EUROPEAN CENTRAL BANK

EUROSYSTEM

Working Paper Series

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Unconventional monetary policy and the anchoring of inflation expectations

Task force on low inflation (LIFT)

No 1995 / January 2017

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

The research is carried out in three workstreams:

1) Drivers of Low Inflation;

2) Inflation Expectations;

3) Macroeconomic Effects of Low Inflation.

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

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

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

Abstract

The effects of the unconventional monetary policy (UMP) measures undertaken by the U.S. Federal Reserve (and other major central banks) remain a crucial topic for research. This paper investigates their effects on the anchoring of long-term inflation expectations, a key dimension of UMP that has been largely overlooked. Our analysis provides two key insights. First, the anchoring of inflation expectations deteriorated significantly since late 2008. Second, the expansion of the Fed's balance sheet contributed decisively to prevent and gradually reverse that de-anchoring during the Great Recession. Using a SVAR framework extended to incorporate policy news, we show that accounting for the predictable path of the balance sheet following the Fed's asset purchase announcements is fundamental to properly assess the effects of UMP.

JEL codes: E43, E44, C52, C55

Keywords: Inflation expectations, unconventional monetary policy, news shocks

Non-technical summary

This paper investigates the effects of the unconventional monetary policy (UMP) measures undertaken by the U.S. Federal Reserve on the degree of anchoring of long-term inflation expectations.

The paper provides two important contributions to the literature. First, more than quantifying the impact of the policy measures on asset prices and inflation expectation as usually done by the literature (e.g. Krishnamurthy and Vissing-Jorgensen, 2011), it argues that the degree of anchoring of inflation expectations is a key dimension over which the Fed's UMP should be assessed. By constructing a measure of anchoring based on the pass-through from short to long-term inflation expectations in a time-varying model, the paper provides new evidence on the significant deterioration of the anchoring of long-term inflation expectations since late 2008. In particular, the paper documents that, in the 2003-2008 period, long-term inflation expectations did not react to fluctuations in short-term expectations, which were more influenced by cyclical factors. In contrast, between 2009-2014, the pass-through became positive and significant, suggesting a weak(er) degree of anchoring and a bigger influence of low actual inflation readings and short-term inflation expectations onto longer-term inflation outlook. The papers also shows that the expansion of the Federal Reserve's balance sheet reduced the risks of a de-anchoring of long-term inflation expectations and counteracted high tail risks of deflation (or very low inflation).

Second, this paper proposes a new framework for the assessment of UMP effects. The existing literature has analyzed the effects of balance sheet expansions via Structural Vector Autoregressive (SVAR) models during the Great Recession (e.g. Gambacorta et al., 2014, Weale and Wieladek, 2014) in similar fashion as monetary policy decisions via interest rates (e.g. Christiano et al. 1999). This paper argues that it is important to extend that framework to take into account that the Fed usually announced its programmes some time ahead of its actual implementation, often describing the intended pace of expansion of its balance sheet over a given number of months or a given period. To account for those crucial characteristics of UMP, those "news" about the future path of the balance sheet are included into a SVAR framework along the lines of the recent contributions to the analysis of fiscal policy shocks (e.g. Romer and Romer, 2010; Mertens and Ravn, 2013; Ricco, 2014) and the literature on news and anticipated shocks (e.g. Schmitt-Grohe and Uribe, 2013). This novel framework therefore allows to distinguish the effects of the announced pace and the unexpected shocks due for example to the specific implementation of that intended pace of expansion.

Armed with this machinery, the paper shows that the Fed's UMP contributed decisively to control and over time reverse the de-anchoring of long-term inflation expectations during the Great Recession, while sustaining the GDP and price levels. Both the announced (anticipated) path and the unexpected component of the balance sheet expansion significantly decreased the risk of de-anchoring.

The deterioration in the degree of anchoring of long-term inflation expectations over the last few years is not exclusive of the U.S. economy and other major economies have also experienced a significant decline of long-term inflation expectations since 2014. Hence, the lessons from the Fed experience are very relevant for many other central banks currently engaged in UMP. For example, the slide of euro area long-term inflation expectations since 2014 has contributed to the ECB announcing an active balance sheet policy to steer the inflation rate back towards its policy target of below, but close to 2% (e.g. Draghi, 2016).

1 Introduction

The intensification of the financial turbulences following Lehman Brothers collapse led the Federal Reserve – and other major central banks – to lower interest rates and hit the zero-lower bound. To provide additional stimulus to the economy during the Great Recession, the Federal Reserve then turned to unconventional monetary policy (UMP henceforth) measures, in particular a series of Large Scale Asset Purchase (LSAP) programmes. Those asset purchases led to a significant expansion of its balance sheet, which replaced interest rates as the main monetary policy instrument.

Understanding the effects and potential implications of UMP measures is fundamental for researchers and policymakers alike. Indeed, despite significant insights in many aspects and a rapidly growing empirical literature on the effects of central bank's balance sheet policies, controversy still surrounds their assessment in the policy debate (e.g. Financial Times, 2014, Gross et al., 2015). A sizable part of studies has mainly focused on the financial market effects of the Fed's unconventional measures by means of event studies, and found noticeable impact effects of their announcements on a wide range of financial asset prices.[1] By contrast, the modelling of the persistent effects of UMP remains more challenging. The assessment is, overall, positive, but studies of the effects of Fed's actions on real activity and inflation are more limited.[2]

This paper contributes to the study of the effects of UMP measures in two fundamental aspects. First, we argue that the anchoring of inflation expectations is a key dimension over which the Fed's UMP should be assessed. We provide new evidence on the significant deterioration of the anchoring of long-term inflation expectations since late 2008. Ahead of the crisis, the fairly strong anchoring of inflation expectations was a crucial aspect of the macroeconomic landscape, but its deterioration during the crisis posed a serious challenge for monetary policy, in particular in the light of the sluggish economic recovery and the recurrent deflation fears in recent years. To gauge the degree of anchoring of long-term inflation expectations, we measure the pass-through from short to long-term inflation expectations in a time-varying model built along the lines of Stock and Watson (2007) and Jochmann et al (2010). We document that, in

[1] See among others Bauer and Rudebusch (2012), D'Amico, English, Lopez-Salido and Nelson (2013), D'Amico and King (2013), Gagnon et al (2011), Hamilton and Wu (2012), Joyce and Tong (2013), Krishnamurthy and Vissing- Jorgensen (2011), Li and Wei (2013), Meaning and Zhu (2011), Neely (2010), Rosa (2012), Rogers, Scotti and Wright (2014), and Swanson (2011)

[2] See for example Chen, Curdia, and Ferrero (2011), Chung et al (2012), Baumeister and Benati (2013), Gertler and Karadi (2013), and Weale and Wieladek (2014), Engen et al. (2015).

the 2003-2008 period, long-term inflation expectations did not react to fluctuations in short-term expectations, which are more influenced by cyclical factors. In contrast, between 2009-2014, the pass-through coefficient became positive and statistically significant, suggesting a weak(er) degree of anchoring and that the low actual inflation readings and short-term inflation expectations also influenced longer-term inflation expectations.

We show that the expansion of the Federal Reserve's balance sheet reduced the risks of a de-anchoring of long-term inflation expectations and counteracted high tail risks of deflation (or very low inflation). Specifically, conditional regression estimates suggest that the risk of de-anchoring decreased in periods in which the Fed was actively expanding its balance sheet through asset purchases. In contrast, when the Fed's balance sheet was not expanding (i.e. roughly constant or even contracting) the anchoring weakened again. Moreover, available evidence from the Philadelphia Fed's SPF probability forecasts also suggest that the perceived deflation and recession tail risks also decreased when the Fed was actively expanding its balance sheet.

This paper proposes a new framework for the assessment of UMP effects. Existing literature has analyzed the effects of balance sheet expansions via Structural Vector Autoregressive (SVAR) models during the Great Recession (e.g. Gambacorta et al., 2014, Weale and Wieladek, 2014) in similar fashion as monetary policy decisions via interest rates (e.g. Christiano et al. 1999). We argue that it is important to extend that framework to take into account that the Fed usually announced its LSAP programmes some time ahead of its actual implementation, often describing the intended pace of expansion of its balance sheet over a given number of months or a given period. To account for those crucial characteristics of UMP we incorporate those "news" about the future path of the balance sheet into a SVAR framework along the lines of the recent contributions to the analysis of fiscal policy shocks (e.g. Romer and Romer, 2010; Mertens and Ravn, 2013; Ricco, 2014) and the literature on news and anticipated shocks (e.g. Schmitt-Grohe and Uribe, 2013). Our novel framework therefore allows for distinguishing the effects of the announced pace and the unexpected (or, better, *misexpected*) shocks due for example to the specific implementation of that intended pace of expansion.

