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THE MACROECONOMIC EFFECTS OF FALLING LONG-TERM INFLATION EXPECTATIONS

by Stefano Neri*

Abstract

Long-term inflation expectations in the euro area reached historically low levels at the end of 2019, suggesting a possible de-anchoring from the European Central Bank's 'below, but close to, 2 per cent' inflation aim. The decline in long-term inflation expectations exerted a downward pressure on inflation between 2014 and 2016, and in 2019. Counterfactual simulations show that had the European Central Bank not reacted to the fall in expectations, the decline in inflation would have been larger in both episodes and economic activity would have declined. A small-scale calibrated DSGE model can rationalize this evidence.

JEL Classification: C32, E31, E32, E37.
Keywords: long-term inflation expectations, monetary policy, VAR, Bayesian methods.
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"[…] *one reason to also act now concerns inflation expectations that we've seen not only the ones that are now at low levels but we see that inflation expectations are not de-anchoring but are re-anchoring at levels between zero and 1.5% which is not our aim*."

Mario Draghi, President of the ECB, press conference of the Governing Council meeting on 12 September 2019.

1. Introduction[1]

Long-term inflation expectations play a key role in monetary policy. Their anchoring to the inflation target is a necessary condition for central banks to maintain price stability, as it prevents temporary shocks from having persistent effects on inflation. Well-anchored long-term inflation expectations are a sign of the credibility of the monetary policy strategy and contribute to preserving the policy space required for compressing long-term yields with asset purchases.

Large and persistent inflation forecast errors can lead investors, firms and households to revise their long-term inflation expectations, which can become de-anchored from the central bank's target. In the terminology of Ball and Mazumder (2011), in those circumstances long-term expectations are "shock de-anchored". If a central bank is fully credible, long-term expectations are insensitive to data releases (Bernanke, 2007).

After the global financial crisis and the subsequent persistently low inflation in many advanced economies, several studies have assessed the anchoring of long-term inflation expectations using survey- and market-based indicators (see Corsello et al., 2021, for a review). The literature on the macroeconomic effects of changes in long-term expectations is, however, still scant.

Arias et al. (2016) show that a decline in long-term inflation expectations can be contractionary if real interest rates increase because either the policy rate is at its effective lower bound or the central bank fails to react. The asymmetry posed by the effective lower bound generates an asymmetry in the probability distribution of output, which becomes skewed towards negative outcomes. Carvalho et al. (2019) show, using a small-scale model with endogenous long-term inflation expectations, that large and persistent forecast errors lead firms to doubt a constant inflation target and to switch to a constant gain expectation formation mechanism to infer about the target. The authors, however, do not assess the real effects of changes in long-term expectations. Ireland (2007) estimates a New Keynesian model to infer about the Federal Reserve's (unobserved) inflation target. Exogenous increases in the target cause a permanent increase in both inflation and the nominal short-term rate. As inflation over-shoots in the short run, while the nominal rate adjusts only gradually, the real rate falls and generates a persistent increase in output. De Michelis and Iacoviello (2016) use a Vector AutoRegressive (VAR) model to quantify the macroeconomic impact of changes in the inflation target of the Bank of Japan. The authors use a theoretical model in which agents gradually update their estimate of the

[1] The views expressed in this article are those of the author alone and do not necessarily represent the position of Banca d'Italia or the Eurosystem. I would like to thank Fabio Canova, Matteo Iacoviello, Francesco Corsello, Alex Tagliabracci, Andrea Silvestrini, Fabrizio Venditti, Massimiliano Pisani and Tiziano Ropele for their comments. I am particularly grateful to Marco Bernardini and Antonio Conti for also helping me with the WinRats code. I also thank the participants at the conference "Advances in Business Cycle Analysis, Structural Modeling and VAR Estimation" in honor of Fabio Canova and held in Hydra (Greece) on 23-24 October 2021. I thank Valentina Schirosi for proofreading the text.

target to account for the sluggish estimated response of nominal and real variables to an exogenous change in the target.

To the best of my knowledge, very few VAR-based studies assess the impact of changes in long-term (survey-based) inflation expectations. Geiger and Scharler (2020) study the revision of survey expectations in response to macroeconomic shocks, which are identified with sign restrictions. Lukmanova and Rabitsch (2021) identify shocks to the Federal Reserve's inflation target assuming that these shocks explain the largest share of the variance of long-term inflation expectations. Diegel and Nautz (2021) studies the role of long-term expectations for the monetary transmission mechanism using a VAR model estimated on U.S. data. The authors find that these expectations play an important role in the transmission of monetary policy.

