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THE MACROECONOMIC EFFECTS OF UNCONVENTIONAL MONETARY POLICY IN THE EURO AREA USING NON-LINEAR MODELS*

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1 INTRODUCTION

The global financial crisis of 2007-2009 and the subsequent debt crisis in the euro area led the European Central Bank (ECB) to adopt an accommodative monetary policy stance, with a view to maintaining price stability in the euro area.[1] By way of illustration, in the context of monetary accommodation, the ECB has lowered its key interest rate on the main refinancing operations (MROs) by 425 basis points (b.p.) over the past ten years (2007-2016), from 4.25% in July 2007 to 0% in March 2016. However, as key interest rates approach the so-called zero lower bound (ZLB), there is no room for monetary policy to boost the economy, and central banks resort to non-standard or unconventional monetary policy tools in order to counter the risks to economic and financial stability.[2]

As early as in October 2008, the ECB had announced and implemented a series of non-standard monetary policy (NSMP) measures which were mainly aimed at addressing dysfunctions in money and capital markets, with a view to restoring the smooth functioning of the (conventional) monetary policy transmission mechanism through the strengthening of banks' lending capacity and the subsequent continued financing of the real economy. In general, the literature distinguishes non-standard monetary policy measures into three categories: (i) forward guidance, which provides information about the future level of key interest rates; (ii) quantitative easing (QE), which is mainly related to an increase in the size of central bank balance sheets; and (iii) credit easing, which entails changes in the composition of central bank balance sheets (Bernanke and Reinhart 2004; Bernanke et al. 2004). Since 2008 ECB has been conducting unconventional monetary policy by implementing a combination of measures from all of the above three categories, depending on the overall economic and financial conditions prevailing in the euro area (see Section 2 for a more detailed presentation of NSMP measures). The NSMP measures that were implemented in the euro area brought about an increase in the banking system's liquidity that was tantamount to the expansion of the ECB's balance sheet (see Bank of Greece 2015a). Chart 1, which depicts the evolution of the size of the ECB's balance sheet over time, clearly shows the upward trend observed especially from 2008 onwards. In particular, in times when policy rates approach their effective lower bounds, changing the size of central bank balance sheets basically replaces interest rates as the main monetary policy instrument (Gambacorta et al. 2014).

Overall, the literature on the effectiveness of NSMP measures mainly focuses on the impact that these have on money markets, such as the recent study by Rompolis (2017) for the euro area.[3] By contrast, the purpose of this study is to explore the macroeconomic effects of the NSMP measures that were implemented in the euro area roughly over the past ten years. More specifically, the analysis seeks to examine the effect of an exogenous positive shock on the ECB's assets, i.e. the effect of an accommodative NSMP shock on the level of real income (GDP) and the price level in the euro area. The econometric analysis employs a structural vector autoregressive (structural

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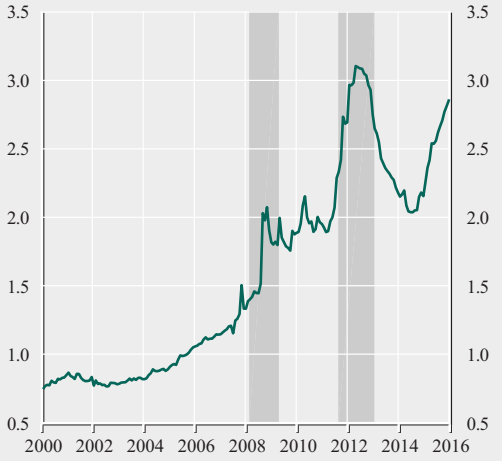
1 The primary objective of the ECB's monetary policy is to maintain price stability over the medium term. In this context, price stability is defined as a year-on-year increase in the Harmonised Index of Consumer Prices (HICP) of below, but close to, 2% over the medium term. For further details on the ECB's monetary policy, see http://www.bankofgreece.gr/Pages/en/MonetaryPolicyEurosystem/monetary.aspx.

2 Non-standard or unconventional measures are associated with significant changes in the operational framework, i.e. instruments and procedures, for conducting monetary policy (see Bank of Greece 2010).

3 See also the references therein.

Chart 1 The ECB's total assets

(EUR trillions)



Source: ECB.
Note: Shaded areas correspond to periods of recession in the euro area, as defined by the CEPR Euro Area Business Cycle Dating Committee (Centre for Economic Policy Research).

VAR) model, under which the parameters as well as the volatility of the residuals vary with time (hereinafter TVP-VAR model) (Primiceri 2005).[4] In a similar study for the euro area, Gambacorta et al. (2014) use VAR models, albeit with fixed parameters, to investigate the macroeconomic effects of NSMP measures over the 2008-2011 period.

TVP-VAR models are quite flexible and have the ability to account for the structural changes that occur over time in the transmission of shocks. Given that during the period under examination (2007-2016) the euro area economy passed through different phases of the business cycle[5] and different stages of monetary policy (conventional and unconventional), the use of TVP-VAR models will help us explore any structural changes in the transmission of NSMP shocks. In addition, it is possible to assess from a macroeconomic perspective the impact of the various NSMP measures that have been implemented by the ECB over time, such as the public sector purchase programme (PSPP) with which the ECB actually initiated its quantitative easing (QE) policy.

The use of non-linear models in studying the macroeconomic effects of unconventional monetary policy is not new in the literature. Baumeister and Benati (2013) and Kapetanios et al. (2012) examine the macroeconomic effects of unconventional monetary policy using non-linear models with time-varying parameters for the United Kingdom and the United States, respectively. More recently, Michaelis and Watzka (2017) investigated the effectiveness of the various quantitative easing (QE) programmes in Japan using TVP-VAR models. Notwithstanding, this study is, to our knowledge, the first to employ TVP-VAR models in order to explore the macroeconomic effects of unconventional monetary policy in the euro area.

Another point that differentiates this study from the aforementioned ones is the choice of the variables used for the identification, i.e. the distinction, of economic shocks. So far, a large strand of the literature (see e.g. Baumeister and Benati 2013) has focused on ten-year government bond yields or risk spread in order to identify NSMP shocks and scrutinise their macroeconomic effects. The rationale behind this is that a NSMP shock would lead to lower ten-year government bond yields or spreads via a decline in uncertainty and a normalisation in financing conditions. Nevertheless, the identification of a NSMP shock on the basis of government bond yields alone may be inadequate, all the more so if central bank assets are not included in the model (Bork 2015). Furthermore, it is clear that NSMP measures are broadly aimed at normalising financing conditions rather than merely addressing dysfunctions in the government bond market. Against this background, the present study identifies NSMP shocks using as variables the ECB's assets as well as an indicator of implied volatility in euro area stock markets, which can successfully synopsise the overall

4 The term TVP-VAR, which stands for "Time-Varying Parameter Vector Autoregressions with Stochastic Volatility", is extensively used in the international literature.
5 See for instance the shaded areas in Chart 1, which correspond to the periods of recession in the euro area, as defined by the CEPR Euro Area Business Cycle Dating Committee.

financial conditions in the economy (Gamabcorta et al. 2014; Bork 2015).