Our main findings are as follows. The Fed's UMP contributed decisively to control and over time reverse the de-anchoring of long-term inflation expectations during the Great Recession. Our results show that both the announced, and therefore anticipated, path of the balance sheet and the unexpected component of balance sheet expansion decreased the risk of de-anchoring. Yet, our framework suggests that it was the anticipated news which contributed to a larger part of the variation in the anchoring of inflation expectations. As regards inflation and output, our extended framework corroborates existing results pointing to significant but lagged and anyway temporary response following expansionary UMP shocks (e.g. Gambacorta et al, 2014).

The rest of the paper is organized as follows. Section 2 describes in detail the measure to gauge the anchoring of inflation expectations and documents its deterioration during the Great Recession. The section also presents evidence of a important role of the Fed's balance sheet expansion to control and eventually revert that deterioration. Additional empirical evidence based on the perceived tail risks in output and inflation probability forecasts corroborate the positive effects of UMP measures on the anchoring of inflation expectations and the macroeconomy. Section 3 introduces a SVAR news shocks framework for the modeling of UMP and discusses the main empirical results in terms of impulse response and counterfactual analysis. Section 5 concludes.

2 Gauging the anchoring of inflation expectations

To understand the effects of the financial crisis and the Great Recession on the anchoring of long-term inflation expectations, we need a quantitative measure of anchoring. A useful metric of the degree of anchoring of inflation expectations is the pass-through from short to long-term inflation expectations (e.g. Jochmann et al. 2010):

$$\Delta_k \pi_t^{e,long-term} = \alpha_t + \beta_t \Delta_k \pi_t^{e,short-term} + e^{h_t/2} \varepsilon_t \tag{1}$$

where $\Delta_k \pi_t^e$ is computed as changes in (short or long-term) inflation expectations over the previous k periods, β_t (the pass-through measure) is modelled as a time-varying parameter and h_t is a stochastic volatility term to account for potential changes in market conditions and volatility since the beginning of the financial crisis.

The rationale of equation (1) is that, if inflation expectations are well-anchored, developments in short-term inflation expectations, reacting for example to developments in actual inflation readings, should not have a significant impact on long-term inflation expectations and β_t should be statistically insignificant.

Operationally, we measure the long-term expectations by the long-term forward (five years forward rate in five years) break even inflation rate (BEIR) calculated from zero-coupon nominal Treasury and TIPS yields (see Gurkaynak et al., 2010). In turn, short-term expectations are measured by the 2-year spot BEIR. These measures are available with a daily frequency since January 2004. Figure 1 plots the monthly time series of the 2-year spot and the five-year forward in five years.

FIGURE 1 HERE

It is important to bear in mind that financial indicators do not only comprise the expected level of inflation over a given horizon but also the pricing of the uncertainty and risks surrounding it in the form of inflation risk premia. BEIRs are therefore better interpreted as overall inflation compensation measures. Since the focus here is the degree of anchoring of inflation expectations, for which the uncertainty and risks surrounding inflation expectations are also of crucial relevance, inflation compensation measures provide a richer set of information than single point forecasts. In what follows, we will nonetheless continue to refer to them as inflation expectations.

The reaction of long-term inflation expectations to changes in short-term ones may not be immediate and may be influenced by the persistence of observed changes in one specific direction. To capture such effects $\Delta_k \pi_t^e$ is computed as changes in short-term inflation expectations over the previous six months ($k = 6$ with monthly data).

Equation (1) is estimated at monthly frequency using Bayesian methods and allowing for stochastic volatility along the lines of Stock and Watson (2007). In particular, defining $\theta_t = (\alpha_t', \beta_t')'$, the following distributional prior assumptions are made:

$$
\begin{aligned}
\theta_t &= \theta_{t-1} + u_t \qquad u_t \sim N(0, \Omega) \\
h_t &= h_{t-1} + v_t \qquad v_t \sim N(0, \omega)
\end{aligned}
$$

where

$$\omega \sim inverse - Gamma(\nu_h, S_h)$$

and Ω is diagonal with

$$\Omega_{ii} \sim inverse - Gamma(\nu_0, S_0)$$

The initial conditions for θ_0 and h_0 are respectively

$$
\begin{aligned}
\theta_0 &\sim N(0, V_\theta) \\
h_0 &\sim N(0, V_h).
\end{aligned}
$$

We use the efficient algorithm developed by Chan and Jeliazkov (2009) and Chan and Hsiao (2014) for time-varying and stochastic volatility models. The values of the hyperparameters and initial conditions are calibrated to their univariate examples. Specifically, we choose: $\nu_0 = 3$; $S_0 = 0.05$; $\nu_h = 5$; $S_h = 0.2^2\,(\nu_h - 1)$; $V_\theta = \hat{V}_{ols}$; and $V_h = 9$. Experimenting with different sets of hyperparameters did not change the results.

It could be argued that our results may be driven by the changes in the different liquidity premia embodied in TIPS yields compared to standard Treasuries. We however also conducted the same analysis using inflation-linked (IL) swap rates as an alternative measure of inflation compensation, which recent literature has shown to be less prone to mispricing depending on market conditions (e.g. Fleckenstein et al , 2014). The fact that the results were qualitatively very similar suggests that our findings are truly related to the pricing of inflation compensation (i.e. inflation expectations and related premia) and not driven by potential fluctuations in liquidity premia.

2.1 The de-anchoring of inflation expectations since 2008

Figure 2 plots the (monthly) posterior distribution of β_t (median and 68% Bayesian interval) as measure of the degree of anchoring of long-term inflation expectations over the sample 2005:1-2015:12. A key goal of this paper is to relate the evolution of the degree of anchoring of inflation expectations to the implementation of the Fed's UMP measures. Figure 2 therefore depicts three periods of active asset purchases by the Federal Reserve by shadow bands – denoted as QE1, QE2 and QE3 to help interpret the dynamics of the β_t coefficient in the context of UMP.

FIGURE 2 HERE

Two main features of the dynamics of the inflation pass-through coefficient are worth noting. First, from mid-2004 to the intensification of the financial crisis with the collapse of Lehman Brothers, the inflation pass-through fluctuated within a relatively narrow range (between -0.1 and 0.3) but was statistically not different from zero throughout the period, with the exception of a brief spell in the first half of 2005. The intensification of the financial turbulences in September 2008 and the subsequent financial crisis however changed that pattern. The pass-through coefficient rose sharply from mid-2009, and since then fluctuated within the 0-0.5 range to an average of around 0.35, well above the highest values reached between 2004 and 2008. Even more importantly, in sharp contrast to the pre-crisis period, the inflation pass-through remained statistically significant for most of the period until late 2013 and then again in 2015.

The second noticeable finding concerns the fluctuations of the inflation pass-through during the financial crisis period. Our pass-through estimates tend to rise in the periods in which the Federal Reserve is not actively engaged in asset purchases. In contrast, the announcement and implementation of QE measures seems to be decisive to lower the inflation pass-through, particularly in the periods in which the government bonds were the main focus of the Fed's asset purchases: (i) from September 2009 to March 2010 within the QE1 period, (ii) from September 2010 – when the FOMC signalled its intentions to start a QE2 programme that was officially launched on November 2010 – until its end eight months later, and (iii) since shortly after the start of QE3 bond purchases in September 2012. This evidence suggests that the Fed successfully counteracted risks of de-anchoring of inflation expectations through its QE programmes.[3]

2.2 Balance sheet expansion and the risks of de-anchoring

The size and pace of the asset purchases undertaken by the Fed had a direct impact on its balance sheet. The expansion of the Fed balance sheet can therefore be used to gauge the magnitude of the monetary policy stimuli introduced into the US economy. In order to shed light on the impact of the Fed's balance sheet expansion on the risk of de-anchoring of long-term inflation expectations, we consider the evolution of the balance sheet relative to US GDP and investigate how the estimates of the inflation pass-through vary with the balance sheet expansion. Specifically, we estimate the same equation (1) conditioning the sample on the periods over which the Fed's balance sheet was expanding or contracting. Our conditioning variable is the change in the balance sheet size over the previous six months from 2009 to 2014, and condition the subsample.