The objective of this paper is to contribute to the scant literature on the macroeconomic effects of changes in long-term inflation expectations by focusing on the euro area and the European Central Bank (ECB). I see several reasons why the euro area is an ideal case for assessing the macroeconomic effects of changes in long-term inflation expectations. First, there is evidence that long-term expectations have de-anchored from the inflation aim of the ECB (Corsello et al., 2021). Second, the inflation target of the ECB is vaguely defined as "*below, but close to, 2 per cent*", in contrast with most central banks in advanced economies, which have adopted a 2 per cent target. Third, since 2013, both survey-based and market-based measures of long-term inflation expectations in the euro area have been systematically below those in the U.S. Fourth, the policy rates of the ECB have remained close to their effective lower bound since mid-2014. Fifth, inflation has remained well below 2 per cent since 2013 despite the ECB's Asset Purchase Programme (APP) adopted in early 2015 and, more generally, a very accommodative monetary policy stance.

The paper poses the following research questions. What are the macroeconomic effects of changes in long-term inflation expectations in the euro area? What is the role of the ECB's monetary policy in the transmission of shocks to long-term expectations to inflation and economic activity? To answer these questions, I rely on a Bayesian VAR and a small-scale DSGE model. I use the long-term inflation expectations from the ECB Survey of Professional Forecasters (SPF) as a measure of the perceptions of the vaguely defined "*below, but close to, 2 per cent*" inflation aim of the ECB, (Section 2) and the VAR to quantify the macroeconomic effects of shocks to these perceptions. I identify the shocks using a combination of zero, sign, narrative and variance decomposition restrictions. I then use the DSGE model to rationalize the empirical findings. I rely on both the VAR and the DSGE model to carry out counterfactual simulations to highlight the role of monetary policy. With the VAR, I focus on 2013-14 and 2019, two periods characterized by falling long-term inflation expectations. The counterfactuals can be very useful in light of the quotation by ECB's President Mario Draghi at the beginning of this Introduction.

The analysis is subject to two important assumptions. First, changes in long-term inflation expectations are the result of shocks rather than smooth or swift endogenous changes in the expectation formation mechanism as in Carvalho et al. (2019). Therefore, a de-anchoring of long-term expectations is captured by a sequence of shocks of the same sign. Negative shocks to inflation expectations, which are more difficult for the central bank to counteract, in particular if the policy rate is at its effective lower bound, may have different macroeconomic effects compared with positive shocks. Second, the consequences of the presence of the effective lower bound to the policy rate and the impact of quantitative easing measures on interest rates are taken into account in the empirical analysis by means of a shadow interest rate.

I contribute to the literature by providing evidence on the macroeconomic impact of shocks to long-term inflation expectations and the role of the ECB's monetary policy in the euro area. Unlike Lukmanova and Rabitsch (2021) and Diegel and Nautz (2021), and De Michelis and Iacoviello (2016), who focus, respectively, on the U.S. and Japan, I study the euro area case. As for the identification, compared with these studies, I do not assume that changes in long-term inflation expectations are due to exogenous variations in the inflation target. I rather assume that these changes are due to the revisions of forecasters' perception of the ECB's inflation aim. Neither Lukmanova and Rabitsch (2021) nor De Michelis and Iacoviello (2016) use narrative restrictions à la Antolín-Díaz and Rubio-Ramírez (2018). Compared with Diegel and Nautz (2021), who also use zero and sign restrictions and impose restrictions on the systematic component of monetary policy (Arias et al., 2019), I focus on the euro area and use a small-scale model to rationalize the empirical findings.

The analysis yields the following answers to my research questions. First, negative shocks to long-term inflation expectations exerted a downward effect on euro-area inflation in 2013-14 and in 2019. Second, had the ECB failed to respond to negative shocks to expectations, economic activity would have declined and inflation would have fall by more, particularly in 2019. This result provide support to the monetary policy measures adopted by the ECB in September 2019. Third, a stylized small-scale DSGE model, in which agents' perceptions about the inflation target are revised in response to changes in inflation, is able to replicate from a qualitative viewpoint the effects of changes in expectations estimated with the VAR and confirms the stabilising role of monetary policy.