The rest of the study is structured as follows: Section 2 provides an overview of the Eurosystem's interventions in the context of the NSMP measures implemented between 2008 and 2016. The econometric model is presented in Section 3, while Section 4 describes the empirical results of the study. Lastly, Section 5 summarises and concludes.

2 AN OVERVIEW OF THE EUROSYSTEM INTERVENTIONS IN THE CONTEXT OF NON-STANDARD MONETARY POLICY MEASURES

This section briefly presents the ECB's interventions in the context of its NSMP measures. More specifically, Table 1 provides a timeline of the most important unconventional monetary policy measures that were implemented between October 2008 and December 2016.[6,7]

In general terms, the NSMP measures introduced and implemented by the ECB are adopted on the basis of the economic, monetary and financial conditions prevailing each time in the euro area. Thus, from 2008 to date, we can broadly distinguish three periods or phases of NSMP measures, which are presented below.[8]

In greater detail, the **first phase** refers to those NSMP measures that were implemented from the onset of the global financial crisis to mid-2010 (until May 2010, to be precise – see Table 1). The set of measures that were implemented during the first phase was designed to provide "enhanced credit support" to the euro area economy, with forthcoming liquidity arrangements for the banking system. The measures were aimed at: (i) ensuring that interbank and lending rates reflect the ECB's monetary policy, and (ii) maintaining the flow of funds from the financial system to the real economy to a larger extent than what would have been possible to achieve only with key interest rate cuts (ECB 2010b).

The **second phase** comprises NSMP measures which were designed to address the debt crisis and the subsequent banking crisis in the euro area and were implemented from May 2010 to mid-2014. During this phase, namely from early 2010 onwards, severe strains were observed in government bond markets amid concerns about the fiscal positions of some Member States. The ECB intervened in bond markets by introducing specific measures such as the Securities Markets Programme and Outright Monetary Transactions (see Table 1), with an aim to ensure sufficient depth, increase liquidity and remove market dysfunctions that hamper the smooth transmission of monetary policy (see Bank of Greece 2010b). Furthermore, the introduction of the three-year longer-term refinancing operations (3-year LTROs) made a decisive contribution to improving banks' liquidity over the medium term and thereby preserving their lending capacity. It should be noted that as from autumn 2011 and on account of European banks' exposure to government bonds, the national banking systems came under pressure, which hindered banks' access to money markets for refinancing their short-term obligations. The sizeable decline in deposits also contributed to a worsening in liquidity in some of the national banking systems (Cour-Thimann and Winkler 2013).

The **third phase**, starting from mid-2014, comprises the NSMP measures under the

6 It should be noted that the table refers to the dates on which a measure was first implemented or established, while due to space and time considerations the dates on which the implementation of a measure was renewed or extended are omitted.

7 From August 2007 until the collapse of Lehman Brothers in mid-September 2008 severe strains were observed in the euro area money market, resulting in liquidity constraints in the interbank market and upward pressures on interbank interest rates. With a view to averting the risk of a systemic financial crisis as well as to ensuring the smooth functioning of the monetary policy transmission mechanism, the ECB expanded and differentiated liquidity provision to credit institutions, mainly by increasing the frequency and the maturity of open market operations (for further details, see Cour-Thimann and Winkler 2013; ECB 2010a; Bank of Greece 2008a and 2008b). With regard to these particular interventions, the ECB did not have to change the structure of the operational framework for the conduct of monetary policy (Bank of Greece 2008b) and therefore they are not seen as NSMP measures.

8 See also Cour-Thimann and Winkler (2013) for a categorisation of NSMP measures until 2013 in the same vein.

Table 1 The Eurosystem's non-standard monetary policy measures (2008-2016)

Date	Non-standard monetary policy measures
October 2008	– All **regular open market operations** for the provision of liquidity to banks (against collateral) are conducted at a **fixed rate** and **with full allotment** (that is, all bids are fully satisfied). In contrast with the ECB's standard policy, the interest rate is not determined as the minimum bid rate but is fixed for all banks. – Establishment of **longer-term refinancing operations (LTROs) with a maturity of six (6) months**. No maximum allotment amount is determined and no variable rate tender is carried out. – **Expansion of the list of assets eligible as collateral** and of credit institutions eligible as Eurosystem counterparties. – **US dollar liquidity-providing operations** with full allotment at a fixed rate, against Eurosystem-eligible collateral or liquid assets in euro.
June 2009	Establishment of **longer-term refinancing operations (LTROs) with a maturity of twelve (12) months.** The extension of the maturity of LTROs aims to support the provision of liquidity to banks on favourable terms over the medium term and to keep the respective interbank interest rates at low levels.
July 2009	– **First covered bond purchase programme (CBPP1).** The objectives of the programme are: (i) to reduce the term rates on covered bonds; (ii) to increase transaction volumes with third parties with a view to enhancing depth and liquidity in the secondary covered bond market; (iii) to improve banks' liquidity through the issuance of new covered bonds; and (iv) to increase lending to relatively safe borrowers, so that banks use those loans as a cover pool for the issuance of new covered bonds. **Duration:** July 2009-June 2010. **Total value**: EUR 60 billion. – The **European Investment Bank (EIB) becomes an eligible counterparty** in the Eurosystem's credit operations.
May 2010	Establishment of the **Securities Markets Programme (SMP)**. Purchases of government bonds and private sector debt securities on the secondary market (and on the primary market for private sector debt securities). **Objective:** to ensure depth and liquidity in malfunctioning segments of the debt securities markets. **Duration:** May 2010-September 2012. **Total value:** EUR 201 billion.
November 2011	**Second covered bond purchase programme (CBPP2).** Purchases of covered bank bonds on the primary or secondary market. **Duration:** November 2011-December 2012. **Total value:** EUR 16 billion.
December 2011	**First longer-term refinancing operation (LTRO) with a maturity of 36 months**
January 2012	**Reduction in the reserve ratio** from 2% to 1%. **Objective:** (i) to support activity in the money market and (ii) to reduce banks' reliance on the Eurosystem for liquidity and thereby the amount of collateral to be mobilised.
September 2012	Introduction of **Outright Monetary Transactions (OMTs)**. Purchases of government bonds with a maturity of 1-3 years on the secondary market with full allotment.
July 2013	The Governing Council of the ECB begins using **forward guidance**. **Objective:** guidance of economic agents' expectations about the future path of short-term interest rates.
June 2014	Launch of **targeted longer-term refinancing operations (TLTROs)**. The Eurosystem's liquidity provision to credit institutions is linked to the volume of their loans (other than for house purchase) to non-financial corporations and households (fixed rate). **Objective:** (i) to enhance the banking system's liquidity and (ii) to encourage new lending. Duration: up to 4 years.
October 2014	**Third covered bond purchase programme (CBPP3)**
November 2014	**Asset-backed securities purchase programme (ABSPP)**
March 2015	**Private sector purchase programme (PSPP)**
March 2016	Launch of a **second series of targeted longer-term refinancing operations (TLTRO II)**
March 2016	**Corporate sector purchase programme (CSPP)**

Sources: Bank of Greece and ECB.

expanded asset purchase programme, which marks the adoption of a quantitative easing (QE) policy by the ECB.[9] Although, in practice, the asset purchase programme was considerably expanded in early 2015 to include government debt securities and other securities issued by the public sector in the euro area (see Table 1), the markets had already anticipated since mid-2014 that the Eurosystem would conduct large-scale purchases of government debt securities, with a view to preventing deflationary conditions from taking hold in the euro area (see Bank of Greece 2015a, Box III.1, p. 37). Thus, it is reasonable to assume that any positive effects of the programme are likely to have spread to the entire economy quite earlier than the time of the official introduction and implementation of quantitative easing.