FIGURE 3 HERE

Figure 3 depicts the density estimation of the inflation pass-through coefficient in periods in which the Fed's balance sheet was expanding (red) and when it was contracting (blue). The results support the effectiveness of QE measures aimed at the expansion of the Fed's balance

[3] In addition, we also investigated the response of far-forward inflation compensation measures on the surprise component of inflation (and other macroeconomic) surprises, a widely-used metric of anchoring (see e.g. Gurkaynak et al, 2010). Our results, which are fully consistent with a deterioration of the anchoring of long-term inflation expectations over the Great Recession period as a whole, but significantly attenuated over the QE periods, are available upon request.

sheet on the risks of de-anchoring of long-term inflation expectations. Whenever the Fed's balance sheet was expanding, the density estimates for the inflation pass-through are clearly low and barely higher than zero on average. In contrast, when the Fed's Balance sheet was not expanding (remaining roughly constant or even contracting) the density estimate of the pass-through is on average clearly higher (about 0.17) and statistically different from zero at all significance levels. The uncertainty surrounding the estimates seem to point to a strong control over the pass-through coefficient by the Fed's by means of its balance sheet expansion.

2.3 Insights from the perceived macroeconomic risks

The positive effects of the Fed's UMP measures in re-anchoring inflation expectations were most likely related to the improvement in macroeconomic conditions. To assess the impact on the Fed's QE measures on deflation (or low inflation) risks we use the probability forecasts of the Survey of Professional Forecasters (SPF) of the Federal Reserve Bank of Philadelphia. Every quarter the SPF requests panelists to assign the probability of inflation falling within pre-specified intervals, i.e. a density forecast in the form of a histogram. Once averaged across panelists, the probability mass assigned to low outcomes (below 1%) provides a direct quantitative measure of perceived tail risks for inflation (and growth), which is free from potential model misspecification.[4]

The perceived macroeconomic risks depicted in Figure 4 help gauge the effectiveness of the Fed's QE initiatives to counteract tail risks. It has however to be taken into account that the SPF is conducted at quarterly frequency and therefore no immediate reaction to the measures could be identified. Our emphasis here is in the trend observed in the perceived macroeconomic tail risks, but for the sake of transparency we keep the expected probabilities constant at their levels observed in the last survey conducted, hence the steps in the Figure, rather than smoothing them.

FIGURE 4 HERE

The SPF risks show that following the Lehman Brothers collapse the US economy was indeed expected to entail a severe recession, with the probability of experiencing an inflation rate below 1% perceived to be above 45%. Subdued growth risks (below 1%) were even higher, reaching almost 100% in May 2009. While the QE1 measures were not initially perceived to be able

[4] The US SPF only request density forecasts for calendar years, e.g. current and next year. To proxy one-year ahead macroeconomic risks we weight the probabilities in the current and next year forecasts.

to counteract those risks, a significant decline in those tail risks can however be seen since the second half of 2009.

More direct evidence of the effectiveness of QE measures to counteract tail risks can be found in late 2010, with the implementation of the QE2 measures. This is arguably the most relevant episode for two reasons. First, at the time of launching QE2 asset purchases low growth risks were relatively limited, but inflation tail risks were increasing since early 2010 and reached around 35% in the July 2010 SPF, with deflation fears mounting. Second, in the light of this situation the specific purpose of QE2 measures was to counteract those deflation risks, as explicitly stated in FOMC and Fed Chairman Bernanke communication at the time.[5]

The effectiveness of QE2 asset purchases to counteract deflation risks in the US economy in 2010-2011 is indeed striking. Figure 3 suggests that perceived tail inflation risks started to decline immediately after Fed's announcement and continue doing so steadily over the period of QE2 implementation, decreasing by around 25% to merely 10% around July 2010.

The launching of further monetary policy easing by the Fed in late 2012 as part of the QE3 measures cannot be easily motivated by tail macroeconomic risks, and was mainly oriented to provide additional support to the US job market sluggish recovery at the time. Notwithstanding, both growth and inflation tail risks remained relatively subdued during QE3 implementation in 2012-2013 despite the still fragile recovery in US economic activity.

3 Modelling UMP: A SVAR with news shocks

The main goal of this paper is to study the impact of UMP on the anchoring of inflation expectations. The empirical evidence presented in previous sections show that the Fed's UMP measures appeared to be decisive to restore the anchoring of long-term inflation expectations, which was weakened following the intensification of the financial crisis and the subsequent Great Recession. The purpose of this section is to introduce an empirical framework that allows for analyzing the dynamic effects of UMP measures while at the same time taking into account the evolving macroeconomic environment.

Modelling the dynamic effects of UMP measures is however far from trivial. UMP measures generally consist of a path of announced increases in the central bank's balance sheet, and

[5] After having signalled its intentions in the previous months, the FOMC finally announced on November 3, 2010, that it would purchase an additional $600 billion in U.S. Treasuries to "promote a stronger pace of economic recovery and to help ensure that inflation, over time, is at levels consistent with its mandate."

therefore, we need to disentangle the announced monthly increased for the central bank's balance sheet in the future, and the unexpected component of the balance sheet expansion for example due to the specific implementation of the announced pace of asset purchases over time. It is fundamental to separate both components. In the case of fiscal policy analysis, for example, recent research has shown that the timing of the announcements in government spending is crucial. Ramey (2011) finds that correcting for expected government spending shocks a SVAR model can change substantially the results of an unexpected fiscal shock (both in magnitude and sign).

To account for the specific characteristics of UMP, we propose a SVAR that it is augmented with news and anticipated shocks (SVAR+News) similar to the approach followed in Schmitt-Grohe and Uribe (2012) and more in line with the analysis of fiscal policy shocks proposed by Romer and Romer (2010) and Mertens and Ravn (2013) among others. Our approach allows to incorporate into the analysis the information set of economic agents at each period in time, and therefore, we can separate the effects of an increase in the balance sheet that was announced several periods in advance before its implementation, and the truly unexpected component of innovations to the central bank's balance sheet. More specifically, we identify the expected path of the central bank's balance sheet by means of a set of auxiliary innovations to the balance sheet variable that account for the expected announced –and therefore expected by economic agents– increases in the balance sheet by the Federal Reserve, from the FOMC minutes and the speeches of chairman Bernanke. Such path is modelled as an observable counterpart to the latent anticipated innovations in the model, with a measurement error to account for possible deviations of market expectations from the announcement.

3.1 Model

Our empirical framework can be interpreted as a VARX model with M endogenous variables augmented with a process of the announced (news) shocks, $\tilde{\varepsilon}_t$, to capture the peculiar characteristics of UMP measures, and can be written as follows

$$x_t = B(L)x_{t-1} + \gamma\tilde{\varepsilon}_t + A\xi_t$$

where x_t and ξ_t are of dimension $M \times 1$, γ is $M \times K$ and $\tilde{\varepsilon}_t$ is $K \times 1$. The UMP measures imply the announcement of some future expansion in the Fed's balance sheet that, strictly speaking, is not yet observable, but, as in Schmitt-Grohe and Uribe (2012), they can be written as a latent process,

$$\tilde{\varepsilon}_t = F\tilde{\varepsilon}_{t-1} + Qv_t$$

More specifically, consider an example where for simplicity the number of endogenous variables $M = 2$, and that the announced information is about the future path of the variable ordered first. More specifically, suppose that there is a period t for which economic agents had information (news) already in three previous periods $t-1$, $t-2$ and $t-3$: that is, three periods ago economic agents received some information about time the value of the variable in period t by means of a central bank announcement. Denoting $\tilde{\varepsilon}_t^i$ as the information known i periods ago, we can write the news shocks vector as[6],

$$\tilde{\varepsilon}_t = \begin{bmatrix} \varepsilon_t^1 \\ \varepsilon_t^2 \\ \varepsilon_{t-1}^2 \\ \varepsilon_t^3 \\ \varepsilon_{t-1}^3 \\ \varepsilon_{t-2}^3 \end{bmatrix}$$

and γ will be as follows :

$$\gamma = \begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 1 \\ \gamma_{21} & 0 & \gamma_{22} & 0 & 0 & \gamma_{23} \end{bmatrix}$$

The representation of γ above allows for an anticipated shock to the balance sheet to have a direct effect on the other variables of the model, once the programme is implemented. Finally, the latent process for the news shocks can be written as,

$$\begin{bmatrix} \varepsilon_t^1 \\ \varepsilon_t^2 \\ \varepsilon_{t-1}^2 \\ \varepsilon_t^3 \\ \varepsilon_{t-1}^3 \\ \varepsilon_{t-2}^3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \varepsilon_{t-1}^1 \\ \varepsilon_{t-1}^2 \\ \varepsilon_{t-2}^2 \\ \varepsilon_{t-1}^3 \\ \varepsilon_{t-2}^3 \\ \varepsilon_{t-3}^3 \end{bmatrix} + \begin{bmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \sigma_3 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_t^1 \\ v_t^2 \\ v_t^3 \end{bmatrix}$$

In this framework the UMP measures announced by the central bank are therefore modeled as an announced –and therefore anticipated– path v_t^i for the variable through which unconventional monetary policy is implemented (i.e. the central bank's balance sheet) and some additional

[6] For a more detailed exposition on the construction of this vector, see the supplementary appendix from Schmitt-Grohe and Uribe (2012)

unexpected shocks ξ_t that could be related for example to the actual implementation of those measures around the announce path.

