma_i)^2$ is a factor that accounts for the different scale of the variables of the model.

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 covariance matrix of the residuals, which has a Wishart distribution. Inference is conducted using the Gibbs sampling algorithm. For each draw from the posterior distribution of the VAR we search for a rotation $\tilde{Q}$ until we identify the four shocks jointly. Once we identify the four shocks we generate another draw from the posterior distribution.

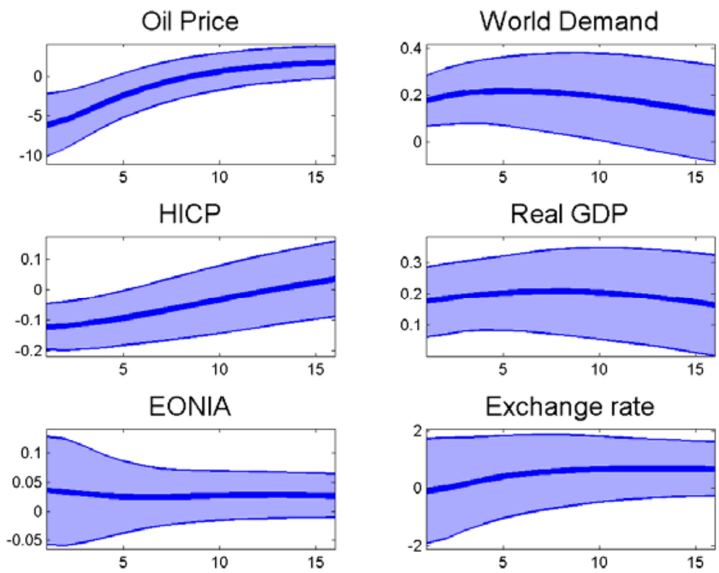
3. Results

In this Section we present and discuss the impulse responses to the identified shocks and their contribution to the actual evolution of inflation and real GDP, with a special focus on the 2013-2014 period. The results are based on 50,000 draws from the posterior distribution and 10,000 from the unitary sphere.

3.1 Impulse responses

Figures 5 to 8 report the median (solid thick blue line) responses together with 0.68 probability intervals (light blue shaded areas) of the posterior distribution of the responses. Figure 5 shows that an oil supply shock drives inflation and output in opposite directions while the short-term interest rate remains unchanged, possibly reflecting the trade-off facing the central bank between stabilizing the inflation rate and closing the output gap.

Figure 5. Impulse responses to a positive oil supply shock

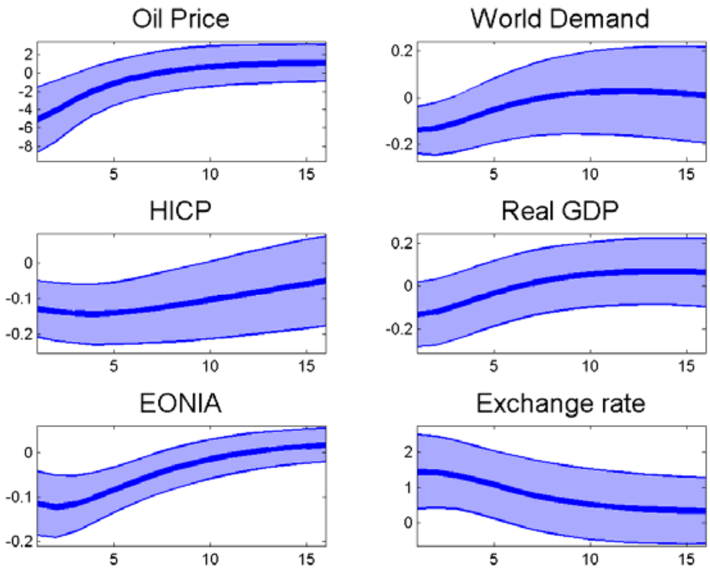


Note: percentage deviation from baseline. Thick blue line: median of the posterior distribution; light blue shaded area: 0.68 probability interval of the posterior distribution.

The shock significantly rises real GDP, which reaches a peak after about two years. For the whole simulation horizon the 0.68 probability interval is above zero, suggesting that the result is not driven only by the restriction imposed on impact. The negative effect on consumer prices is less persistent.

Figure 6 shows the effects of a negative RoW demand shock.

Figure 6. Impulse responses to a negative RoW demand shock



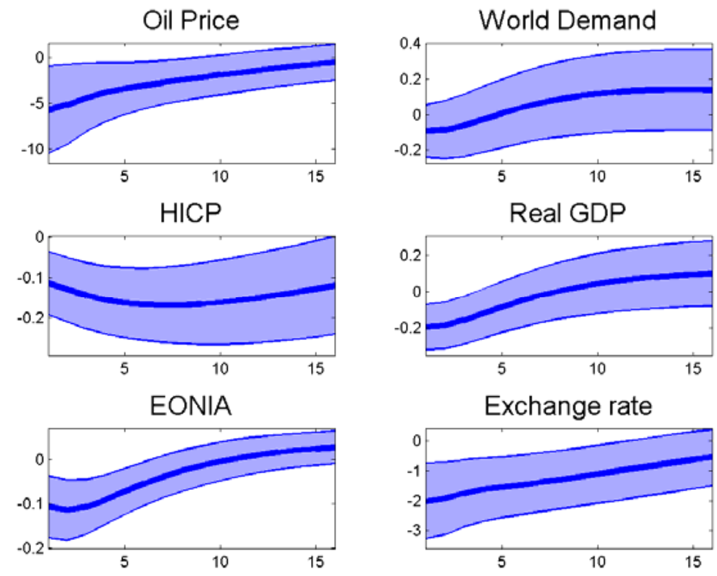
Note: percentage deviation from baseline. Thick blue line: median of the posterior distribution; light blue shaded area: 0.68 probability interval of the posterior distribution.

The effect on the price of oil is similar to that in the case of an oil supply shock and so is the impact on inflation. Real GDP declines on impact. This result is interesting since in the model developed by Bodenstein and Guerrieri (2011) the effect is uncertain.[9] Our main view is that, following a negative RoW demand shock, the adverse effect on euro area real GDP stemming from the decline in trade more than counterbalances the beneficial impact of the oil price decrease and the easing in monetary conditions. Riggi and Venditti (2014) identify shocks to the supply and demand for oil in a time-varying VAR with stochastic volatility and find that the sign of the correlation between oil prices and euro area exports is positive conditional on an increase in oil demand fostered by stronger global growth.

[9] Forni et al. (2012) found similar results for the euro area by means of an estimated new-Keynesian small open economy model with Bayesian methods. They find that higher oil prices stemming from an increase in the rest of the world aggregate demand drive euro-area GDP and inflation up, whereas negative oil supply have stagflationary effects. The model, however, does not allow to study the effects of oil supply and demand shocks on monetary policy and the exchange rate, being a real business cycle model. Related contributions are Adolfson et al. (2007), Christoffel et al. (2008) and Jacquinot et al. (2009).

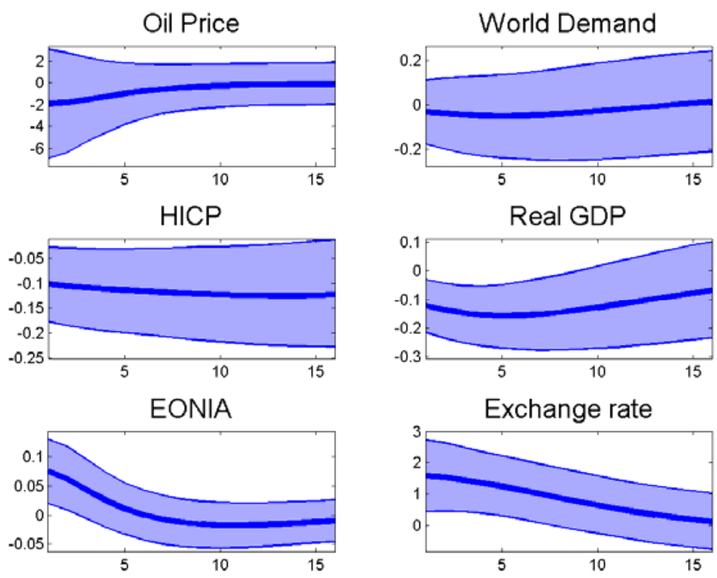
Figure 7 shows the dynamic effects of a domestic aggregate demand shock.