Although the third phase of NSMP measures also comprises other significant interventions on the ECB's part (see Table 1),[10] the success of these measures depends to a great extent on the progress of the public sector purchase programme, given the size of government bond markets. The ultimate goal of almost all NSMP measures, and of QE policies in particular, is to ensure that changes in key interest rates pass through to the real economy. Yet, this is achieved at a first stage through the improvement of financing conditions in the economy.[11]

At this point, it should be stressed that the aforementioned distinction of the ECB's extraordinary measures is by no means definite, since several measures, particularly of the first phase, are still in place even today. The new NSMP measures that have been adopted by the ECB impact on the economy as a complement to standard measures (as evidenced by the empirical results presented further below). Besides, it is noted that on occasion and depending on the financial conditions prevailing in the euro area each time (e.g. in December 2009), the ECB has decided to phase out some of the non-standard measures only to reinstate them shortly thereafter (May 2010) or has replaced some of them with other more effective ones.[12]

3 THE ECONOMETRIC MODEL

The econometric analysis rests upon a time-varying parameter vector autoregressive model with stochastic volatility (TVP-VAR). Such models can accurately capture macroeconomic relations as well as the volatility of macroeconomic shocks, which may vary strongly across time. A reduced-form TVP-VAR model is defined as follows:

$$y_t = c_t + B_{1,t}\, y_{t-1} + \ldots + B_{p,t}\, y_{t-p} + u_t \qquad (1)$$

$$u_t \sim N(0, \Omega_t) \qquad (2)$$

where y_t is the $n\times1$ vector of the endogenous variables of the model for $t=1,\ldots,T$. c_t is the $(n\times1)$ vector of fixed terms, $\{B_{i,t}\}_{i=1}^{p}$ are the $n\times n$ matrices of the dynamic coefficients and p is the number of lags. u_t are the disturbance terms of the reduced-form model of equation (1), which are distributed as normal distribution with a mean 0 and a variance-covariance matrix, Ω_t. The Ω_t matrix is factored following the standard practice in the literature, that is:

$$Var(u_t) \triangleq \Omega_t = A_t^{-1} H_t (A_t^{-1})' \qquad (3)$$

where H_t is a diagonal matrix, whose main diagonal consists of the stochastic volatility of the residuals, u_t:

$$H_t \overset{\text{def}}{=} \begin{bmatrix} h_{1,t} & 0 & 0 & 0 \\ 0 & h_{2,t} & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & h_{n,t} \end{bmatrix}$$

Respectively, A_t is a lower triangular matrix that models the contemporaneous interactions

9 For an assessment of any negative effects from the ECB's very accommodative monetary policy under the QE programme, see Bank of Greece (2015b), Box III.

10 For further details on the targeted longer-term refinancing operations (TLTROs), the asset-backed securities purchase programme (ABSPP) and the third covered bond purchase programme (CBPP3), see Bank of Greece (2014), Box III.1, p. 35.

11 The mechanisms through which non-standard monetary policy measures have a favourable effect on banks' lending capacity are discussed in Box III.1 of the report on *Monetary Policy 2014-2015* (Bank of Greece 2015a).

12 For example, the Securities Markets Programme was replaced with the introduction of Outright Monetary Transactions (for further details, see Bank of Greece (2012), p. 60).

of the endogenous variables, with the elements of the main diagonal consisting of units:

$$A_t \overset{\text{def}}{=} \begin{bmatrix} 1 & 0 & 0 & 0 \\ a_{21,t} & 1 & 0 & 0 \\ \vdots & \vdots & \ddots & 0 \\ a_{n1,t} & \dots & a_{nn-1,t} & 1 \end{bmatrix}$$

As can easily be understood, the subscript t in matrices (or vectors) suggests that these vary over time, so that in each point in time t we have a different (varying) estimation for the coefficients of the equation as well as for the volatility of macroeconomic shocks.

Next, in order to facilitate both the estimation and the presentation of the models, we collect the elements of c_t and $\{B_{i,t}\}_{i=1}^{p}$ in the ϑ_t vector, the elements of the main diagonal of the H_t matrix in the h_t vector and the non-zero and non-one elements of the A_t matrix in the α_t vector. Adopting the usual practice (see Primiceri 2005), we assume that ϑ_t and α_t follow a driftless random walk, that is:

$$\vartheta_t = \vartheta_{t-1} + \upsilon_t, \quad \upsilon_t \sim N(0, Q) \tag{4}$$

and

$$\alpha_t = \alpha_{t-1} + \zeta_t, \quad \zeta_t \sim N(0, S) \tag{5}$$

The h_t vector is modelled as a geometric random walk:

$$lnh_t = lnh_{t-1} + \eta_t, \quad \eta_t \sim N(0, W) \tag{6}$$

Finally, we assume that the vector of disturbance terms $[\varepsilon_t, \upsilon_t, \zeta_t, \eta_t]'$, where ε_t comes from $u_t = A_t^{-1} H_t^{\frac{1}{2}} \varepsilon_t$, is distributed as Normal with a mean 0 and a variance-covariance matrix:

$$Var\left(\begin{bmatrix} \varepsilon_t \\ \upsilon_t \\ \zeta_t \\ \eta_t \end{bmatrix}\right) = \begin{bmatrix} I_n & 0 & 0 & 0 \\ 0 & Q & 0 & 0 \\ 0 & 0 & S & 0 \\ 0 & 0 & 0 & W \end{bmatrix} \tag{7}$$

where I_n is the unit matrix with dimensions $n \times n$ and the S matrix is a block diagonal matrix, i.e. the coefficients $\alpha_{ij,t}$ which belong to the same equation (i.e. the row of the S matrix) are assumed to evolve over time independently from the corresponding coefficients in other equations. This assumption facilitates the model estimation in computational terms (Primiceri 2005).

4 EMPIRICAL ANALYSIS

4.1 CHOICE OF THE VARIABLES

In this section, we present the variables used to empirically investigate the macroeconomic effect of NSMP shocks. Specifically, the y_t vector of the model in equation (1) includes the following endogenous variables: the growth rate of euro area real GDP, the rate of change in the euro area Harmonised Index of Consumer Prices (HICP), the rate of change in the ECB's assets, the MRO rate, and the implied volatility index Vstoxx. All time series are of a monthly frequency and the sample spans the period from February 2000 to December 2016.[13] Chart 2 depicts the five endogenous variables of the model.

It can be observed for all variables that during the recent economic crisis periods, which correspond to the shaded areas, there is a sharp rise in volatility, justifying the use of stochastic volatility models.[14] Moreover, Chart 2 vividly captures the impact of the economic crisis on key macroeconomic variables, i.e. GDP and price level negative growth rates, as well as the heightened uncertainty in the economy, as reflected in the Vstoxx index. The path of the MRO rate confirms the ECB's very accommodative monetary policy especially over the past three years, when the level of the interest rate approached zero. Finally, the impact of NSMP measures on the ECB's assets is better illustrated in Chart 1 of Section 1.