To help the identification of the anticipated path and unexpected component of balance sheet shocks, we introduce the available information revealed by the central bank in the observable vector of the model, E_t, that therefore captures the announced policy changes to be implemented from a future period t. Then, the additional equation that relates the latent states to the observed announcements can be written as,

$$E_t = S\tilde{\varepsilon}_t + R\eta_t$$

with S being a selection matrix comprised of zeros and ones, and $R\eta_t$ can be interpreted as a measurement error.

The full model is then given by

$$\begin{aligned} x_t &= B(L)x_{t-1} + \gamma\tilde{\varepsilon}_t + A\xi_t \\ E_t &= S\tilde{\varepsilon}_t + R\eta_t \\ \tilde{\varepsilon}_t &= F\tilde{\varepsilon}_{t-1} + Qv_t \end{aligned}$$

If we define $z_t = [x_t' \; E_t']'$, and $\psi_t = [\xi_t', \eta_t']'$ then, the model can be expressed as,

$$\begin{aligned} z_t &= D(L)z_{t-1} + G\tilde{\varepsilon}_t + H\psi_t \\ \tilde{\varepsilon}_t &= F\tilde{\varepsilon}_t + Qv_t \end{aligned}$$

which is just a linear (and Gaussian) state space model that can be estimated using a Gibbs Sampler and the Kalman Filter.

By construction, our SVAR + news framework allows for analyzing the economic effects of announced (and anticipated) UMP measures, for example the monthly path of expansion of the central bank balance sheet via asset purchases that is represented by a change in v_t^i, and an unexpected component ξ_t that may reflect surprises or unanticipated shocks related to the precise implementation of the asset purchases by the central bank. Each announced UMP measure introduces in the model M coefficients to be estimated.

3.2 Data and Estimation

In order to estimate the SVAR+News model, we use monthly data over the sample period 2008M11 – 2014M06. The variables that we use are GDP (interpolated), CPI, the size of the Balance Sheet of the Federal Reserve (as measured by the ratio of total asset over GDP), and the quantitative measures of de-anchoring introduced in the previous sections (so $x_t = [GDP_t, CPI_t, BS_t, \beta_t]'$). All the variables enter the model in log levels. Finally, we use a constructed dataset of QE announcements from the Federal Reserve as E_t. The announcements are summarized in the table below:

QE announcements by the FOMC

dates	measure
November 2008	\$600 billion
March 2009	Expansion to \$1.75 trillion
November 2010	\$600 billion until 2011Q2
September 2012	\$40 billion per month
December 2912	from \$40 to \$80 billion per month
June 2013	tapering

We estimate the posterior distribution of $\Theta = \{B(L), \gamma, A, Q\}$ by means of Bayesian techniques. Specifically, we consider a Minnesota prior for $B(L)$, with an own lag tightness of $\lambda_1 = 0.8$, and a cross lag decay of $\lambda_2 = 2$. We also set an Inverse-Wishart prior for $\tilde{A} = AA'$, Inverse-Gamma priors for each σ_i^2 and a weakly informative Normal distribution for γ.

Given an initial draw Θ^0, a Gibbs sampler pseudo-algorithm can be constructed as follows:

1. Conditional on $B(L), \gamma, A$ and Q, it is possible to obtain a draw of the latent states, $\tilde{\varepsilon}^T$, using the Carter and Kohn (1994) algorithm, among other possibilities.

2. Conditional on the latent states, it is possible to draw the variances of the states, σ_i^2. Given that F is known and we consider an Inverted Gamma prior, the posterior distribution for the elements in Q is also an Inverse-Gamma.

3. Conditional on the latent states and γ, then we draw $B(L)$ and $\tilde{A}$ from their conjugate posterior distribution.

4. Finally, conditional on the latent states, $B(L)$, and $\tilde{A}$, we can draw γ, which is constrained so that the row corresponding to the Balance Sheet has only zeros and ones.

We estimate the model using two lags (supported by the BIC in a standard VAR framework), and with 12 months of anticipated shocks, since most of the announcements from the Federal

Reserve are done for a long period of time. In order to not to increase the number of latent states substantially, but to keep the information set as wide as possible, we consider that 12 months is a reasonable representation.

3.3 The effects of Unconventional Monetary Policy

This section discusses the impact of UMP measures using our SVAR+News framework model. Specifically we report three pieces of evidence focusing on the impact of shocks to the central bank balance sheet. First, in line with the standard approach of monetary policy analysis in similar frameworks, we show the estimated impulse responses to the unanticipated component of the balance sheet expansion. We then move on to consider an announced change in the path of the central bank's balance sheet, which we construct along the lines of the type of announcements made by the Federal Reserve when introducing its LSAP programmes. Finally, we perform a counterfactual analysis in which we simulate the evolution of the degree of anchoring of long-term inflation expectations coefficient should the Federal Reserve not announced the LSAP programmes and thereby changed the path of its balance sheet.

3.3.1 Unanticipated shocks to the balance sheet

We first focus on the unexpected component of the central bank's balance sheet expansion. Figure 5 shows the response of the endogenous variables in our model after an unexpected one standard deviation shock to all of the variables in the model. The shocks are identified using a Cholesky decomposition of the covariance matrix, under the assumption that GDP and the CPI do not react within the month to an expansion of the balance sheet, but the anchoring coefficient can adjust. No other restrictions are imposed on the other shocks, since we are mostly interested in balance sheet expansion shocks.

FIGURE 5 HERE

We can extract several messages from the impulse responses. First, the model predicts that the unexpected component of the UMP measures increases GDP over the medium-to-long run, and it has not a significant effect on the price level. The impact on GDP, however, is moderate, with a maximum peak of a 0.08 percent. More importantly, it has a negative impact on our de-anchoring measure, implying that the pass-through of short term to long term expectations is reduced, in line with the results shown in the previous sections.

Note also that the Balance Sheet of the Federal Reserve does not react significantly to macroeconomic changes, suggesting that it is a pure exogenous policy instrument. Finally, we observe a significant decrease in the degree of de-anchoring after an inflation shock, which is likely to reflect that in our sample the risk of de-anchoring was closely related to deflationary risks. Thus, a recovery in the inflation rate should contribute to re-anchor long-term inflation expectations.

Peersman (2011) identifies unconventional monetary policy shocks using sign restrictions and including financial variables, and imposes that the reaction of market uncertainty is negative. He also finds that there is a positive effect on real activity, but also on prices. However, it is not clear that an unexpected monetary policy shock should reduce volatility in the financial markets (indeed, in the United States, periods of high macroeconomic volatility are many times associated to periods with high monetary policy uncertainty). To check the robustness of our results, we also estimate a standard VAR imposing the same zero and sign restrictions as in Peersman (2011). We introduce our measure of anchoring in the VAR and we identify the unconventional monetary policy shock assuming that it has no contemporaneous impact on GDP or inflation, but as in Peersman (2011), it reduced volatility in the financial markets. In this case we also find that the impact on anchoring is negative.

3.3.2 Announced path for the balance sheet

A substantial part of the balance sheet expansion however followed the announcements made by Chairman Bernanke and the FOMC about the Federal Reserve's intentions to engage on several episodes of asset purchases. As described in the previous section, our empirical framework explicitly accounts for the presence of such *news* on the future evolution of the Fed's balance sheet to be anticipated by economic agents.