The remainder of the paper is the following. Section 2 discusses the drivers and trends in long-term inflation expectations. Section 3 describes the VAR and the identification of the structural shocks. Section 4 provides quantitative evidence on the macroeconomic effects of shocks to long-term inflation expectations. Section 5 describe the small-scale DSGE model, which I use to rationalize the empirical findings. Section 6 studies the role of monetary policy by means of counterfactuals. Section 7 assesses the robustness of the results. Section 8 offers some concluding remarks.

2 Long-term inflation expectations in the euro area: drivers and trends

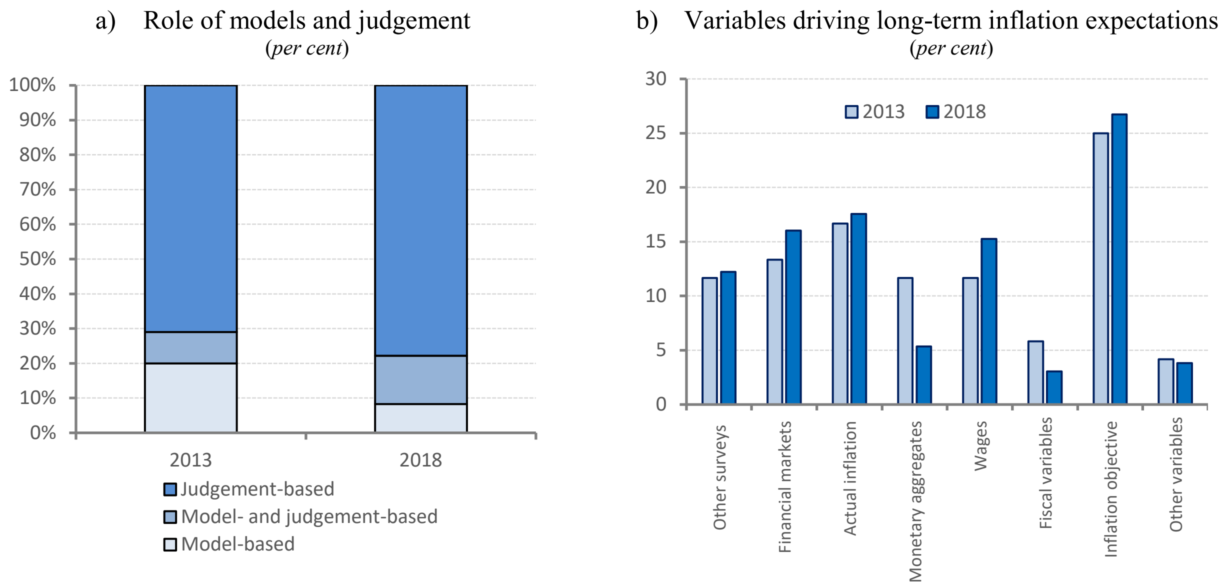
The ECB has been carrying out the SPF since 1999. The survey provides a comprehensive assessment of professional forecasters and experts' views on the euro-area macroeconomic outlook. The survey provides forecasters' views on expected inflation, real GDP growth and the unemployment rate for horizons up to five years ahead (ECB, 2019). The ECB asks participants to provide their point forecasts as well as the probability distributions. Short-term expectations are used to assess how forecasters evaluate the impact of aggregate shocks. Long-term expectations quantify forecasters' views on potential output growth, long-run unemployment and the ECB's inflation aim. The probability distributions permit an assessment of the uncertainty around the point forecasts. Long-term is the horizon between four to five years ahead.

2.1 Drivers of long-term inflation expectations

The ECB carried out three special surveys, in 2008, 2013 and 2018, to understand how participants produce their forecasts, which models they use, and the role of judgment.

The replies to the question on the role of models and judgement, which was posed in 2013 and 2018, show that forecasters rely mostly on judgement when providing their long-term inflation expectations (Figure 1, panel a). The share of these forecasters increased from 71 in 2013 to 78 in 2018. Replying to a question in the 2018 special survey on the impact of the 2013-14 disinflation on forecasting, participants said that they had increased their reliance on judgement.