13 Quarterly GDP has been converted into monthly using the Chow-Lin interpolation method. Industrial production and the volume of retail sales in the euro area are the key indices of a monthly frequency, on which the above conversion was based (see Gambacorta et al. 2014).

14 The shaded areas in Chart 2 reflect the periods of recession in the euro area, as defined by the CEPR Euro Area Business Cycle Dating Committee.

Chart 2 The time series of the model's endogenous variables

(%)

Sources: Eurostat, ECB and Thomson Reuters Datastream. Author's own calculations.
Notes: For the variables Total assets, Real GDP and HICP, the rates of change are calculated as log first differences. All the aforementioned variables are seasonally adjusted. The MRO rate and the Vstoxx index are kept unchanged. Shaded areas correspond to periods of recession in the euro area, as defined by the CEPR Euro Area Business Cycle Dating Committee (Centre for Economic Policy Research).

It is clear that the choice of the variables serves the purposes of this analysis, in line with the recent studies by Gambacorta et al. (2014) and Bork (2015).[15] In greater detail, GDP and the price level are the variables that synopsise the macroeconomic conditions in the euro area, while the MRO rate is the main tool of con-

15 Besides, it should be pointed out that the use of TVP-VAR models imposes certain restrictions as to the number of the variables used, as we should also take into account any computational limitations arising from the estimation of such a model that includes a large number of parameters considerably reducing the available degrees of freedom. Against this backdrop, the use of more variables for the identification of the various shocks (see Section 4.3) in TVP-VAR models is rather prohibitive (see for instance the study by Baumeister and Benati (2013), in which the authors use four (4) variables for the identification of NSMP shocks).

ventional monetary policy.[16] Conversely, the ECB's assets constitute the main instrument of unconventional monetary policy and are used to approximate the effects of the various NSMP measures that were described in Section 2 (see also the discussion in Section 1). As already mentioned, such measures are aimed at addressing the turmoil in money and capital markets, thereby reducing risk spreads and facilitating the bank financing of the economy. For this reason, Baumeister and Benati (2013) and Kapetanios et al. (2012) use ten-year government bond spreads to identify NSMP shocks.[17]

Given that several NSMP measures also aim at markets other than the government bond market (e.g. money markets or corporate bond markets) as well as at an overall improvement in financing conditions, we chose to use a broader measure as a proxy for financial conditions in the euro area, such as the Vstoxx index (Gambacorta et al. 2014; Bork 2015; Rompolis 2017). In general, implied volatility indices, which are also known as "fear indices", have the ability to capture uncertainty levels in money markets, and their use is of critical importance for identifying the exogenous structural shocks of unconventional monetary policy. This is the case because the expansion of the ECB's balance sheet is the reaction of the central bank to heightened financial risks, as captured by the Vstoxx index (Gambacorta et al. 2014).

4.2 ESTIMATION OF THE MODEL

The estimation of the TVP-VAR model described in equations (1) through (7) is performed using Bayesian methods, namely the Gibbs sampler which is proposed by Primiceri (2005) and Del Negro and Primiceri (2015).

The first steps in Bayesian analysis are to determine the prior distributions of the model's parameters and then, using Bayes' theorem, to estimate the posterior distributions of the parameters on which the statistical inference will be based.[18] More specifically, to elicit the prior distributions we rely on the estimations of the parameters of a VAR model with fixed coefficients, which is estimated using the first seven years of the sample (i.e. the first 84 observations). Thus, taking also into account lags, the TVP-VAR model is estimated for the period April 2007-December 2016, which corresponds to 117 monthly observations (about 10 years) and coincides with the period that we are interested in reviewing with regard to NSMP measures.

For the estimation of the model and following the common practice in the literature, we use two lags, i.e. p=2 (see Primiceri 2005). Moreover, the estimation relies on 15,000 draws for the parameters, which are obtained from the conditional posterior distributions using the Gibbs sampler. Out of a total of 15,000 draws, the first 10,000 are discarded, while out of the next 5,000 draws we keep 1 in every 10 draws in order to ensure the convergence of the algorithm and reduce the autocorrelations of the draws.

4.3 IDENTIFICATION OF STRUCTURAL SHOCKS

In this paper, the empirical investigation of macroeconomic effects from NSMP measures is based on impulse response functions – hereinafter IRFs, which are functions of the TVP-VAR model's parameters, providing a summary of the key findings resulting from its estimation. In greater detail, IRFs enable us to investigate how a variable of interest (in our case, we are interested in GDP and the price level in the euro area) reacts to an exogenous structural shock, ε_t, on the economy.[19] The

16 Gambacorta et al. (2014) have not included the policy rate in their baseline model, since they believe that, when the interest rate reaches the zero lower bound, it is replaced by a central bank balance sheet policy. Notwithstanding, to our belief, the policy rate should be included in the model, as the sample comprises periods during which the MRO rate is far from approaching the zero lower bound. In addition, the use of non-linear time-varying models enables us to take account of this change in the levels of the policy rate.

17 However, in these studies the authors have not used the size of the central bank's assets to identify NSMP shocks. With regard to the methodology for identifying NSMP shocks, see also Section 4.3.

18 For more details on the model's estimation and prior distributions, see Primiceri (2005) and Del Negro and Primiceri (2015).

19 For the computation of the IRFs we rely on the fact that a VAR model may be written as a vector moving average (VMA) model, i.e. as an infinite sum of weighted structural shocks (see for example Lütkepohl 2005).

Table 2 Restrictions on the impulse response functions (IRFs) for the identification of structural shocks

Variables	ε_t^{NSMP}	ε_t^{CMP}	ε_t^{AD}	ε_t^{AS}
Total assets	+	?	?	?
MRO rate	0	-	+	?
GDP	+	+	+	+
HICP	+	+	+	-
Vstoxx	-	?	?	?

Notes: The HICP variable is the Harmonised Index of Consumer Prices. ε_t^{NSMP}, ε_t^{CMP}, ε_t^{AD} and ε_t^{AS} are the structural shocks of non-standard monetary policy, conventional monetary policy, aggregate demand and aggregate supply, respectively. The question mark (?) denotes restrictions on the IRF of that variable.

application of a non-linear time-varying model also allows us to explore whether the diffusion of the various shocks to the economy varies over time. As already mentioned in Section 3.1 and equation (7), for structural shocks it holds true that $E(\varepsilon_t)=0$, $E(\varepsilon_t \varepsilon_{t-j}')=0 \forall t$ and j ($j \neq 0$) and $E(\varepsilon_t \varepsilon_t')=I_n$ and that they are associated with reduced-form shocks, u_t, as follows: $\varepsilon_t=\left(A_t^{-1}H_t^{\frac{1}{2}}\right)^{-1} u_t=C_{0,t}^{-1} u_t$.[20] The identification of the structural economic shocks, that is the methodology for distinguishing an economic shock (e.g. an aggregate demand shock) from another (e.g. an aggregate supply shock), basically leads to the identification of a structural VAR model, while at the same time it is a highly active field of research in the international literature (see Fry and Pagan 2011).[21]

In this study, we choose to identify structural shocks and hence the structural TVP-VAR model, employing restrictions on IRFs (Canova and De Nicolo 2002; Uhlig 2005; Mountford and Uhlig 2009; Arias et al. 2014). That is, we choose the IRFs so that they have those signs or values which are dictated by economic theory or economic reasoning. In general, the identification of structural shocks using restrictions on IRFs rests upon the methodology for generating several alternative models through orthogonal rotations, whereby we keep only those models that satisfy the restrictions imposed on IRFs (see Fry and Pagan 2011 for a more detailed analysis).