Figure 7. Impulse responses to a negative aggregate demand shock



Note: 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 8. Impulse responses to a contractionary monetary policy shock



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

Following a negative shock oil prices decline on impact. This result is worthwhile emphasizing since oil prices, which are fixed in international markets, are usually considered exogenous with respect to euro-area macroeconomic developments. The most striking result is that the effects on euro-area inflation and the exchange rate are much more persistent than those induced by foreign shocks, such as oil and world demand ones.

Finally, Figure 8 show the effects of a monetary policy shock that raises the short-term interest rate. The shock leads to a persistent decline in output and inflation and to an immediate appreciation of the euro. The increase in the short-term rate reduces oil prices and causes a moderate decline of world demand of euro-area goods and services.

It should be stressed that inflation responds significantly to all the shocks. The persistence of the responses is much lower than in Peersman and Van Robays (2009). This may reflect at least two differences in the estimation setting. First, we rely on the Minnesota prior. Second, the sample used by Peersman and Van Robays (2009) ends in 2008, while our sample includes both the global financial and sovereign debt crises during which output fell substantially and inflation declined persistently. In Section 6 we test the robustness of our results by estimating the model over the solely pre-crisis period.

4. The drivers of inflation in the euro area

Having studied the dynamic effects of the identified shocks, we can now quantify their contributions to actual developments in the euro area inflation and real GDP. In this Section we provide a structural interpretation of inflation developments with a particular focus on the most recent period and on the role of oil supply and monetary policy shocks.

To this end we compute the historical decomposition of annual inflation and real GDP growth, drawing the parameters of the VAR from their posterior distribution and using the shocks identified with the sign restrictions.[10] We start the historical decomposition in the first quarter of 1998 to remove the dependence of the results on initial conditions.

4.1 Inflation in the full sample

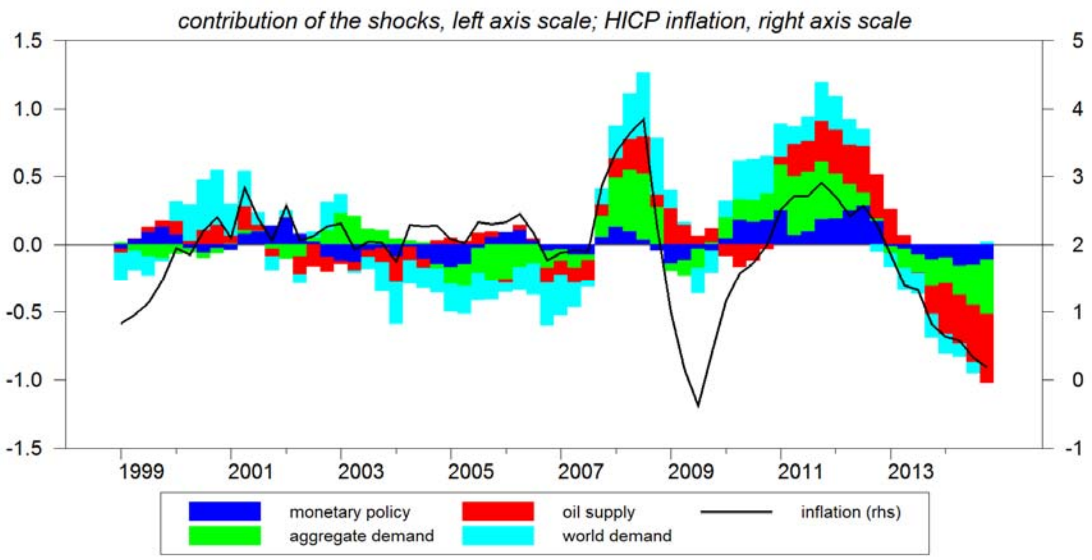
The historical decomposition of the euro-area HICP is shown in figure 9; it highlights the median of the posterior distribution of the contribution of each shocks to the deviation of inflation from the baseline for each quarter of the sample. The contribution to annual inflation are obtained by taking the four-quarter differences of the contribution to the price level.

Several remarks are in order. First, among the shocks we have identified, aggregate demand shocks and foreign shocks are the main drivers of inflation in the euro area over the

[10] We disregard the draws that are characterized by eigenvalues of the companion matrix of the reduced form VAR that are larger than one in absolute value since in these cases the baseline of the variables would display an explosive path.

full sample. Second, shocks to world demand explain a large part of the 2008 increase in inflation and the subsequent decline in 2009, whereas oil supply shocks are responsible for the increase but they are less important in accounting for the disinflation. Third, among the identified shocks, the contribution of monetary policy ones was the smallest. Unidentified shocks account for a large fraction of consumer price dynamics. In the next section we focus on the 2013-14 period in which inflation fell to unprecedented low values.

Figure 9. Historical decomposition of euro-area inflation



Note: median of the posterior contribution to the historical decomposition of headline inflation. Percentage points.

4.2 Inflation in 2013 and 2014

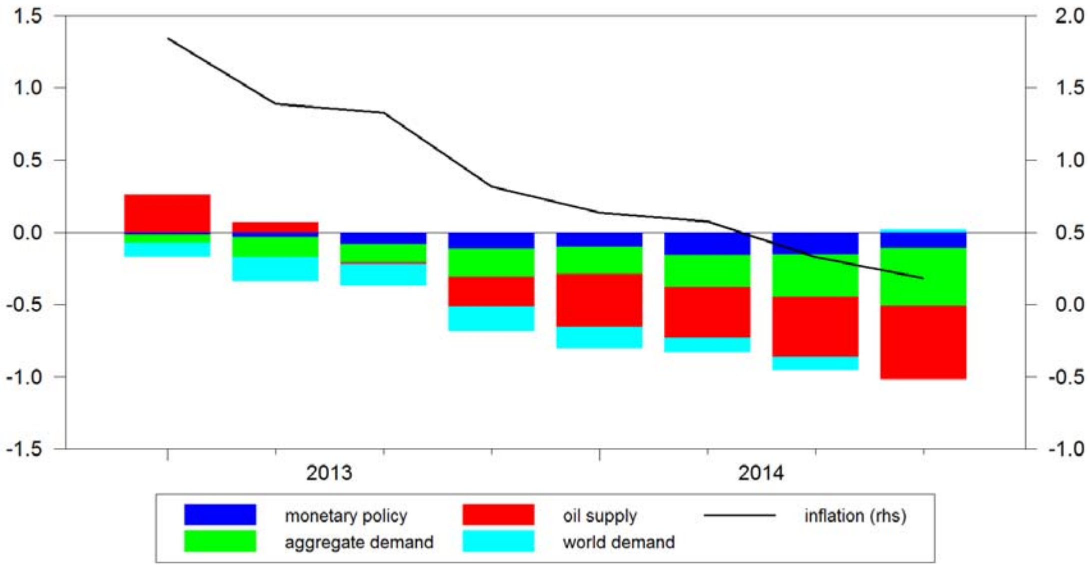
The paper has been motivated by the persistent decline of inflation in 2013 and 2014. It seems therefore natural to zoom in on the drivers of inflation in this period. Figure 10 reports the historical decomposition for this period. The aim is to shed light on the relative contribution of shocks to oil prices, aggregate demand and to monetary policy.

In September 2014 the ECB policy rates were reduced to their effective lower bound.[11] The presence of this constraint implies that any fall in short-term inflation expectations effectively brings about an unwarranted tightening of monetary conditions, which in a situation of weak aggregate demand can push inflation further down. The rise in the real rate may also offset, at least in part, the benefits of the fall in oil prices on real GDP that occurred in the second half of 2014. We find some differences with the period after the most acute phase of global financial crisis, with a positive contribution of the monetary policy shocks to inflation

[11] See "*Life below zero: Learning about negative interest rates*", speech by Benoît Cœuré, Member of the Executive Board of the ECB, presentation at the annual dinner of the ECB's Money Market Contact Group, Frankfurt am Main, 9 September 2014.

in 2010 and 2012. The main explanation is that, during the global financial crisis, the monetary policy rate was still above the zero lower bound and the ample liquidity injections by the ECB brought down the Eonia rate into a negative territory. This effect, albeit due to unconventional measures, is captured by the VAR model as an expansionary monetary policy shock.