Figure 1. The formation of long-term inflation expectations



Note: Panel a) shows the replies of the participants to the question: "*To what extent are your point forecasts model or judgment-based?*" Panel b) shows the replies to the question: "*Which of the following information do you typically use to form your longer-term (five years ahead) inflation expectations?*" Multiple choices were possible. *Source*: Results of the second and third special surveys. The surveys were conducted, respectively, between 16 July and 13 September 2013, and between 22 August and 14 September 2018.

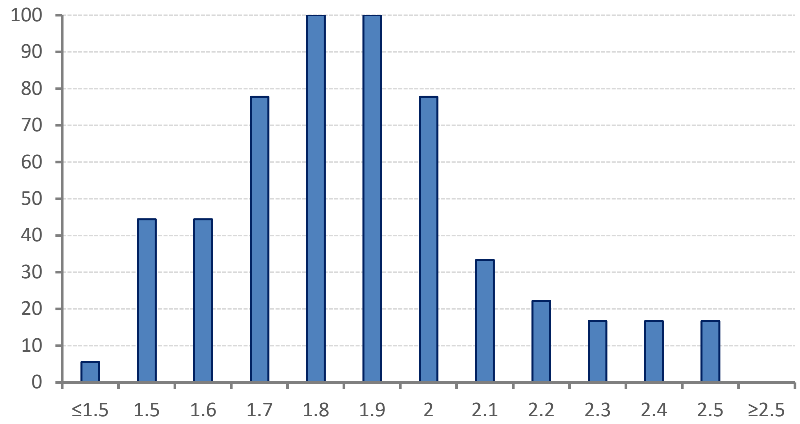
A special question was introduced in 2013 and in 2018 to find out which variables were taken into account by forecasters when forming their long-term inflation expectations. Participants replied that they relied mainly on the ECB's inflation target, on trends in actual inflation and wages, and on market-based measures of inflation expectations (ECB, 2019, and Lane, 2019). The relevance of the ECB's inflation aim, other indicators of expectations and trends in actual inflation was larger in the 2018 survey compared with the 2013 one (Figure 1, panel b).

The ECB's "*below, but close to, 2 per cent*" inflation aim has been considered vague and partly responsible for the low inflation period that began after the 2013-14 disinflation (Corsello et al., 2021), particularly in light of the increased prevalence of negative demand shocks in the second decade of the ECB's monetary policy (Rostagno et al., 2021). A clue about the meaning of the aim was provided by Otmar Issing when presenting the 2003 review of the monetary policy strategy of the ECB. Issing replied to a question on the inflation aim by referring to the 1.7-1.9 per cent range as consistent with it. Another hint was provided by the answers to a special question in the October 2020 round of the SPF. The median response implied an interpretation of the inflation aim in the 1.7-2.0

per cent range. All participants deemed 1.8 and 1.9 per cent as consistent with the inflation aim. President Draghi replying to a question about the ECB's objective during the press conference following the meeting of the Governing Council on 25 July 2019, said that "[…] *the inflation aim, which in a sense is 1.9 – it's close to, but below, 2%.*". Paloviita et al. (2020) estimate the Governing Council's loss function by combining a textual analysis on the Introductory Statements to the press conferences regarding economic outlook and the Eurosystem/ECB staff macroeconomic projections. The analysis suggests that the de facto ECB's inflation aim may have been considerably below 2 per cent. The authors show that the ECB has been more concerned about inflation above rather than inflation below 2 per cent.

Figure 2. The interpretation of the ECB's inflation aim

(*per cent*)



Note: Fraction of respondents that consider the value on horizontal axis as "[…] *in line with the ECB's price stability objective* […]". *Source*: The ECB Survey of Professional Forecasters – Fourth quarter of 2020.