More specifically, in the light of the above, it follows that $\Omega_t=C_{0,t}\, C_{0,t}'$, suggesting that for each orthogonal matrix R (given that $RR'=I$) we can write $\Omega_t=C_{0,t}\, R\, R' C_{0,t}'=\widetilde{C}_{0,t}\, \widetilde{C}_{0,t}'$. This means that for each R we have a new set of structural shocks, $\widetilde{\varepsilon}_t=\widetilde{C}_{0,t}^{-1} u_t$, which can be utilised to check whether our restrictions on IRFs are satisfied. In many cases, the identification of structural shocks is facilitated by the introduction of zero restrictions on IRFs. Therefore, this study adopts the methodology by Arias et al. (2014), who propose a fast algorithm for the estimation of those IRFs that satisfy zero and sign restrictions. Table 2 provides an overview of the restrictions which are imposed on IRFs for the identification of structural shocks, as discussed further below.

Overall, in identifying NSMP shocks and in setting restrictions on IRFs we follow Baumeister and Benati (2013), Gambacorta et al. (2014) and Bork (2015). In greater detail, an exogenous accommodative NSMP shock is assumed to increase the ECB's assets and at the same time lead to an improvement of the overall financial conditions, thereby easing uncertainty, as captured by the Vstoxx index.

20 The main difference between structural economic shocks and reduced-form shocks is that the former are uncorrelated (mutually orthogonal), in contrast with the latter.

21 A structural VAR model uses the economic theory to determine the contemporaneous relationships between variables (Stock and Watson 2001), whereas, according to Fry and Pagan (2011), a reduced-form model summarises the information obtained from the data and a structural model provides an economic interpretation of the data.

Reduced uncertainty and improved bank financing of the economy are expected to boost economic activity and bring about a rise in the general price level. Yet, in order to distinguish a NSMP shock from a conventional monetary policy shock, it should additionally be assumed that the policy rate does not react (at least initially) to a NSMP shock (zero restriction) (Baumeister and Benati 2013).

On top of that, following the practice widely used in the literature, we identify three additional accommodative shocks, namely (i) a conventional monetary policy shock, (ii) an aggregate demand shock, and (iii) an aggregate supply shock, using sign restrictions (Baumeister and Benati 2013). The identification of additional shocks helps both to identify with greater accuracy the shocks which are of interest to us (in this case, NSMP shocks) (Uhlig 2005) and to tackle the "multiple models problem" (Fry and Pagan 2011). Furthermore, on the basis of Chart 2 it follows that all restrictions are mutually exclusive, which helps us to distinguish between each one of the shocks. Lastly, following Gambetti and Musso (2016) and Bijsterbosch and Falagiarda (2015), restrictions on IRFs are imposed only during the first period (i.e. for $t=0$), allowing the IRFs to evolve without restrictions over the subsequent periods.

4.4 EMPIRICAL RESULTS

This section presents the empirical results of the study, with a focus on the estimations of the IRFs regarding NSMP shocks. The IRFs have been normalised to reflect the impact of an accommodative NSMP shock, which corresponds to a 1% increase in the ECB's assets.

4.4.1 The average effect of NSMP shocks

In this section, we outline the average estimated effects of a NSMP shock, taking account of the entire sample from April 2007 through December 2016. Specifically, Chart 3 shows the average value of the IRFs in terms of t, which enables us to examine how the model's variables react, on average, to a NSMP shock under the reviewed sample.[22]

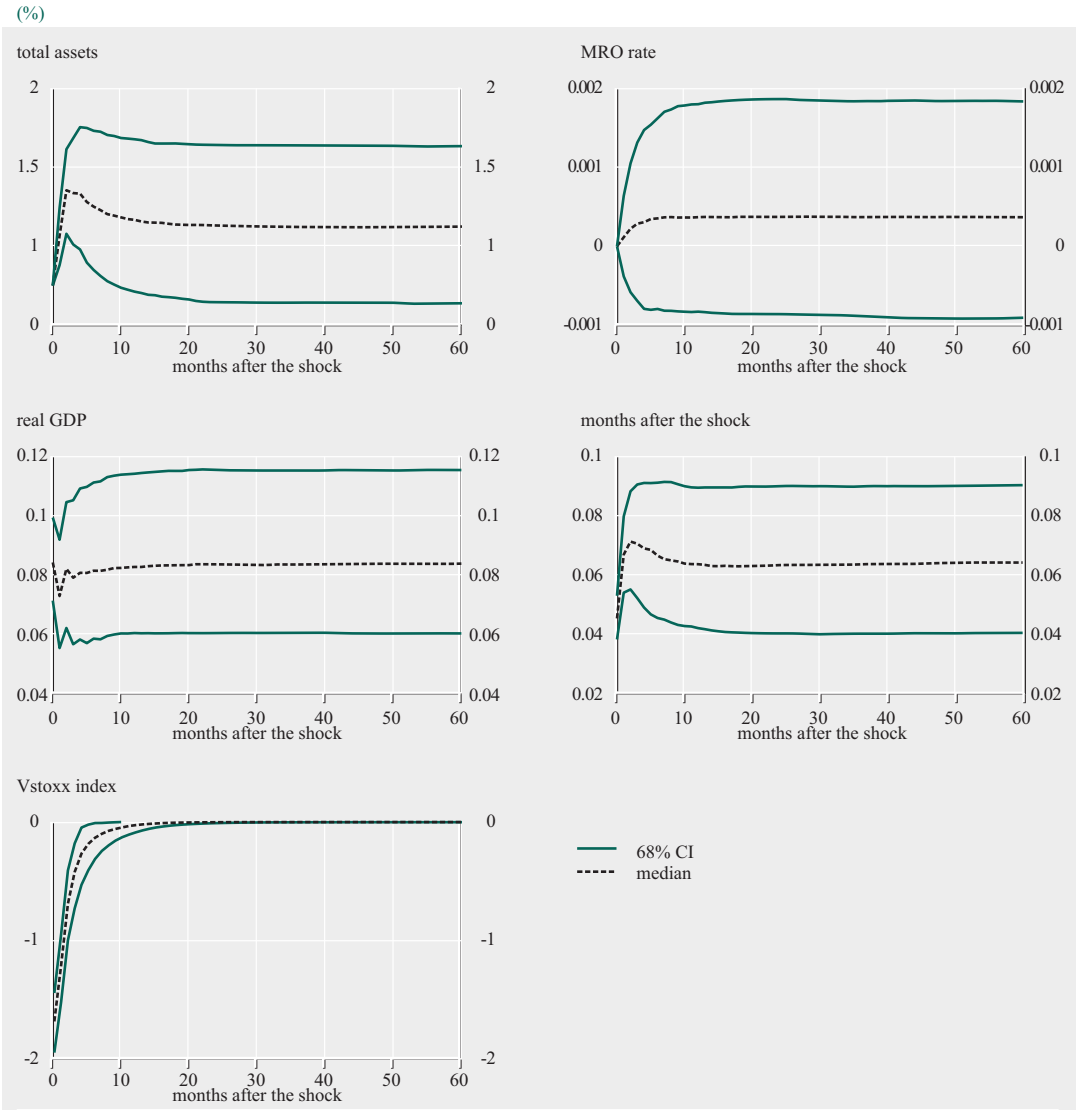
The empirical findings that are outlined in Chart 3 are broadly in line with the results by Gambacorta et al. (2014) for the euro area, as well as with other studies for different economies (see for example Michaelis and Watza 2017; Baumeister and Benati 2013; Weale and Wieladek 2016). Turning to the macroeconomic effects, which are the focal point of this study, we observe that the NSMP measures which were implemented by the ECB over the past ten years are very effective. In detail, an increase of 1% in the ECB's assets will bring about, on average over the 2007-2016 period, a rise of 0.07% in the general price level after about 3 months, as well as a maximum increase of 0.08% in real GDP (see the green line in Chart 1).[23] Moreover, as regards the effect on money markets, a 1% increase in the ECB's assets will immediately bring down the implied volatility index Vstoxx by 1.5%. The effect on Vstoxx is weakening and persists for the next 10 months more or less. It should be noted that the range of confidence intervals is quite narrow, implying that the estimated effects are statistically different from zero.