FIGURE 6 HERE

In Figure 6 we show the effects of an scenario in which the Federal Reserve announces that the Balance Sheet will expand 75 billions each month during the following twelve months. This is a similar episode as the second Quantitative Easing program, launched by the Federal Reserve in November 2010. Note also that an increase in 75 billions corresponds to a two and a half standard deviations shock to the unanticipated component. This expansionary policy also has a strong negative effect on the de-anchoring coefficient, thus suggesting that LSAP programmes and announcements affected the economy through the expectations-anchoring channel. Note that the size of the reduction in the deanchoring coefficient is quite large compared to the units of the original coefficient.

As robustness check, we also introduce the VIX as in Peersman (2011). The results also show that the programs support a medium and long term increase in output, while there is a suggestion that the price level could increase. Moreover, the scenario shows that in this case, the expansion path of the Balance Sheet that we consider has no significant effect on the VIX, and if any, there is a reduction, which suggests that a well defined and communicated monetary policy path should not affect macroeconomic volatility (or, if it does, it should reduce it).

3.3.3 How important was UMP?

We have shown that both the announced (and expected) as well as the unexpected component of the Fed's balance sheet expansion are effective in reducing the de-anchoring risks.

FIGURE 7 HERE

As a final evidence, Figure 7 reports the results of a counterfactual path for the deanchoring coefficient. We construct it as follows. First, for each posterior draw, we recover the reduced-form shocks of the model,

$$\epsilon_t^s = x_t - B(L)^s x_{t-1} - \gamma^s \tilde{\varepsilon}_t^s$$

Then, we reconstruct a new path for the variables in the model ($\hat{x}_t$) allowing for our model economy to be hit by the same unexpected component of the shocks but without any expansion–nor any announcement of such an expansion obviously–of the central bank's balance sheet ($\tilde{\varepsilon}_t = 0$),

$$\hat{x}_t^s = B(L)^s \hat{x}_{t-1} + \epsilon_t^s$$

Since the Lucas critique applies to any counterfactual analysis, we need to bear in mind that economic agents might have acted differently if they understood that there is a possibility of a Quantitative Easing programme. Bearing that in mind, our model suggests that the pass-through coefficient would have been higher and de-anchoring therefore persisted during the whole sample period if the Federal Reserve had not engaged in the UMP. Together with the previous results, in the light of this evidence we conclude that the anchoring of expectations is an important channel in the operating mechanism of balance sheet expansions.

For the sake of completeness, figure 7 also reports what the model would imply for the macroeconomic variables in our model, namely GDP and prices, which helps answer the question: what would the counterfactual look like for GDP and inflation in the absence of UMP? In line with the evidence from the IRFs reported above, both GDP and prices would have been lower, albeit not necessarily significantly different from the observed path under the UMP measures. Notwithstanding the caveats around these counterfactual experiments, these results are not only interesting in their own right, but also help validate the soundness of the model framework.

4 Concluding remarks

This paper investigates the macroeconomic effects of the US Federal Reserve's unconventional policy (UMP) through asset purchase programmes that lead to a significant expansion of its balance sheet. We focus on a novel channel of UMP, namely its effects on long-term inflation expectations, a key dimension of UMP that has been largely overlooked in existing literature. To that end, we first documented the deterioration of the degree of anchoring of U.S. long-term inflation expectations during the Great Recession. We then showed that the launching of UMP measures allowed the Federal Reserve to re-gain control of inflation expectations, and curtail severe deflation and recession risks.

To assess the impact of UMP on the anchoring of inflation expectations, the key novelty of our analysis is an extension of a SVAR with news on anticipated shocks that can account for the key characteristics of UMP announcements. The framework introduced in this paper therefore allows to distinguish between the effects of announced–and therefore anticipated– pace of expansion of the Fed's balance sheet and the unexpected component due to the LASP along that expansion path. Our model shows that it was the anticipated news on the Fed's balance sheet expansion which contributed to most of the variation in the anchoring of inflation expectations. Moreover, our model can also be used to assess the effects of the UMP measures on inflation and output, and we find a positive but relatively limited impact of UMP in the macroeconomy, in line with existing literature. Our results therefore show that it is important to allow for news effects in the analysis of UMP measures, and underscore the role of the signalling channel of UMP.

We believe that the re-anchoring of inflation expectations is a key dimension over which to evaluate the Fed's UMP. Moreover, given that the deterioration in the degree of anchoring of long-term inflation expectations over the last few years is not exclusive of the U.S. economy and other major economies have also experienced a significant decline of long-term inflation expectations since 2014, the lessons from the Fed experience are likely to be very relevant for many other central banks currently engaged in UMP. For example, the slide of euro area long-term inflation expectations since 2014 contributed to the ECB announcing an active balance sheet policy to steer the inflation rate back towards its policy target of below, but close to 2% (e.g. Draghi, 2016).

Understanding the Fed's experience with UMP measures is of particular relevance for policy-makers, but also a very important topic for research. In this regard, the framework introduced in this paper provides enough flexibility to analyze the different specific episodes of QE undertaken by the Fed and thereby obtain additional insights on their effects. It can also be extended to explore further the transmission channels through which UMP may have impacted the US macroeconomy and financial markets, for example along the lines of Krishnamurthy and Vissing-Jorgensen (2011), two extensions that are already in our agenda.