Figure 10. Historical decomposition of euro-area inflation



Note: median of the posterior contribution to the historical decomposition of headline inflation. Percentage points.

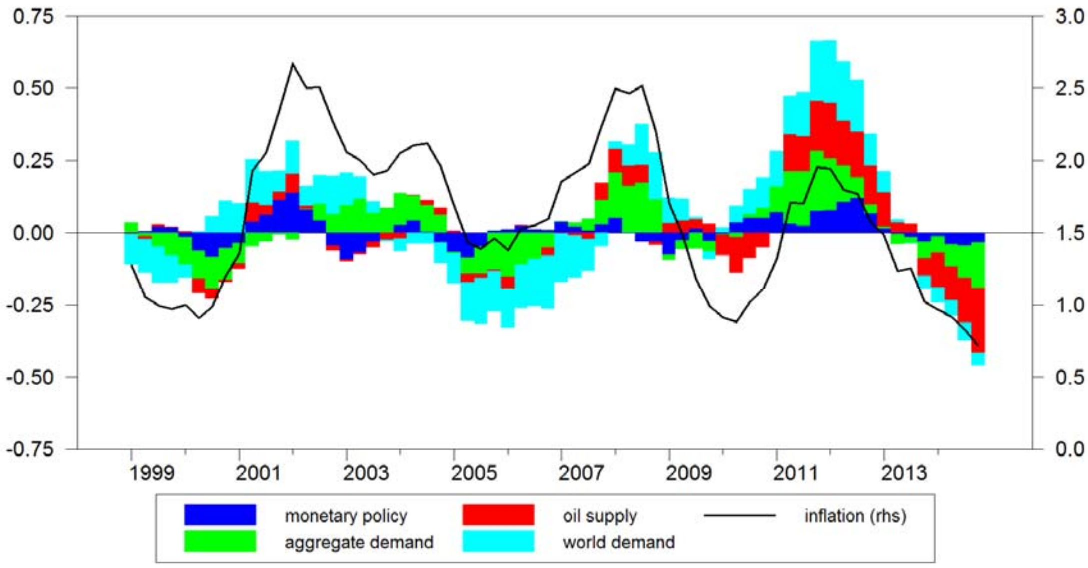
The contribution of monetary policy has always been negative, reaching a maximum of -0.15 percentage points in the second quarter of 2014, just before the introduction of additional accommodation by the ECB through the asset purchase programmes (covered bonds and asset-backed securities) and the targeted longer-term refinancing operations (TLTROs). The importance of aggregate demand shocks has increased over time, reaching a maximum in the last quarter of 2014. Oil shocks have also become increasingly important in driving inflation developments. In the last quarter of 2014 their contribution has been similar to that of aggregate demand shocks. Since we are using on a linear model we are not take into account the possibility that the relationship between inflation and aggregate demand may have strengthen after the global financial crisis (Riggi and Venditti, 2015).

4.3 The drivers of core inflation

Central bankers have long accepted that, in view of the lags in the transmission mechanism and the medium-term orientation of monetary policy, transitory inflation developments should not, in principle, unduly affect monetary policy decisions. This view implies that monetary policy should look through the short-term movements in the more volatile components of consumer prices and to focus on "core" inflation.

In the euro area while the ECB mandate is clearly set in terms of price stability of the ECB the year-on-year changes in the overall HICP, national statistical agencies and the ECB itself routinely report in their official publications and analyse an array of core inflation measures that are supposed to allow for a better assessment of the inflationary pressures. These measures are obtained by removing oil and unprocessed food prices from the overall index of consumer prices. Based on these considerations, we substitute the overall index in the VAR with core prices and run the empirical analysis once more without changing the identification of the shocks and the specification of the model. The historical decomposition of euro-area core inflation is reported in Figure 11.

Figure 11. Historical decomposition of core inflation



Note: median of the posterior contribution to the historical decomposition of headline inflation. Percentage points.

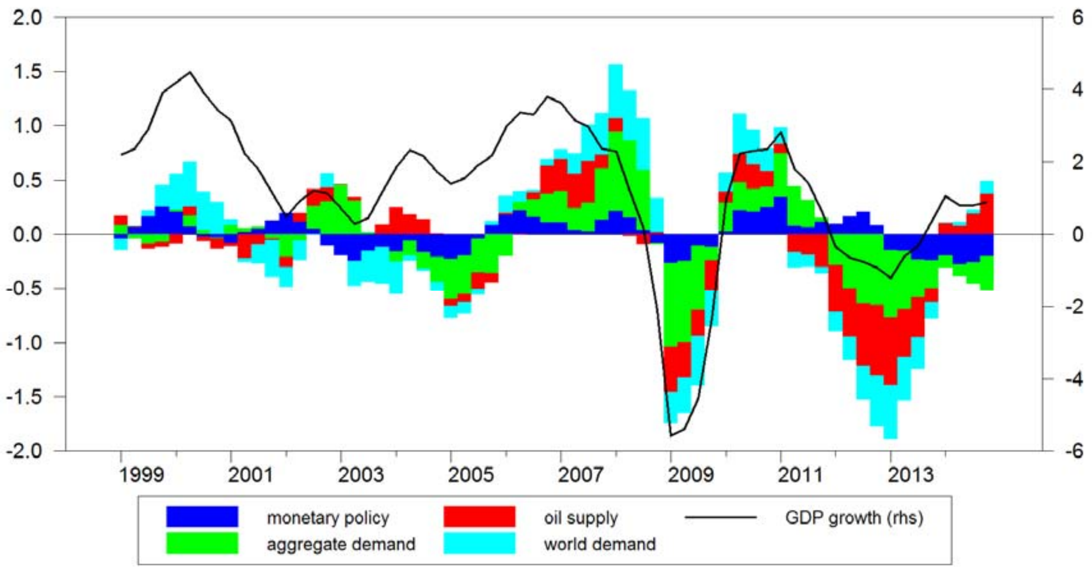
The recent developments in oil prices affected also core inflation, pointing to significantly larger second round effects than those prevailing in 2008 and 2009. Including nominal wage dynamics in the model would allow understanding the role of wage setting, without, however, altering the assessment of the contribution of oil shocks to core inflation developments. As expected, aggregate demand turns out to be, as a key driver of core inflation. The negative contribution of monetary policy is confirmed, meaning that our main conclusions regarding the role played by monetary policy is not affected by the dynamics of the most volatile HICP components. All in all, the identified shocks account for a larger fraction of inflation developments when core consumer prices are considered.

4.4 The drivers of economic activity

Having provided a description of the factors behind inflation dynamics in the euro area, we now turn to assessing the drivers of real GDP. Figure 12 shows the historical decomposition of the year-on-year growth rate of output and figure 13 zooms on in the 2013-14 period.

Aggregate demand shocks explain a significant fraction of GDP developments. Their contribution was particularly large during the 2008-09 Great Recession, which was also caused by falling demand from the rest of the world and, to a smaller extent, by the surge in oil prices in the first half of 2008. Interestingly, oil supply shocks also contributed to keeping GDP growth negative in 2012 and 2013. Monetary policy shocks provide the smallest contribution to output growth (roughly nil on average, but more significant in the last two years).