Concluding, we can argue that the above empirical findings highlight the necessity of NSMP measures over the 2008-2016 period, as an expansionary exogenous NSMP shock will lead, on average, to a statistically significant rise in the general level of prices and boost the real economy in terms of GDP. In this way, not only was the main objective of NSMP measures in that period achieved, i.e. to avert deflationary pressures, but also the broader inflation target of below, but close to, 2% through the smooth transmission of monetary

22 In particular, the average value of the IRFs has been calculated as follows: for each draw of the model's parameters from the posterior distribution we calculate the IRFs based on the restrictions set for each t. Next, we calculate the average value of the IRFs in terms of t. After the process of successive sampling from the posterior distributions we obtain 500 observations of the average IRFs, based on which we estimate the median as well as the 16th and the 84th quantile (i.e. the 68% confidence interval shown in Chart 3).

23 On an annual basis, the rates of increase are 0.84% and 0.96%, respectively.

Chart 3 Impulse response functions (IRFs) of a NSMP shock



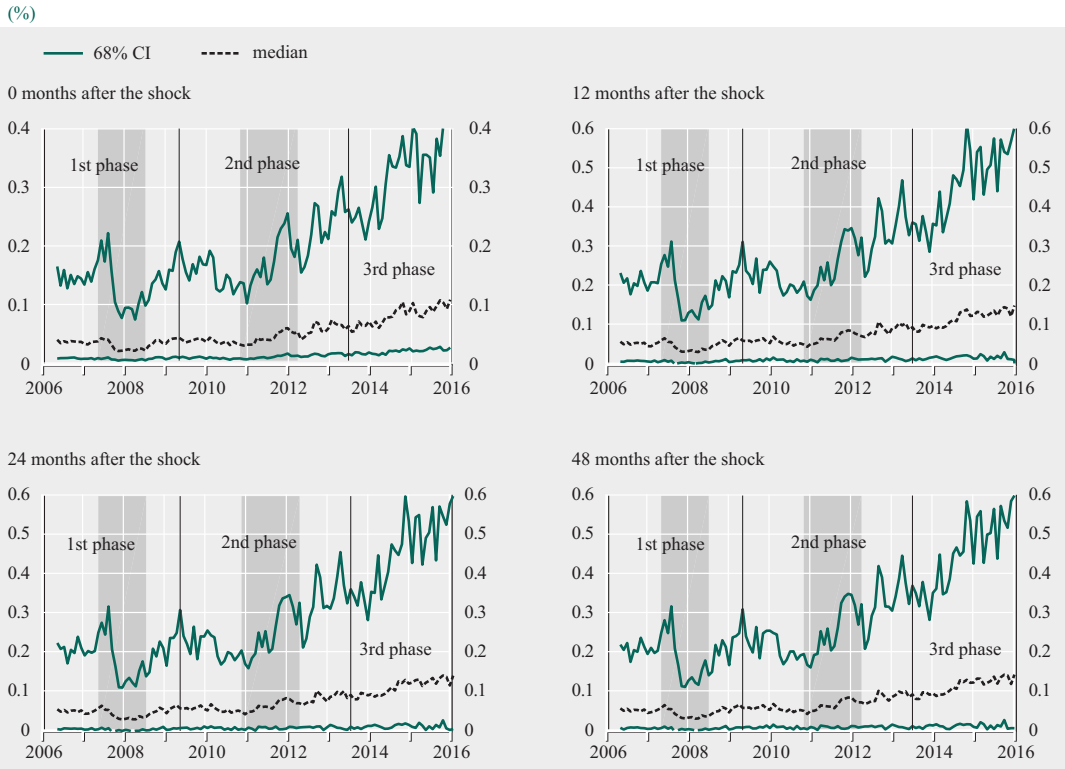
Sources: Eurostat, ECB and Thomson Reuters Datastream. Author's own calculations.
Notes: Sample average (April 2007-December 2016). For the variables Total assets, Real GDP and HICP, the cumulative IRFs are presented. CI: confidence interval.

policy accommodation. In this respect, it should be pointed out that the attainment of NSMP targets should always be seen in a relative context; that is, compared with what would have been the price level or the economic growth rate in the euro area if such measures had not been adopted and implemented. In the following section we explore the evolution of macroeconomic effects from NSMP measures over time, relying on the fact that under a TVP-VAR model the coefficients vary across time.

4.4.2 The evolution of effects from NSMP shocks over the 2007-2016 period

Charts 4 and 5 depict the development of the effects from a NSMP shock on the general level of prices and on GDP, respectively, throughout the sample (April 2007-December

Chart 4 The effect of a 1% increase in the ECB's assets on the price level over time