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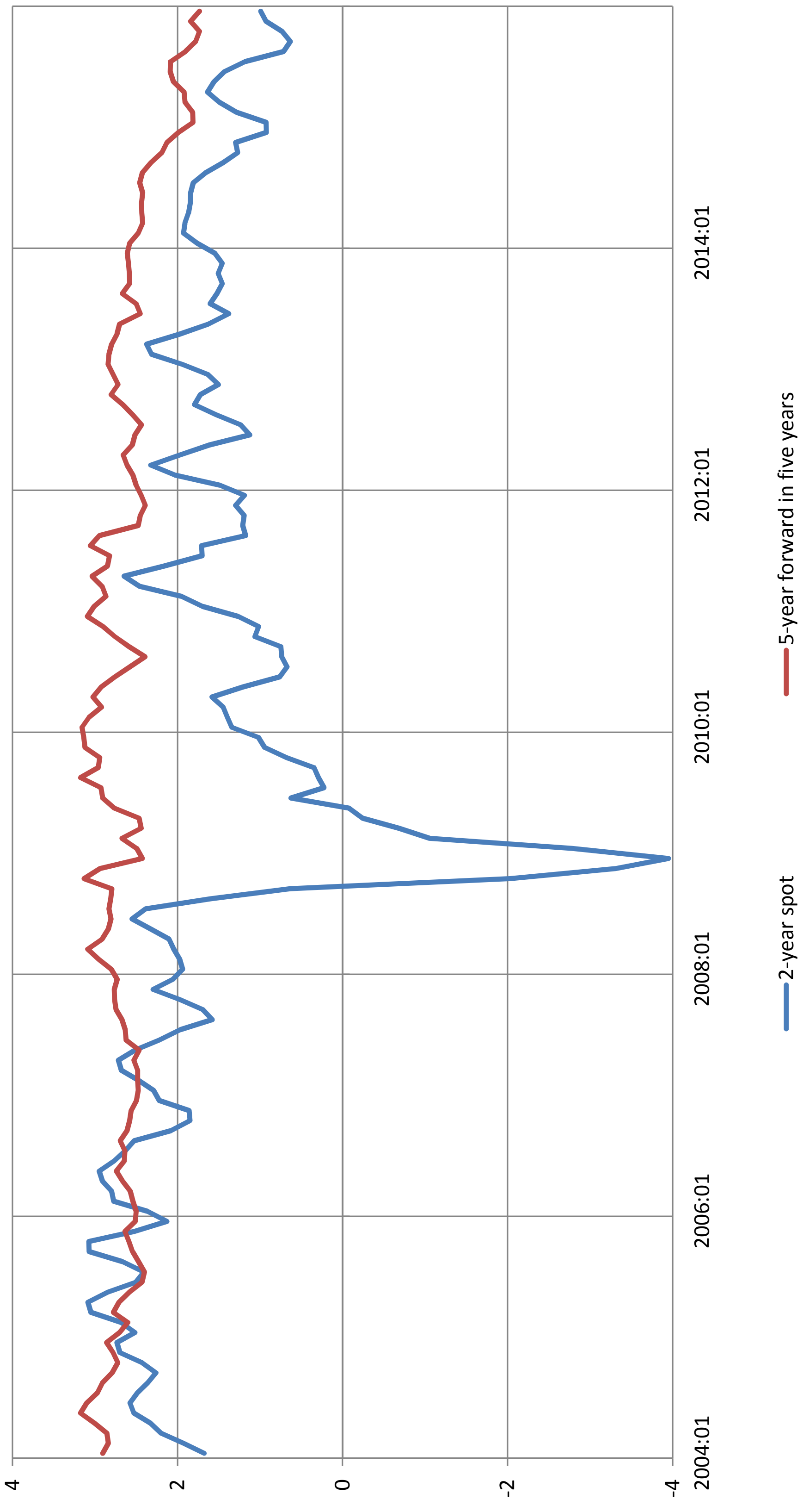
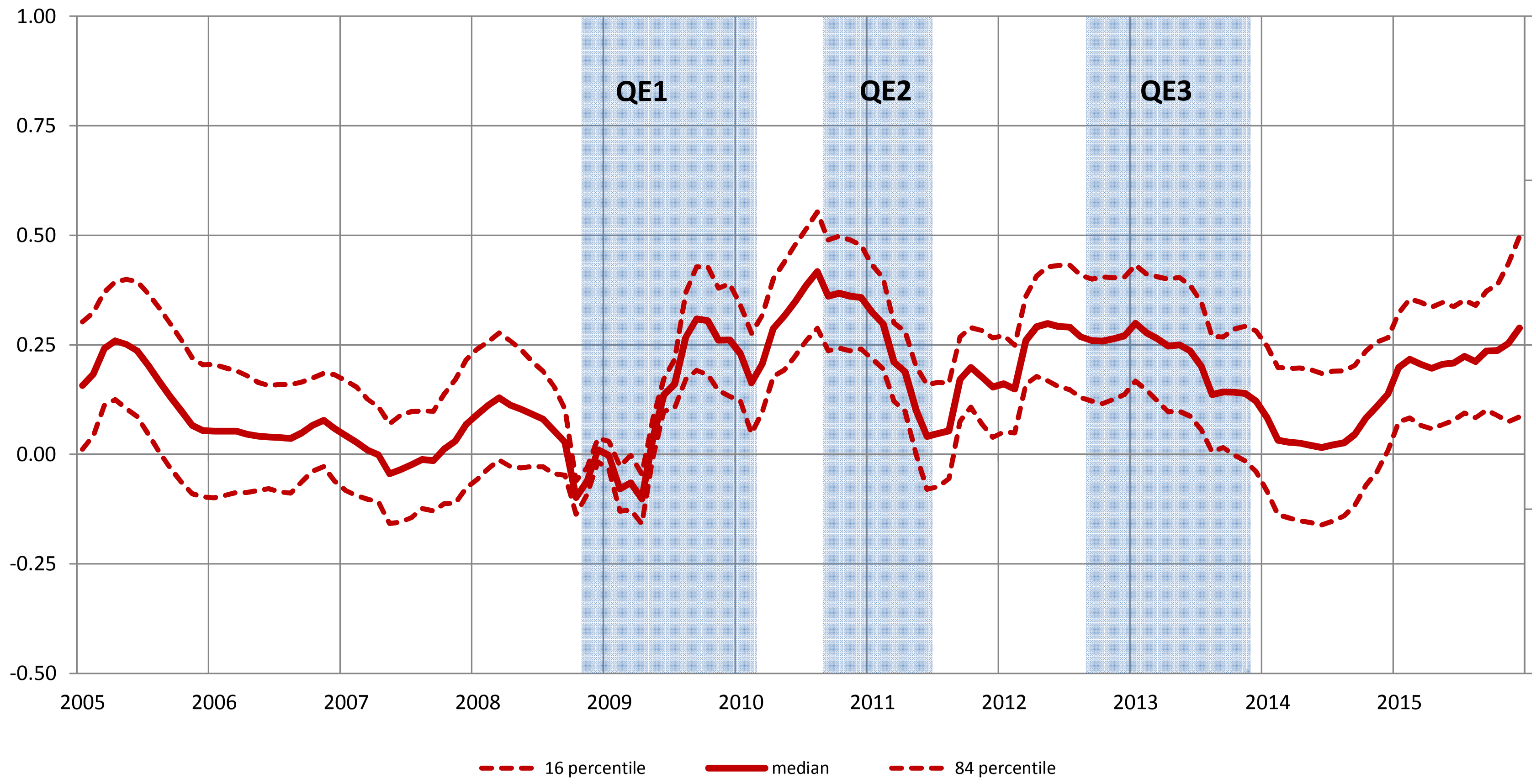
Figure 1. Inflation compensation