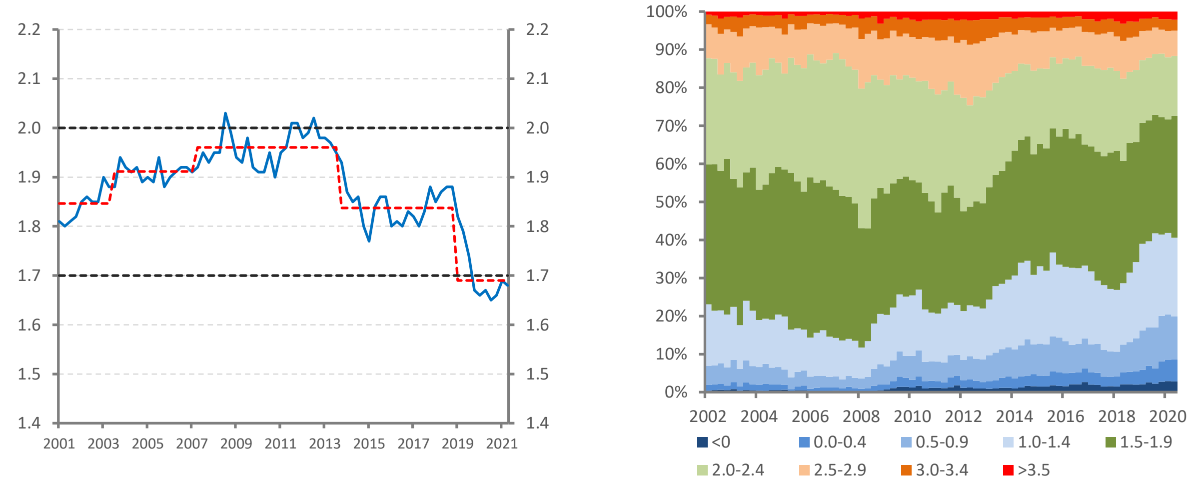
Based on the results of the special surveys, the following conclusions can be drawn. First, judgement plays a key role in the formulation of the long-term inflation expectations. Second, the definition of the ECB's inflation aim is the most important factor influencing long-term inflation expectations. Third, values in the 1.7-2.0 per cent range are considered as consistent with the ECB's inflation aim. Based on these facts, the SPF-based long-term inflation expectations can be considered a estimates/perceptions of the ECB's inflation target.

2.2 *Trends in long-term inflation expectations*

The long-term inflation expectations surveyed in the ECB SPF have undergone significant changes since its launch in 1999. In the period before the global financial crisis, long-term expectations increased from 1.8 per cent in 2001 to 1.9, on average between 2004 and 2007 (Figure 3, panel a). The review of the monetary policy strategy in May 2003 may have contributed to bringing expectations closer to 2.0 per cent. In the summer of 2008, in the context of elevated inflationary pressures also connected with potential second-round effects, SPF participants revised up their long-term inflation expectations, to just above 2.0 per cent for the first time. In the period between the global financial and the sovereign debt crises, long-term inflation expectations moved in the 1.9-2.0 per cent range. The beginning of the low inflation period in early 2013 caused a large and persistent downward revision of long-term expectations. Between early 2013 and late 2014, expectations fell by 20 basis points. After hovering around 1.8 per cent between late 2014 and early 2019, inflation expectations started falling again and rapidly, reaching a new historical minimum at 1.67 in 2019:Q4.

Figure 3. Trends in long-term inflation expectations

a) Long-term inflation expectations (*per cent*) b) Probability distribution (*per cent*)



Note: Panel a) mean point long-term inflation expectations (blue solid line) and break in the level (red dashed line) based on Bai and Perron (2003). The black dashed lines denote the range of values which are deemed compatible with the definition of the ECB's inflation aim. Panel b) aggregate probability distribution of long-term inflation expectations. *Source*: Bulligan et al. (2021).

A persistent shift in the level of long-term inflation expectations is evidence of de-anchoring. Corsello et al. (2021) and Bulligan et al. (2021) show, using the SPF, that long-term inflation expectations de-anchored from the ECB's inflation aim in 2013, when they fell sharply and became responsive to short-term negative news about current inflation. Bulligan et al. (2021) update the level-anchoring analysis in Corsello et al. (2021) and find that long-term expectations recorded a second downward shift in the first half of 2019 (Figure 3, panel a). The downward shift in late 2013 amounts to 15 basis points while the one in early 2019 to 17, on average across the different measures of expectations. The 2019 shift caused long-term expectations to fell below 1.7 per cent, the lower end of the range of values consistent with SPF analysts' interpretation of the ECB' aim (Section 2.1). The two downward shifts led to a total decline in the level of expectations by around 30 basis points. This downward adjustment is large if one considers that long-term expectations have hoovered between 1.9 and 2.0 per cent before the global financial crisis. Such a change would have been considered as small in the early eighties, when inflation rates and expectations were much higher.