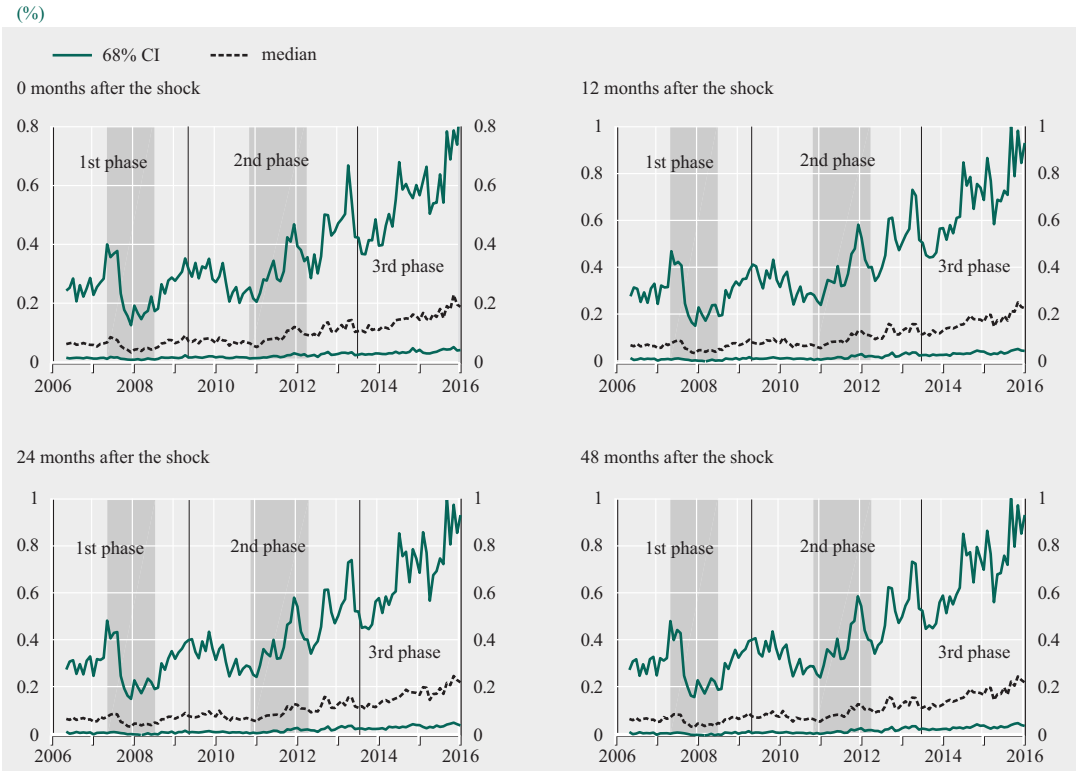


Notes: The chart shows the evolution of the impact on the price level from a NSMP shock throughout the sample (April 2007-December 2016) for 4 selected periods: immediate effect (0 months after the shock), 12, 24 and 48 months after the shock. Shaded areas correspond to periods of recession in the euro area, as defined by the CEPR Euro Area Business Cycle Dating Committee (Centre for Economic Policy Research). The black lines denote the three phases of NSMP measures, as determined in Section 2. CI: confidence interval.

2016) over four selected time horizons: immediate effect (0 months after the shock), 12, 24 and 48 months after the shock. The charts illustrate the recessionary periods, the three phases of NSMP measures, as determined in Section 2, and the 68% confidence interval.

The main feature of both charts is that they point to a statistically significant upward trend throughout the reviewed period, particularly during the last phase of the implemented QE policy. For instance, looking at the immediate effect (0 months after the shock) on HICP from an increase of 1% in the ECB's assets, we can see that the effect stands at levels below 0.05% at the beginning of the sample, whereas towards the end of 2016 it has almost doubled to around 0.1%. Likewise, the effect of a NSMP shock on GDP doubles towards the end of the sample (from 0.1% to 0.2%). A similar picture is painted by all other periods depicted in Charts 4 and 5. It is obvious that the NSMP measures which were introduced and implemented by the ECB throughout the past decade actually doubled the positive effects of a change in the size of the ECB's balance sheet on the price level and on GDP. This finding could be attributed to two factors (or a combination thereof): (a) a qualitative shift in NSMP measures, such as the launch of quantitative easing or forward guidance (see also the analysis in the following paragraphs), and (b) the possible cumulative effect of the various NSMP measures on euro area economic activity over time. It should be recalled that, as mentioned above, several measures dating back to the first phase are still in place. Therefore, the effect of new measures that are intro-

Chart 5 The effect of a 1% increase in the ECB's assets on GDP over time



Notes: The chart shows the evolution of the impact on GDP from a NSMP shock throughout the sample (April 2007-December 2016) for 4 selected periods: immediate effect (0 months after the shock), 12, 24 and 48 months after the shock. Shaded areas correspond to periods of recession in the euro area, as defined by the CEPR Euro Area Business Cycle Dating Committee (Centre for Economic Policy Research). The black lines denote the three phases of NSMP measures, as determined in Section 2. CI: confidence interval.

duced over the years may be complementary to that of the already existing measures.

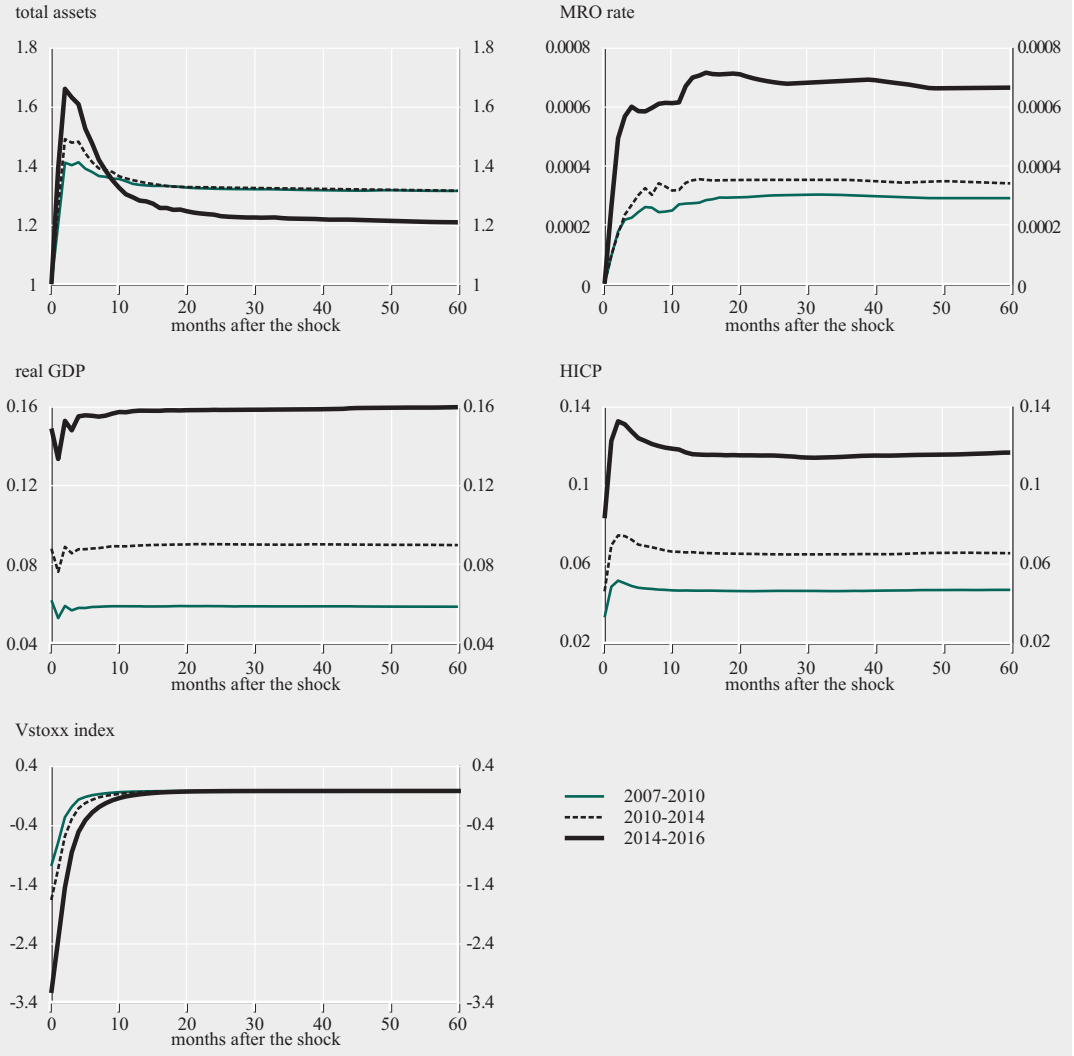
The next step in our analysis is to compare the three phases of NSMP measures, as determined in Section 2. To this end, we calculate the average value of the IRFs for the respective periods of the three phases. The median of the IRF distribution for the three phases of NSMP measures is featured in Chart 6.