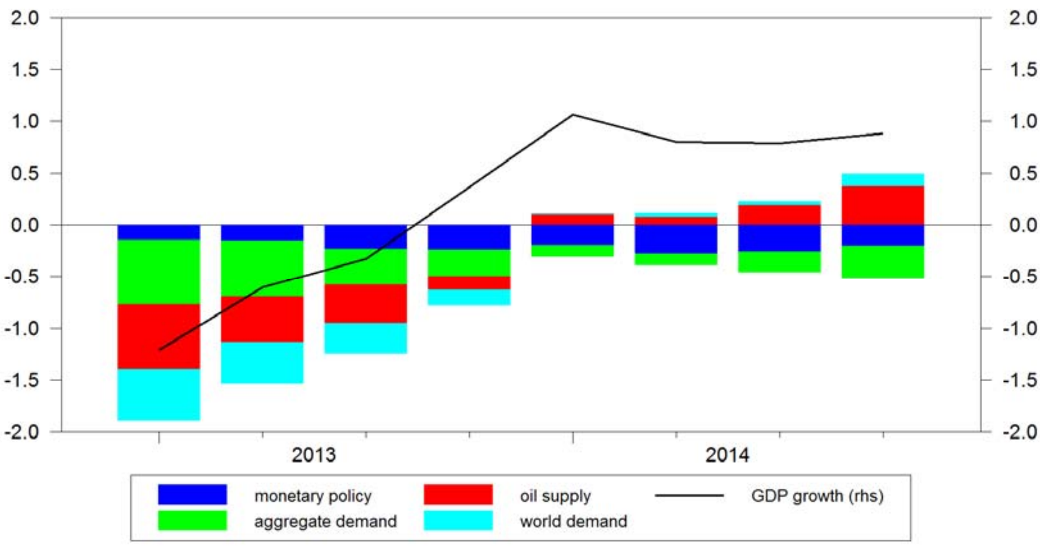
Figure 12. Historical decomposition of euro-area real GDP



Note: median of the posterior contribution to the historical decomposition of real GDP growth. Percentage points.

Contractionary monetary shocks exerted a downward pressure on output growth in 2013 and 2014; this finding is consistent with the negative contributions of monetary policy to inflation developments over the same period (Figures 9 and 11). In the last quarters of 2014, falling oil prices push real GDP up.

Figure 13. Historical decomposition of euro-area real GDP in 2013 and 2014

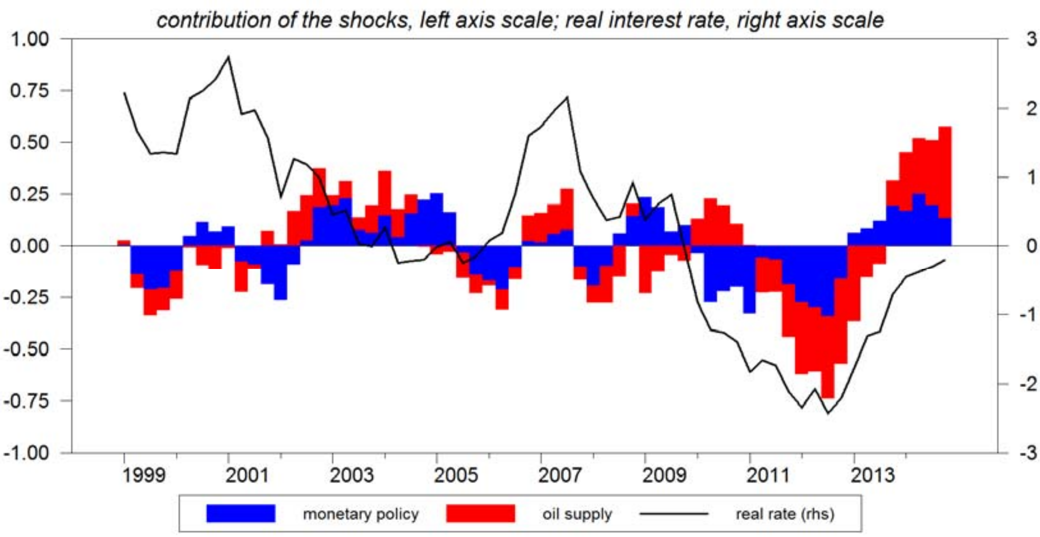


Note: median of the posterior contribution to the historical decomposition of real GDP growth. Percentage points.

4.5 The real short-term interest rate and oil prices

The results of the historical decomposition have highlighted an important role for monetary policy in driving inflation and, to a lower extent, output dynamics. Figure 14 shows, indeed, that monetary policy shocks are key drivers of the real short-term interest rate, which is defined as the nominal short-term nominal rate minus inflation.

Figure 14. Historical decomposition of the real short-term rate



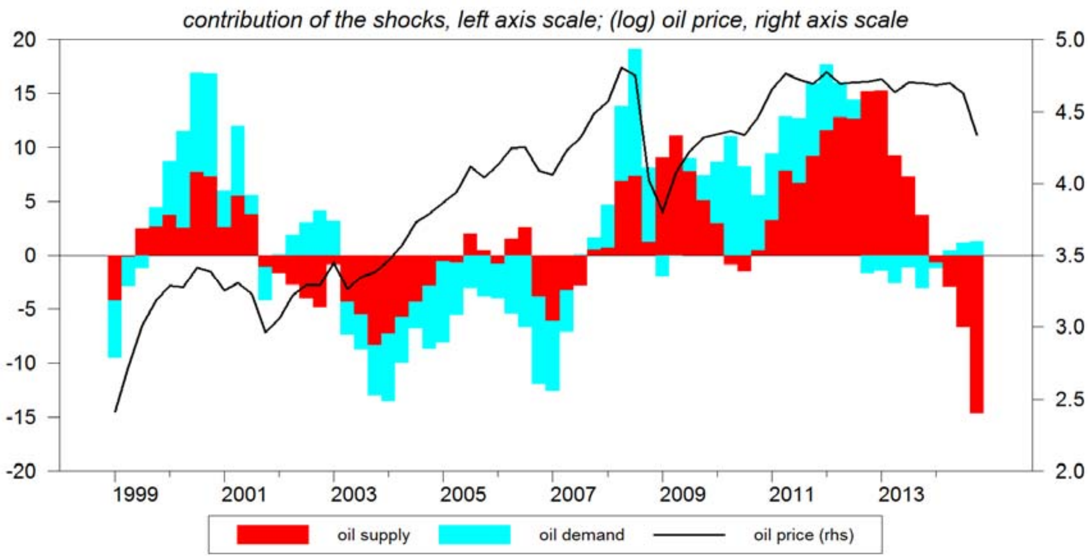
Note: the historical decomposition of the real short-term interest rate is computed as the difference between the historical decomposition of the nominal short-term interest rate and that of the headline inflation rate. It is based on the median of the posterior distribution of the estimated coefficients.

Interestingly, in 2012 negative oil supply shocks pushed inflation up (see figures 9 and 11). As the short-term (EONIA) rate was very close to zero, the increase in inflation resulted into a significant decline in the real rate. The opposite occurred in 2013 and 2014, as falling oil prices, due to positive supply shocks, pushed inflation down, causing an increase in the real rate, given that the nominal rate was at its effective zero lower bound.

The identification of oil supply and RoW demand shocks allows us understanding the role of these shocks in driving the dynamics of the price of oil. The implications of inflation and real GDP of the two shocks are different. Figures 5 and 6 show, indeed, that the sign of the effect of a fall in oil prices on real GDP depends on whether the latter arises because of an increase in the supply of oil (Figure 5) or a decline in world demand, i.e. a decline of the demand for oil. In Figure 15 we show the contribution of oil supply and world demand shocks to oil price developments.

Over the full sample both RoW and supply shocks have been important drivers of oil prices. The sharp increase in 2008 and the subsequent collapse were caused by both shocks. The collapse in 2014 was, instead, due to a sequence of large positive shocks to supply, whereas the role of demand factors was much more limited.

Figure 15. Historical decomposition of oil prices



Note: median of the posterior contribution to the historical decomposition of real GDP growth. Percentage points.

5. Country-level results

In this Section we assess the contribution of the structural shocks to headline inflation in the main euro-area countries. This analysis is particularly relevant because it might suggest cross-country heterogeneity in the transmission of structural shocks and, most importantly, a different contribution of monetary policy that might have exacerbated the differences in the economic performance across core and peripheral countries. We do this by extending the VAR for the euro area as follows:

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

Model (4) is a "near-VAR" (Boeckx et al., 2014). The vector $\boldsymbol{y}_{\mathrm{t}}$ includes the euro-area endogenous variables and A(0) is the contemporaneous impact matrix of the shocks ε_t. The vector $\boldsymbol{Z}_t$ contains the level of real GDP and consumer prices of the individual countries.