The probability distribution of long-term inflation expectations has also undergone significant changes since the global financial crisis (Figure 3, panel b). The probability of inflation below 1.4 per cent in the long-term increased from around 14 per cent in 2007 to close to 40 in the second half of 2019. These developments were mirrored in the sharp decline in the probability of long-term inflation above 2 per cent, from close to 50 per cent in late 2007 to just below 30 in late 2019.

The evidence of a major decline of long-term inflation expectations in the euro area, an estimate of the ECB's inflation target, is the motivation for assessing the macroeconomic impact of changes in these expectations and the role that monetary policy can play in minimizing this impact.

3 The macroeconomic effects of changes in long-term expectations: a VAR approach

In this section, I present the VAR, focusing on its specification (Section 3.1) and the identification of the shocks (Section 3.2).

3.1 Specification

The VAR model includes four variables: the SPF long-term inflation expectations, the (log of the) price level (the Harmonized Index of Consumer Prices, HICP henceforth), (the log of) real GDP and the policy rate. The motivation for the choice of these variables is twofold. First, I want to keep the dimension of the VAR and the number of identified shocks small. Second, the variables in the VAR have counterparts in the theoretical model (Section 5) I use to rationalize the empirical findings. Appendix A provides details on the data.

In order to take the effects of unconventional measures adopted by the ECB since the global financial crisis, I use the EONIA rate up to 2008:Q3 and the shadow rate computed by Krippner (2013, 2020) for the period afterwards. Krippner (2020) estimates the shadow rate for the euro area by allowing for a time-varying effective lower bound, which is assumed to be the rate on the Eurosystem's deposit facility. The justification for using a shadow rate after late 2008 and before the adoption of asset purchases is that the ECB introduced the fixed rate full allotment procedure in all its refinancing operations in October 2008, which allowed banks to obtain all the liquidity they needed. This modality led to excess liquidity in the euro area banking system, which pushed the EONIA rate close to the lower bound of the policy corridor (the rate on the Eurosystem's deposit facility). The HICP and real GDP, which are obtained from the ECB Statistical Data Warehouse, are seasonally adjusted. As for the expectations, I use the mean point long-term inflation expectations from the SPF. I remove in each quarter the individual replies that are below the 5th and above the 95th percentiles to remove outliers. The policy rate and inflation expectations are divided by 100. In Section 7, I discuss the results obtained including oil prices in the VAR and identifying shocks to the supply of oil.

I use Bayesian methods for inference. The sample period runs from 2001:Q1 to 2019:Q4, thus ending before the outbreak of the Covid-19 pandemic in March 2020. The pandemic may have induced structural changes in the relation among the VAR variables. All the equations in the model include a constant and a linear trend. The choice of including a linear trend deserves a discussion. First, the limited size of the estimation sample does not allow me to verify the statistical properties (trend stationarity vs. unit root) of the four time series used in the VAR. Second, the identification of the shocks by means of sign restrictions (Section 3.2) does not require me to take a stance on the statistical properties of the variables. Imposing long-run restrictions to identify (technology-driven) supply shocks would require first-differencing real GDP. Third, the inclusion of a linear trend yields a companion matrix whose largest eigenvalue is in absolute value below 1 and closer to 0.9 compared with the model without the trend, whose largest eigenvalue is very close to 1. The lower maximum eigenvalue allows me to discard a much lower number of explosive draws from the posterior distribution of the reduced form VAR coefficients, which is very convenient when computing the historical decompositions. As I show in Section 7, the results are robust to assuming a unit root prior for the reduced form coefficients and to not including the linear trend.

In what follows, I briefly describe the VAR set-up. Let $\mathbf{y}_t$ be a $n\times 1$ vector of endogenous variables. Their dynamics are described by the system:

$$\mathbf{y}_t'\mathbf{A}_0 = \mathbf{c'_0} + \mathbf{c'_1}t + \sum_{j=1}^{p} \mathbf{y}_{t-j}'\mathbf{A}_j + \boldsymbol{\varepsilon}_t' \qquad \boldsymbol{\varepsilon}_t \sim i.i.d.(\mathbf{0}, \mathbf{I}_n) \quad t = 1, \ldots T \tag{1}$$