Chart 6 reveals the cumulative effect of NSMP measures during the three NSMP phases, as defined in Section 2. The third phase of NSMP measures, which comprises the quantitative easing (QE) measures, appears to have, on average, the strongest positive effect on both the price level and GDP. More specifically, during the first phase of NSMP measures a 1% increase of the ECB's assets could lead to a maximum rise of 0.05% in HICP, whereas during the second and the third phase of NSMP measures these rates increase to 0.07% and 0.13%, respectively.[24] Accordingly, the maximum effects on GDP come to 0.06%, 0.09% and 0.16% in the three phases of NSMP measures under review.[25] The empirical results clearly reveal that the adoption of QE policies by the ECB, with the expansion of the asset purchase programme from mid-2014 until early 2015, contributed greatly to a shift in the diffusion of an exogenous NSMP shock. In particular, during the third NSMP phase the effect of a positive change in the ECB's

24 On an annual basis, the rates of increase stand at 0.60%, 0.84% and 1.56%, respectively.
25 On an annual basis, the rates of increase stand at 0.72%, 1.08% and 1.92%, respectively.

Chart 6 Average estimated effect of a 1% increase in the ECB's assets during the three phases of NSMP measures

(%)



Sources: Eurostat, ECB and Thomson Reuters Datastream. Author's own calculations.
Note: For the variables Total assets, Real GDP and HICP, the cumulative IRFs are presented.

assets on the price level and on income has nearly doubled relative to the averages of the two previous phases.

Nevertheless, it should be noted that a respective escalation in the effects of a NSMP shock is also observed for the Vstoxx index, which, as already mentioned, captures the level of uncertainty in money markets. This outcome is largely due to the fact that since mid-2013 the ECB has been providing forward guidance about the future path of both its conventional and unconventional monetary policy.[26] In times when conventional monetary policy ceases to be effective, i.e. when key interest rates are close to their effective lower bound, the forward guidance provided by a central

26 Forward guidance takes the form of announcements on the part of the ECB regarding the level of key interest rates in the near future or in the long term. The ECB may also announce its intentions about NSMP measures (Coenen et al. 2017) (see for example https://www.ecb.europa.eu/press/pr/date/2016/html/pr161208.en.html).

bank constitutes a key NSMP tool, immediately influencing expectations and affecting uncertainty in money markets (Cœuré 2017, Coenen et al. 2017). In a recent paper, Coenen et al. (2017) stress that the effectiveness of the ECB's announcements in easing uncertainty greatly hinges upon the transparency of their content and the details they provide to the general public. Overall, forward guidance communication must be formulated very carefully, depending on the degree of commitment that the central bank wishes to express regarding specific policies.[27] Forward guidance announcements entailing a stronger commitment are seen as more effective NSMP tools, but this depends to a large extent on their (imperfect) interpretation by economic agents (Coenen et al. 2017).

It can be observed that the ECB's unconventional monetary policy interventions have delivered the desirable outcomes over time, thereby averting deflation and stimulating the economy as well as reducing uncertainty in the economy, as captured by the implied volatility index. At this point, it should be underscored that, according to Eggertsson (2011) and Krugman (2000), in times when key interest rates are close (or equal) to zero, the central bank's policies are effective in stimulating the real economy, so long as (see also the analysis by Michaelis and Watzka 2017): (1) the attempted monetary expansion, i.e. money growth, is viewed by market participants as permanent and (2) the central bank does not return to its standard policies for price stabilisation as soon as the economy exits the crisis period. Against this background, apart from the making of unconventional monetary policy, strong commitment and resolve are warranted on the part of the central bank that NSMP measures will remain in place for as long as necessary to boost the economy. As already mentioned, central bank communication about various policies also plays a key role in markets' perception of the central bank's degree of commitment to a concrete plan or strategy. The more transparent and clear forward guidance is, the more likely it is for money market uncertainty to decline. Therefore, the empirical results of this study show not only that the framework of the ECB's interventions moved in the right direction, but also that the ECB issued clear messages to market participants about the nature and the duration of its interventions.

5 SUMMARY – CONCLUSIONS

In this study, we examined the effectiveness of the ECB's non-standard monetary policy (NSMP) measures in boosting the euro area economy over the 2007-2016 period. In particular, we investigated the effect of an increase in the ECB's assets, which represents a positive NSMP shock, on GDP and the price level in the euro area. The econometric investigation relied on non-linear time-varying models, which are more flexible and have the ability to take into account the structural changes that took place in the euro area economy in the period under review (2007-2016).

Overall, the empirical findings of the study are consistent with the findings of the extant literature. More specifically, an increase of 1% in the ECB's assets could lead, on average over the 2007-2016 period, to an annual rise of 0.84% in inflation and of 0.96% in GDP, confirming the appropriateness of the ECB's policies to address the economic crisis in the euro area. Yet, the most important finding of the study is that the macroeconomic effect of a NSMP shock has changed substantially as a result of the adoption of quantitative easing (QE) policies by the ECB. In greater detail, from mid-2014 through December 2016 an exogenous NSMP shock that brings about a 1%

27 According to Campbell (2013), forward guidance can be split into two categories: (i) announcements that express the central bank's strong commitment to a specific, state-contingent plan on a future reaction (for this type of announcements the term "Odyssean forward guidance" has prevailed, alluding to Odysseus who had himself bound to the mast of his ship to resist the Sirens' call), and (ii) announcements that communicate the central bank's forecast about the likely course of monetary policy without committing to a future plan (for this type of announcements the term "Delphic forward guidance" has prevailed, alluding to the pronouncements from the oracle of Delphi in ancient times) (see also Coenen et al. 2017).

increase in the ECB's assets could result, on average, in an annual increase of 1.56% in the price level and of 1.92% in GDP. These rates are nearly double the respective averages of the 2007-2014 period and demonstrate the positive contribution of QE policies to stimulating the euro area economy. This conclusion is the outcome of time-varying econometric models, which underlines their usefulness in the investigation of NSMP effects.

Concluding, the empirical results of the study corroborate the success of the ECB's overall strategy of unconventional monetary policy interventions. A decisive contribution was made by the expansion of the asset purchase programme and the ECB's strong commitment to pursuing interventions for as long as necessary in order to meet the target of inflation and safeguard economic and financial stability. A further investigation of the macroeconomic effects from unconventional monetary policy in the euro area is warranted to the extent that we wish to explore the effects of the ECB's policies on Member States' national economies. In this respect, possible asymmetries in the intertemporal diffusion of NSMP shocks among Member States could be identified and valuable conclusions about future strategy making could be drawn.

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