In order to keep the structural shocks and the dynamics of the euro-area variables invariant to the inclusion of the individual country variables, we impose a block diagonal structure and assume no feedback of the individual countries on the euro-area and international variables. The alternative approach would, indeed, be to estimate a separate VAR for each individual country, possibly including also area-wide variables. In such case, the resulting area-wide shocks would be, in principal, not invariant to the country chosen, which would make a cross-country comparison less informative.

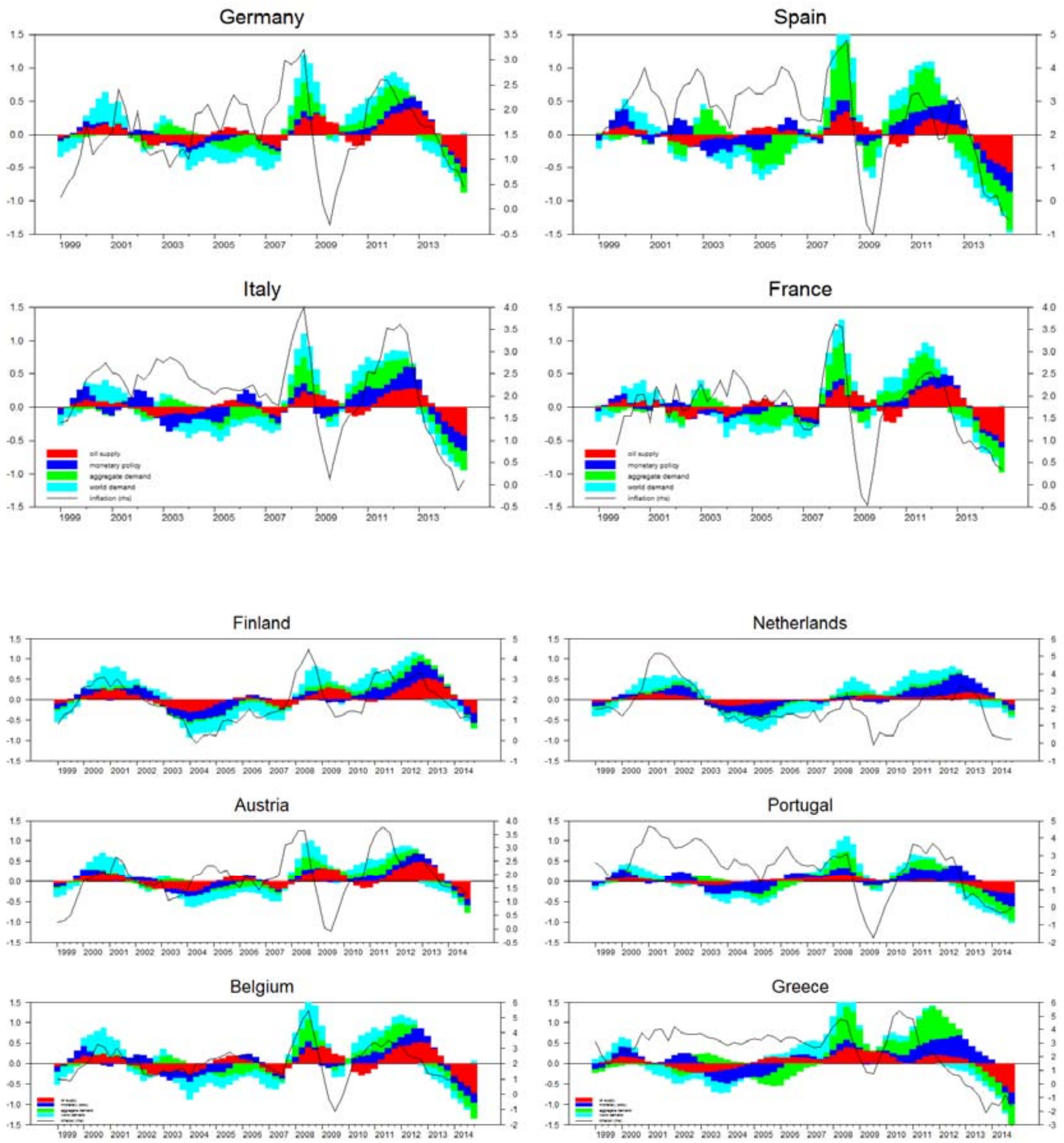
We estimate the model using seemingly unrelated regression (SUR) methods developed by Zellner (1962). Specifically, we do a joint estimation of the area-wide block and all the country-specific blocks for each country. Standard likelihood ratio tests are used to determine the lag-order of the model, which turns out to be 2. Given the estimates of the matrices C, D, E, F we can compute the historical decomposition of country-specific variables.

Figure 16 shows that the negative contribution of monetary policy shock on inflation in most recent period has been widespread across countries but it has been relatively larger for the countries that have been more hit by the sovereign tensions, such as Spain, Italy and Portugal. These results are consistent with evidence in Barigozzi et al. (2014), who find different reaction of Italy and Spain to monetary policy shocks when compared to France, Germany, Belgium and the Netherlands.[12] The contribution of oil supply shocks has been particularly important in driving inflation down in 2013 and 2014 in Germany, Austria and Belgium. The contribution of aggregate demand shocks in the recent period is large in Spain, Italy, France and Portugal. All in all, both aggregate demand and oil supply shocks have driven inflation down in all the main euro-area countries, although with varying intensity across

[12] This result is not a product of the crisis. Indeed the analysis in Barigozzi et al. (2014) stops before the eruption of the global financial crisis: still, asymmetric cross-country behavior is observed, despite an increase of co-movement across member states.

countries, confirming that the disinflation was a widespread phenomenon and not the consequence of relative price adjustment with the monetary union.

Figure 16. Historical decomposition of country-specific inflation rates



Note: median of the posterior contribution to the historical decomposition of headline inflation. Percentage points.

6. Robustness

We test the robustness of the results obtained with the baseline model along several dimensions, including the sample period and the choice of the variables. In this regard, we are interested in assessing whether some of the identified shocks might be considered as a mixture of several shocks that have the same implications for the euro area economy. This may alter the resulting historical decomposition of the euro-area inflation and output.

6.1. Accounting for the unconventional measures and sovereign spreads

Our baseline specification and identification scheme does not fully take into account the role of the unconventional measures undertaken by the ECB during the sovereign debt crisis, namely those expanding the size of the central bank's balance sheet. It is necessary to recall that the impact of such measures on the liquidity conditions in the euro area are taken into account by using the EONIA rather than the rate on the main refinancing operations of the Eurosystem.

In the literature for the euro area there are some attempts to quantify the effects of these measures using high-frequency financial data (Casiraghi et al. 2013), as well as different VAR methods (Lenza et al., 2010; Peersman, 2011; Giannone et al., 2012; Boeckx et al., 2014; Gambacorta et al., 2014; Darracq-Paries and De Santis, 2015). A proper identification of unconventional monetary policy shocks remains very challenging and far from being settled.[13] Despite these difficulties, it is important to assess how robust are the results of our analysis to including variables related to the unconventional measures adopted by the ECB.

Since the euro area has been severely affected by the outbreak of the sovereign debt crisis, it is also necessary to test the robustness of our finding to the inclusion of a measure of sovereign debt tensions. To this end, we include 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 (Neri and Ropele, 2015).