where $\mathbf{c'_0}$ and $\mathbf{c'_1}$ are two $n\times 1$ vector, $\boldsymbol{\varepsilon}_t$ $n\times 1$ vector of exogenous structural shocks, $\mathbf{A}_j$ is a $n\times n$ matrix of parameters for $0 \le j \le p$ with $\mathbf{A}_0$ invertible, p the number of lags and T the sample size. The vector $\boldsymbol{\varepsilon}_t$ is Gaussian with zero mean and covariance matrix $\mathbf{I}_n$, conditional on past information and initial conditions $\mathbf{y}_{0,} \ldots \mathbf{y}_{1-p}$.The model in (1) can be cast in the compact reduced form:

$$\mathbf{y}_t' = \mathbf{x}_t'\mathbf{B} + \mathbf{u}_t', \qquad t = 1, \ldots \ldots T \qquad , \tag{2}$$

where $\mathbf{A}_+' = [\mathbf{A}_1' \ldots \mathbf{A}_p' \; \mathbf{c'_0} \; \mathbf{c'_1}]$, $\mathbf{B} = \mathbf{A}_+\mathbf{A}_0^{-1}$, $\mathbf{u}_t' = \boldsymbol{\varepsilon}_t'\mathbf{A}_0^{-1}$, and $\mathbb{E}[\mathbf{u}_t\mathbf{u}_t'] = \boldsymbol{\Sigma} = (\mathbf{A}_0\mathbf{A}_0')^{-1}$. The matrices $\mathbf{B}$ and $\boldsymbol{\Sigma}$ are the reduced-form parameters, while $\mathbf{A}_0$ and $\mathbf{A}_+$ are the structural parameters. Identifying the shocks amounts to providing a mapping from $\mathbf{B}$ and $\boldsymbol{\Sigma}$ to $\mathbf{A}_0$ and $\mathbf{A}_+$.

The number of lags p is set to four, based on the serial correlation of the residuals. As for the prior distribution, I assume a normal distribution for the VAR coefficients, with a structure similar to the so-called Minnesota prior (Litterman, 1986 and Doan et al., 1983), and a diffuse prior for the covariance matrix $\boldsymbol{\Sigma}$. The mean of the prior of the coefficients of the own first lag is set to autoregressive coefficient estimated for each variable in a model including also a constant and the linear trend. The four autoregressive coefficients range between 0.9 and 0.98.[2] The overall tightness is set to 0.20 (κ_1). The tightness of the variance of the prior of each variable lags relative to the lags of the others is set to 0.5 (κ_2). The variance of the prior coefficients of the lags of each variable is assumed to follow a harmonic decay $l^{-0.5}$ ($\kappa_3 = 0.5$). The priors for the constant and the coefficients on the linear trend are normal with zero mean and standard deviation (κ_4) equal to 100. The posterior distribution of the reduced-form parameters $\mathbf{B}$ and the covariance matrix $\boldsymbol{\Sigma}$, which is obtained by combining the normal likelihood of the VAR with the prior distribution, is normal-inverse Wishart. Inference is conducted using Gibbs sampling. Appendix B provides the details on the prior distributions and the inference.

3.2 Identification

The identification of the shocks combines the sign restrictions proposed by Canova and De Nicolò (2002) and Uhlig (2005) and refined by Rubio-Ramírez et al. (2010), zero restrictions, the narrative restrictions proposed by Antolín-Díaz and Rubio-Ramírez (2018) and the restrictions on the variance decomposition proposed by Uhlig (2004) and recently extended by Volpicella (2021).

In the baseline model, I focus the analysis on a parsimonious set of structural shocks that are relevant for studying inflation and long-term inflation expectations. Given the small size of the VAR, which facilitates the comparison with the theoretical model proposed in Section 5, I identify four shocks: aggregate demand and aggregate supply shocks, monetary policy shocks and shocks to long-term

[2] More precisely, the mean of prior of the own lag coefficients is 0.9 for long-term inflation expectations, 0.98 for the log of the HICP, 0.96 for the log of real GDP and 0.90 for the policy rate.

inflation expectations. I do not include oil prices in the VAR and hence I do not identify shocks to the supply or the demand of oil. I assume that the former shocks are captured by aggregate supply shocks. In Section 7, I assess the robustness of the results to the identification of oil supply shocks. Shocks to the demand for oil are assumed to be captured by aggregate demand shocks. The sign and zero restrictions are reported in Table 1. I rely on the algorithm by Mountford and Uhlig (2009) for imposing zero and sign restrictions. The results are robust to using the one by Arias et al. (2018).