Break Even Inflation Rate



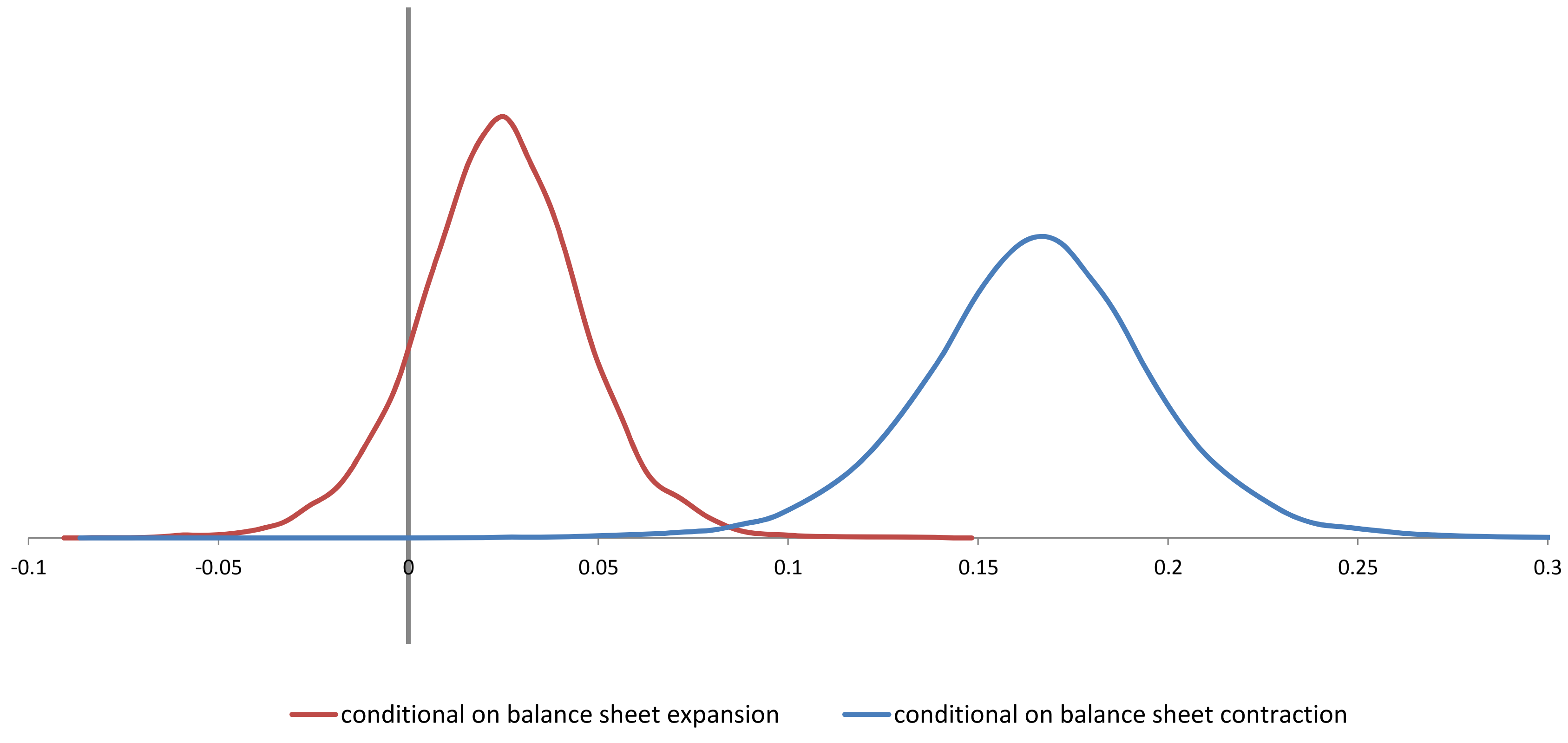
Source: ICAP and author's calculation

Figure 2. Degree of anchoring



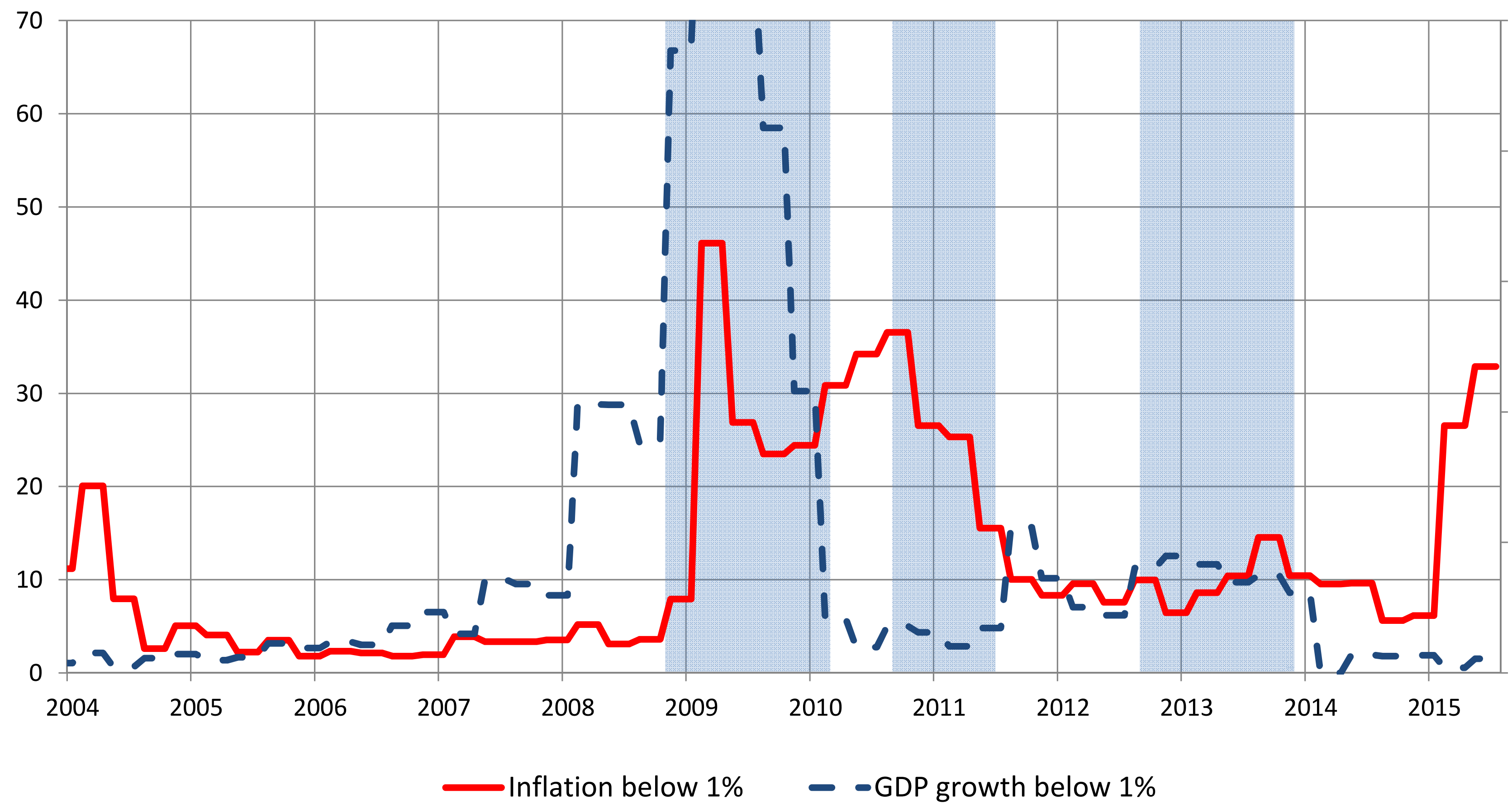
Note: time-varying coefficient measuring the pass-through from short (two year BEIR) to long-term inflation expectations (5-year forward BEIR in 5-years). The zero-coupon BEIR data used in the estimation are downloaded from the webpage of the Board of Governors of the Federal Reserve, and are estimated following Gurkaynak, et .al (2010). For details on the model underlying the estimation of the pass-through coefficient see Section 2. Shadow bands reflect the QE1, QE2 and QE3 episodes of balance sheet expansion.

Figure 3. Conditional sampling estimates of the pass-through from short to log-term inflation



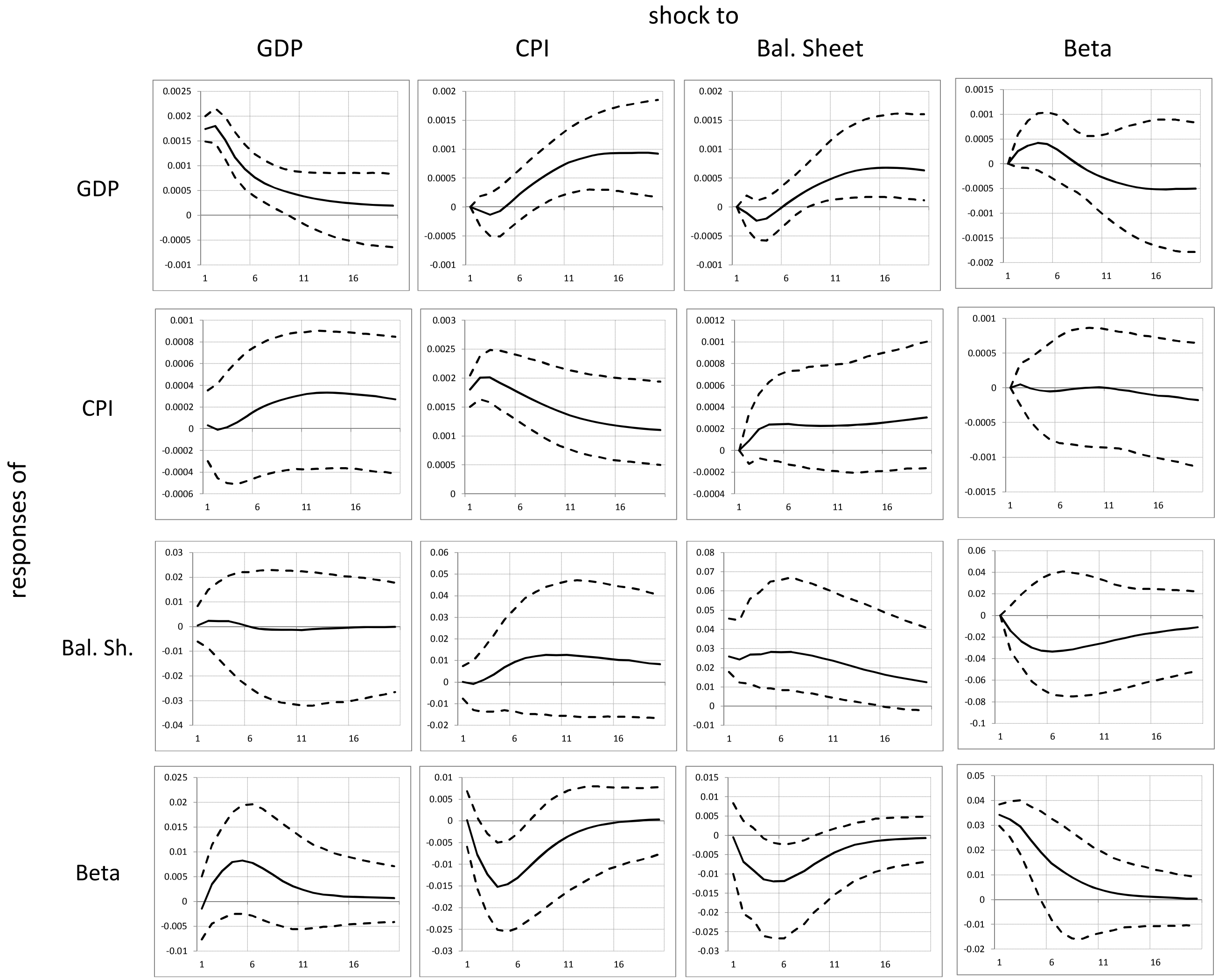
Note: density forecast for the pass-through coefficient (x-axis) from short to log-term inflation expectations in conditional samples defined by an expansion of the Fed’s balance sheet compared to the size in the previous six months.