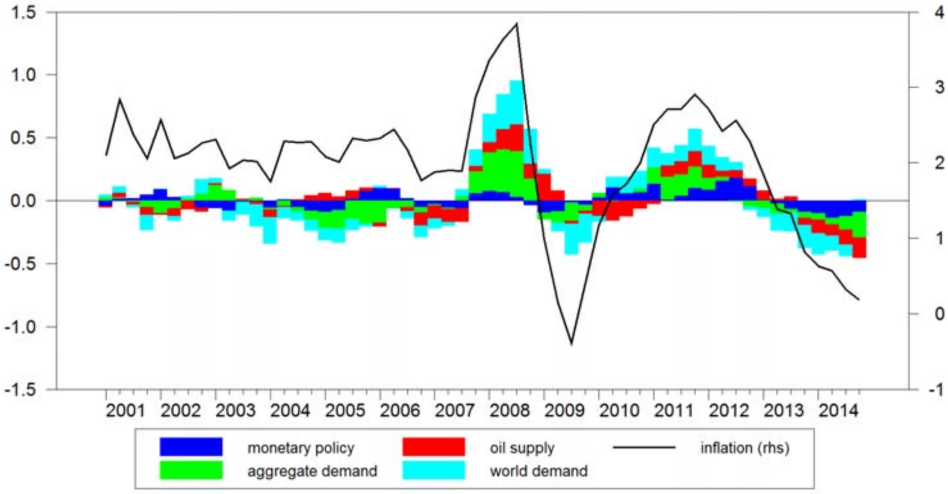
In light of the above considerations, in this Section we enlarge our six-variables baseline specification by including the average sovereign spread and the sum of the liquidity injected into the banking sector through all the Eurosystem refinancing operations and the securities purchased for monetary policy purposes.[14] As for the identification, we leave the responses of these variables unrestricted as we have no clear guidance on how to restrict them. Figure 17 shows the historical decomposition of inflation and real GDP growth.[15]

As for the inflation rate, a visual comparison with Figure 9 suggests some interesting remarks. The contribution of the identified shocks to inflation developments is very similar; the negative contribution of aggregate demand is slightly larger than in the baseline specification. As for real GDP, the contribution of aggregate demand shocks is also slightly larger than in the baseline model (see Figure 12).

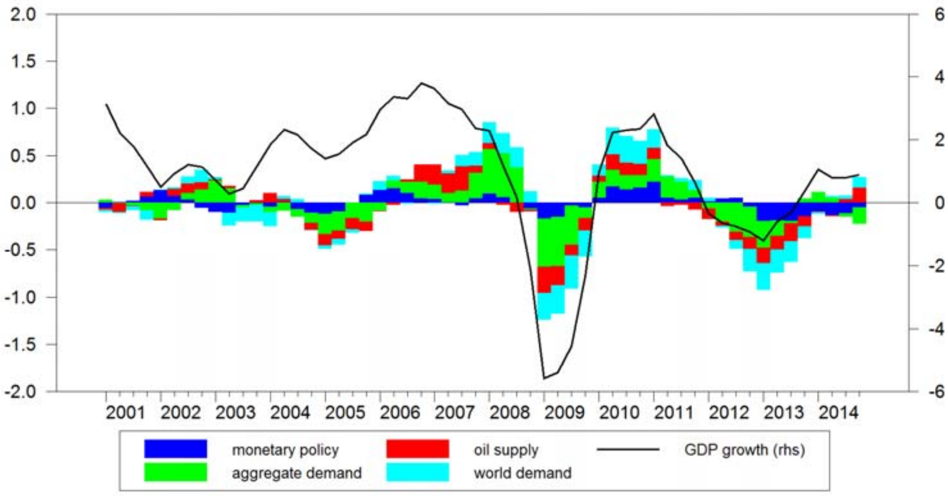
[13] Bernanke et al. (2004) and Cecioni et al. (2011) provide an extensive survey of the theoretical and empirical literature before and after the collapse of Lehman Brothers, respectively.
[14] Data are taken from the AWM and the ECB Statistical Data WareHouse.
[15] The impulse responses are very similar to those in Section 4 and not reported here in order to save space.

Figure 17 Historical decomposition: model with sovereign spread and the Eurosystem's balance sheet

a) inflation



b) real GDP growth



Note: median of the posterior contribution to the historical decomposition of inflation and real GDP growth. Percentage points. As for the measure of the Eurosystem's balance sheet, we used the sum of the items "liquidity injections" and "securities held for monetary policy purposes".

Overall, the results of this robustness analysis seems to validate, if not strengthen, one of the main results of the paper: a non-negligible contribution to the prolonged phase of low inflation of both negative aggregate demand developments and monetary tightening due to the ZLB, which added to that of falling oil prices.

6.2 The role of credit supply

A distinctive feature of the global financial and sovereign debt crises was their impact on credit markets in several euro-area countries. Therefore, including credit variables in the VAR model may be important for two main reasons. First, the loan market amplifies shocks originating in the other sectors. Banks' capability to provide loans to the economy depends on their balance sheet conditions, which in turn change endogenously due to the state of the economy. Based on this consideration we augment our VAR model that features the sovereign spread and the policy-relevant items of the Eurosystem's balance sheet to include the average cost of new lending to the non-financial private sector and the corresponding loan volumes. We leave the sign restrictions on the impulse responses unchanged to facilitate a comparison with the baseline specification of the model. The responses of the variables to the four identified shocks are qualitatively similar to those discussed in Section 3.1, so we do not report them to save on space.

A second important concern for our analysis is that a drop in the aggregate demand is observationally equivalent to an adverse credit supply shock. Indeed, a tightening in the supply of bank lending also reduces output and inflation. A loan supply shock can occur because of unexpected changes in bank capital and funding conditions, in bank risk perception (due, for example, to a generalized increase in risk aversion or to a worsening in the borrowers' creditworthiness) or because of changes in the degree of competition among banks.

Based on this evidence, we identify a loan supply shock as one implying a negative co-movement between the cost and the amount of credit. Table 2 describes the sign restrictions. A loan supply shock is distinguishable from an aggregate demand shock since the response of the cost of credit is opposite in sign; in the latter case the lower demand results in a decrease in the loan rate. Since theory does not provide a clear guidance, we leave the response of inflation unconstrained.[16]

Table 2. Sign restrictions used for identification: VAR including credit variables

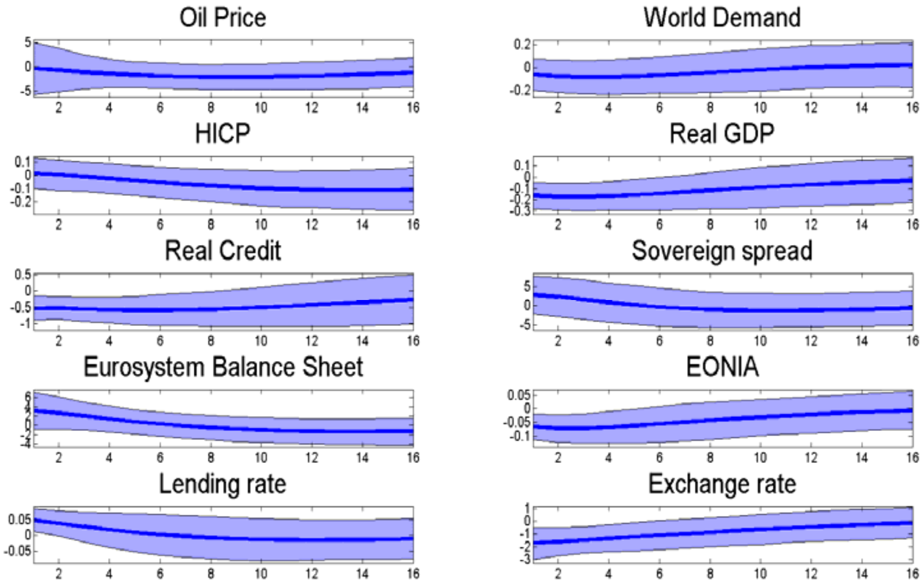
	Structural shocks				
VAR variables	Oil supply	RoW demand	Aggregate demand	Monetary policy	Credit supply
Nominal oil price	-	-			
Rest-of-the-World output	+	-			
Euro-area prices	-	-	-	-	
Euro-area real GDP	+		-	-	-
Real loans			-		-
Sovereign spread					
Balance sheet items					
Euro-area short-term rate		-	-	+	-
Lending rate		-	-	+	+
Exchange rate		+	-	+	-

Note: A "+" (or "-") sign indicates that the impulse response of the variable in question is restricted to be positive (negative) on impact after the shock. A blank entry indicates that no restrictions is imposed on the response. A "+"(or "-") for the exchange rate implies that the structural shock leads to an appreciation (depreciation) of the euro vis-à-vis the US dollar. The lending rate is measured by the average cost of new loans to enterprises and households.

[16] Gambetti and Musso (2014) discuss the identification of loan supply shocks using sign restrictions.

In Figure 18 we show the responses to an adverse credit supply shock.

Figure 18. Impulse responses to an adverse credit supply shock

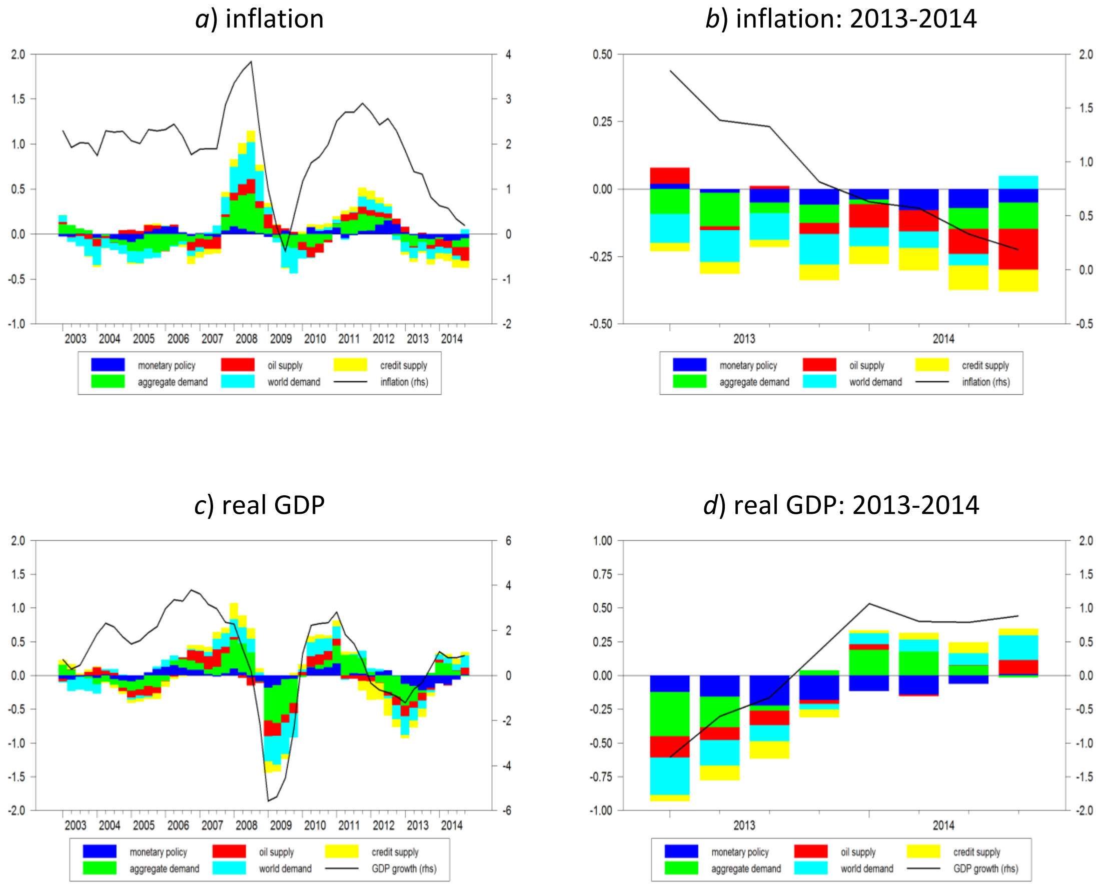


Note: percentage deviation from baseline. Thick blue line: median of the posterior distribution; light blue shaded area: 68% probability interval of the posterior distribution.

It turns out that real GDP declines significantly and persistently, mirroring the strong decrease in real loans. Our estimated effects are more persistent than those obtained by Musso and Gambetti (2014), probably because the authors do not include the sovereign debt crisis period in their empirical analysis. The median response of euro-area inflation is negative, albeit this effect seems to be not statistically significant, similarly to Musso and Gambetti (2014). Interestingly, monetary policy becomes expansionary , as shown by the long-lasting decline in the short-term interest rate and the increase in Eurosystem balance sheet. As for the latter, the estimates response is characterized by large uncertainty, maybe because we left this variable unrestricted in the identification scheme.

We now turn to quantifying the contribution of credit supply shocks to inflation and real GDP growth and to assess the robustness of the role played by the other four shocks. Figure 19 shows that the historical decomposition of the variables of interest. The contribution of credit supply shocks have been more important for output than for inflation, consistently with our findings on impulse response functions.

Figure 19. Historical decomposition real GDP and inflation: VAR model with 5 shocks



Note: median of the posterior contribution to the historical decomposition of headline inflation (panel a-b) and real GDP growth (panel c-d). Percentage points.

Overall, our main results on the contribution of aggregate demand, oil price and monetary policy shocks are robust to identifying credit supply shocks. Some interesting results are worth mentioning. First, credit supply shocks have contributed pushing inflation up in 2012 and down in the next two years, together with monetary policy shocks, that also contributed to lower GDP growth in the last two years. These findings may suggest the working of a cost-channel, according to which the higher cost of credit for firms' financing working capital is passed onto consumer prices. Second, the contribution of aggregate demand shocks, which was fading away in the first half of 2014, increased in the second half. Finally, as for real GDP, credit supply shocks caused output to fall by more in 2011 and 2012 than after the outbreak of the global financial crisis.

6.3 Structural changes in the transmission of shocks

In this Section we test the robustness of our main results to the choice of the sample period. The interpretation of our main results may be indeed subject to the caveat that several structural breaks in the euro-area economy may have changed the transmission mechanism of the various shocks to inflation. This could represent an alternative explanation of our analysis based on constant parameter VAR, according to which the different contribution of each shock to inflation over time simply reflects the magnitude of the shock itself.[17]

6.3.1 The role of the global financial and sovereign crises

According to our baseline 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 economy especially during the crisis period. In this regard, some studies address the role of oil shocks in a time-varying VAR framework for both the US and the euro area, suggesting, however, that some breaks indeed occurred but before the breakout of the crisis.[18]

Besides oil supply shocks, other papers adopt VAR models with nonlinearities, especially to address the transmission of financial shocks to the economy (see Balke, 2000; Ciccarelli et al., 2012; Eickmeier et al., 2013; Hartmann et al., 2013). Recently, Silvestrini and Zaghini (2015) review the evidence on the impact of monetary policy and financial shocks on euro-area economy, showing that it has been different before and during the global financial crisis.

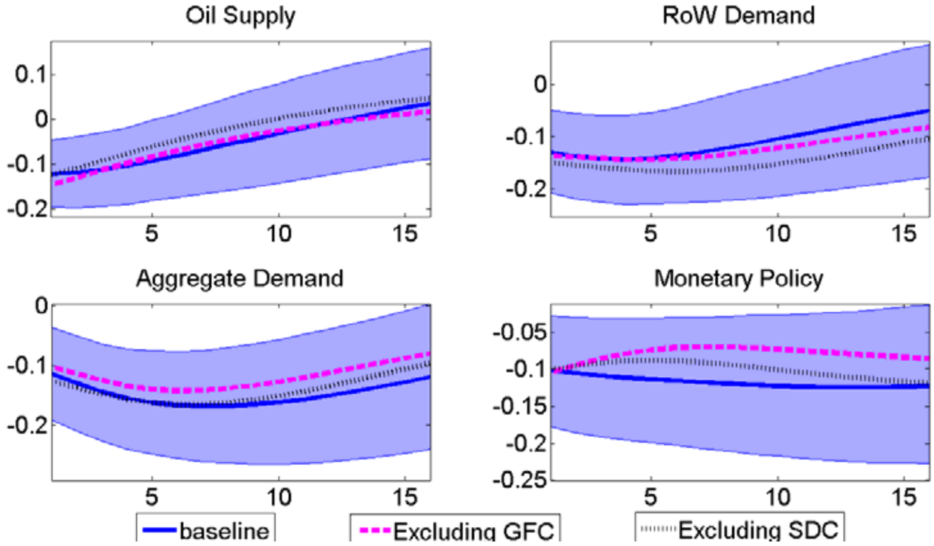
As for the most recent period, the role of nonlinearities at the zero lower bound of monetary policy rate may also be relevant, albeit not being treated explicitly in this paper. One important concern is that there seems to be no chance for the aggregate demand and the monetary policy shocks not to matter in a ZLB situation with the assumed sign restrictions.