Figure 4. U.S. macroeconomic tail risks



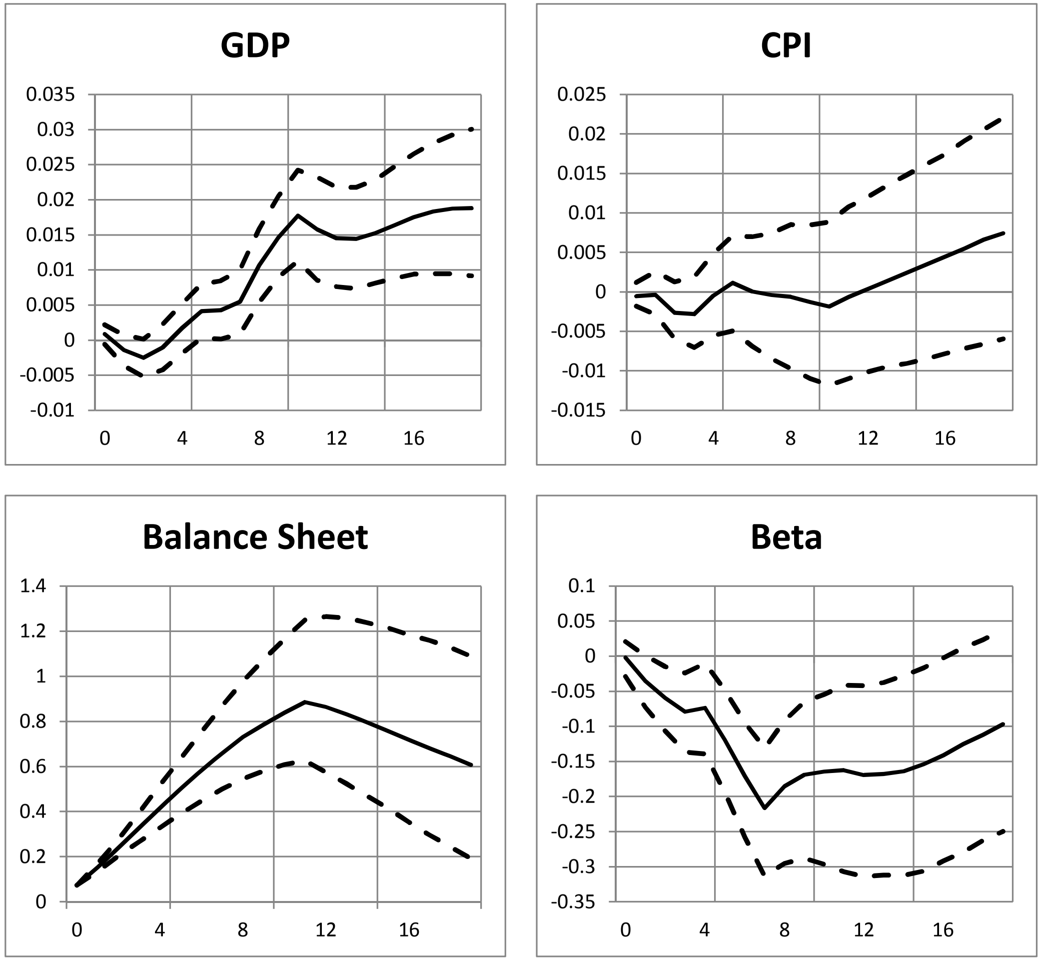
Note: probability mass assigned to inflation and growth outcomes below 1% one-year ahead in the probability forecasts of the Survey of Professional Forecasters conducted for the US economy by the Federal Reserve Bank of Philadelphia.

Figure 5. Impulse Response Functions to unexpected shocks



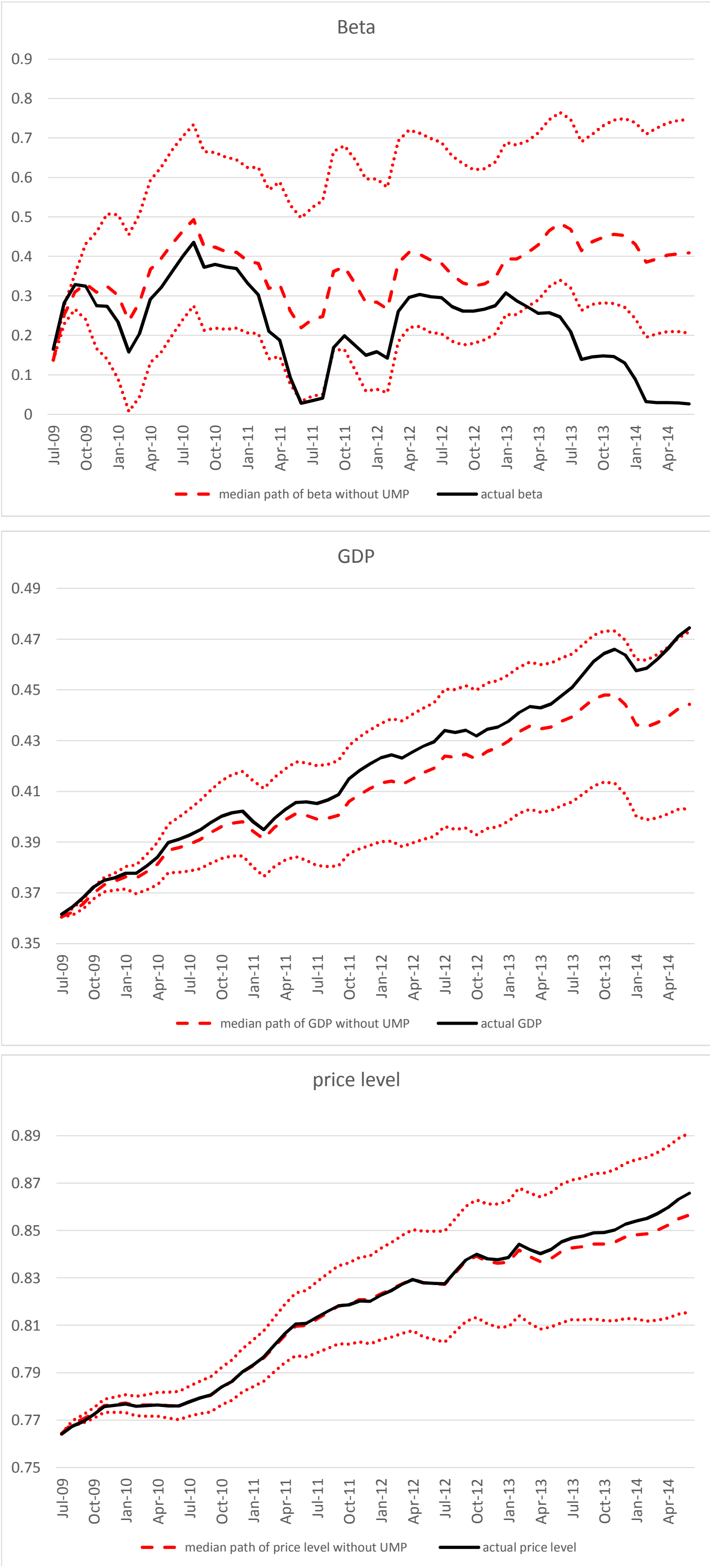
Note: The Impulse Response Functions are based on a Cholesky decomposition of the covariance matrix. The solid line is the median, and the dashed lines represent the 16% and 84% credible interval.

Figure 6. Response to an expected path in the size of the Balance Sheet



Note: The solid line is the median, and the dashed lines represent the 16% and 84% credible interval.

Figure 7. Counterfactual exercise



Note: The black line is the true observed value of the anchoring measure, the log GDP and the log price level. The dashed and dotted red lines are the median and the 16% and 84% credible interval of the counterfactual in absence of policy.

Acknowledgements

We thank an anonymous referee, Fabio Canova Domenico Giannone, Ricardo Gimeno, Giorgio Primiceri, and seminar participants at the ECB and Banca d'Italia for helpful discussions and comments. Excellent research assistance by Renate Dreiskena and Samuel Skoda is gratefully acknowledged. Remaining errors are our responsibility. The views expressed are those of the authors and do not necessarily reflect those of the ECB or the Eurosystem.

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ISSN	1725-2806 (pdf)	DOI	10.2866/00394 (pdf)
ISBN	978-92-899-2717-8 (pdf)	EU catalogue No	QB-AR-17-007-EN-N (pdf)