In light of these considerations it may be useful to assess whether our main results have been altered by the inclusion of the financial crisis period, which may have induced a break in the correlation among variables conditionally to the identified structural shocks. We, therefore, estimated the VAR over the solely pre-crisis period and replicated the whole inference. In Figure 20 we compare impulse response obtained with the whole and the pre-crisis sample period. Results are very similar. The historical decomposition of inflation also remains broadly unaffected.

[17] This issue has been pointed out by Stock and Watson (2003) in their analysis of the US economy in pre- and post-Great moderation periods.

[18] Baumeister and Peersman (2013) found a substantial decline in the short-run price elasticity of oil demand since the mid-1980s in the US, thus, suggesting that an oil production shortfall of the same magnitude is associated with a stronger response of oil prices and more severe macroeconomic consequences over time. Riggi and Venditti (2014) found that from the 1980s onwards the relationship between oil prices and euro-area exports has become less negative conditional on oil supply shortfalls, while more positive conditional on foreign productivity shocks, as the result of larger trade between the euro area and emerging economies, a decline in the oil share in production and increased competition in the product market.

Figure 20. IRF of HICP to baseline structural shocks based on different samples.



Note: percentage deviation from baseline. Thick blue line: median of the posterior distribution, sample 1995Q1 – 2014Q4; light blue shaded area: 68% probability interval of the posterior distribution; thick dashed magenta line: median of the posterior distribution, sample 1995Q1 – 2008Q2; black dotted line: median of the posterior distribution, sample 1995Q1 – 2010Q1.

Furthermore, this result is broadly consistent with recent methodology developed in Canova et al. (2015), who study the consequences of using time invariant models when the data generating process features parameter variations, in terms of identification, estimation, and inference. They find that using structural time invariant VAR model as far as the dynamics induced by structural shocks are concerned, important qualitative features of the structural dynamics are well captured (impact effect, shape and persistence).[19] Overall, in spite of using a linear model, our results look robust to the presence of possible structural breaks and changes in the transmission of the shocks.

6.3.2 The introduction of the single monetary policy: the post-1999 sample

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 has been raised in the literature.

Boivin et al.(2009) study the transmission mechanism of common monetary shocks to a subset of euro area countries and conclude that this mechanism has, indeed, changed with the introduction of the EMU. This brought about an overall reduction of the effects of monetary

[19] Canova et al. (2015) show that the performance of SVAR worsens when shocks to the parameters account for a considerable portion of the variability of the endogenous variables even though the deterioration is not as large as with more structural approaches.

policy on output, inflation and the long-term interest rate and an increase in the effects on the exchange rate. Barigozzi et al. (2014) focus on possible asymmetric effects of monetary policy shocks across euro-area member states. They find that, although the introduction of the euro has changed the monetary transmission mechanism in the individual countries towards a more homogeneous response, EA countries react asymmetrically to the common monetary policy in terms of prices and unemployment, while no difference appears in terms of output. Cecioni and Neri (2011), by contrast, show, by means of a VAR, that the transmission mechanism of monetary policy has not changed significantly with the creation of the monetary union. A more structural analysis based on the Smets and Wouters (2003) model confirms, instead, that the differences between the pre-1999 and post-1999 periods are significant and can be explained with a reduction in the degree of nominal rigidities and an increase in the strength of the systematic reaction of monetary policy to inflation.

In light of the above results, we estimated the VAR over the 1999-2014 period and replicated the whole inference without finding major differences.[20]

6.4 The role of other supply shocks

In the baseline model we focus on oil supply shocks in order to directly refer to the current policy debate about their role in the recent evolution of inflation. One may argue that the small number of shocks combined with the sign restriction might lead to assign as oil supply shocks other supply shocks that are not oil-specific (see Smets and Wouters, 2003). While assessing the contribution of a more general supply shock may be interesting[21], it is important to remark that this alternative experiment could not alter substantially our main results. Aggregate supply shocks imply a negative co-movement between the euro-area output and inflation and, therefore, cannot be confused with monetary policy or aggregate demand shocks.

To this end it may be useful to replace the oil supply shocks with a more general aggregate supply shocks. The identification scheme is reported in Table 3. Following basic theory, a positive aggregate supply shock simply generates an increase of real GDP and a decline in inflation. The main difference with the baseline scheme is that we leave unconstrained the responses of other variables. Lippi and Nobili (2012), indeed, show that the sign of the response of the RoW output to a domestic supply shock crucially depends on the substitution elasticity of foreign and domestic goods. [22]

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[20] Results are not shown here in order to save space, but are available upon request from the authors.

[21] For example, Peersman and Straub (2009) and Alves et al. (2011) found an important role of technology shocks in explaining business cycle fluctuations in the euro area.

[22] Notice that an aggregate supply shock may generate both outside or inside the euro area and may be observationally equivalent to a RoW demand shock, unless imposing further restrictions. One possibility is to consider the real oil price in the VAR and to impose that this variable increases following an aggregate supply shock while declining after a RoW demand shock (see Lippi and Nobili, 2012). Another

Table 3. Sign restrictions used for identification: aggregate supply shocks

	Shock			
Variable	Aggregate Supply	RoW demand	Aggregate demand	Monetary policy
Nominal oil price		-		
Rest-of-the-World output		-		
Euro-area output	+		-	-
Euro-area inflation	-	-	-	-
Euro-area short-term rate		-	-	+
Exchange rate		+	-	+

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

Finally, a second possible concern may stem from the fact the prices of other commodities may have affected inflation developments, beside oil prices. To assess the robustness of the results along this dimension, we replace in the VAR the oil price with an overall commodity price index (comprising both energy and non-energy components) and we leave the identification of the shocks unchanged. We do not report the results as they are remarkably similar to those obtained with the oil price.

7. Concluding remarks

Inflation in the euro area has reached historical lows. Long-term inflation expectations have also fallen to historical minima, raising concerns regarding the credibility of the ECB in delivering on the price stability mandate. Low inflation is a broad phenomenon which characterizes almost all the components of the consumer price index and all countries of the monetary union. Oil prices have been claimed to be the key factor driving inflation in 2013 and 2014. But this story is not fully convincing, as core inflation, which strips down the more volatile components, has also fallen significantly and persistently, pointing to a significant role for aggregate demand shocks.

This paper has shown that oil supply, monetary policy and aggregate demand shocks all have a say about falling inflation. The effective lower bound to policy rates has prevented the ECB from providing the necessary monetary accommodation in the context of weakening prospects for economic activity since 2013. At the lower bound falling inflation expectations have resulted in an unwanted tightening of monetary conditions, as real rates have risen at a

possibility is to impose an impact depreciation of the exchange rate. Although the literature is not conclusive on this point, Farrant and Peersman (2006) found that this is the case for the euro area. We also try with these alternative identification schemes. Again, our findings remain unaffected. The corresponding figures are available upon request.

time in which aggregate demand was weak and inflation already falling to low levels. We have also provided evidence of substantial heterogeneity among euro-area countries. The most challenging finding is that the negative contribution of monetary policy on inflation has been larger for the countries more affected by the sovereign debt crisis.

As for future research, we want to extend our study along two dimensions. First, the analysis has been carried with a linear VAR model. In this regard, it may be useful to better investigate the potential role of non-linearities, such as the lower bound to policy rates, in the transmission of the structural shocks. Second, we want to shed light on the role of second-round effects in the transmission mechanism of the shocks by including nominal wages and labour market indicators in the model.

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