Table 1. Sign and zero restrictions

Variable / shock	Aggregate demand	Aggregate supply	Inflation expectations	Monetary policy
Long-term inflation expectations	0	0	-	?
Consumer prices	+	-	-	-
Real GDP	+	+	?	-
Policy rate	+	?	-	+

Note: a 0 means that the variable in the row does not respond on impact to the shock in the column. A – means that the response is negative, a + means that it is restricted to be positive. A ? means that the impact response is unrestricted.

A crucial assumption for the implementation of the sign-restrictions is the number of periods over which the restrictions are imposed. Canova and Paustian (2011) show that sign restrictions imposed on the contemporaneous relationships among variables are robust to possible misspecifications of the model used to derive the restrictions. I thus impose the restrictions on the impact responses.

A positive (favourable) aggregate supply shock leads to a fall of consumer prices and to an increase in output on impact. A positive aggregate demand shock leads both variables to increase and the ECB to raise the policy rate. Long-term inflation expectations are assumed not to respond on impact to aggregate demand and supply shocks.[3] These identifying assumptions are similar to those in Geiger and Scharler (2020). I deem reasonable to assume that supply and demand shocks do not lead to an immediate revision of long-term inflation expectations. Agents may revise these expectations if they perceive monetary policy as not reacting adequately to demand and supply shocks. In this sense, allowing the policy rate to respond systematically to these shocks may be a reasonable way to indirectly capture the impact of these shocks on long-term inflation expectations.

A monetary policy shock raises the policy rate and causes a decline in consumer prices and output. The response of expectations to monetary policy shocks is not restricted, as in Diegel and Nautz (2021).[4] This assumption allows me to conduct the counterfactual simulations (Section 6.1) to assess the role of monetary policy.

A negative shock to inflation expectations causes an immediate decline in consumer prices and leads to a reduction in the policy rate on impact. The latter restriction is meant to capture the concern of the central bank for long-term expectations over and above the concern for the impact of aggregate demand and supply shocks on expectations. In addition, the restriction is much weaker than the one

[3] The results are robust to assuming that long-term inflation expectations respond on impact to aggregate demand and aggregate supply shocks and that real GDP does not respond on impact to shocks to long-term inflation expectations. In this case, the total number of accepted draws is around 4,800, well below the around 20,000 in the baseline (Section 4).
[4] The results are robust to assuming that inflation expectations fall on impact after a contractionary monetary policy shock.

assumed in the existing literature. For instance, Diegel and Nautz (2021) impose that the policy rate reacts to any change in long-term inflation expectation, independently from the type of shock. In this paper, instead, I assume that the policy rate reacts only to changes in long-term inflation expectations that are driven by inflation expectation shocks. Putting it differently, I impose a "conditional" rather than an "unconditional" restriction. The impact response of output to a shock to long-term expectations is left unrestricted.

As for the narrative identification, based on the evidence in Section 2 on the downward level-shifts in long-term inflation expectations, I make the following two identifying assumptions. First, the shock to inflation expectations is negative in 2019:Q2. This assumption is based on the evidence in Corsello et al. (2021) and Bulligan et al. (2021), which is discussed in Section 2. Second, I assume that the contribution of the shocks to long-term inflation expectations in 2019:Q2 is larger, in absolute value, than the contribution of the monetary policy shock (Antolín-Díaz and Rubio-Ramírez, 2018), the only other shock that contemporaneously affects long-term inflation expectations. I assume that the monetary policy shock is negative in 2014:Q3, when the ECB cut the deposit facility rate by 10 basis points, bringing it to -0.20 per cent (from -0.10 reached in 2014:Q2). This restriction is based on the evidence in Altavilla et al. (2019). In September 2014, the announcement of the policy rate cut led to a sharp decline in very short-term money market rates. Only 7 per cent of the analysts interviewed by Reuters a few days before the meeting of the Governing Council were expecting a policy rate cut.

As for the restrictions on the variance decomposition, I assume, following Volpicella (2021) and based on the evidence in Figure 1, that shocks to expectations account for no less than 60 per cent of the variance of the forecast error of long-term inflation expectations at the 40 quarter horizon.

4 Results

Inference is based on 50,000 draws from the posterior distribution of the reduced form parameters of the VAR (eq. 3) and, for each of them, 100 draws from the unitary sphere. I discard around 6,300 draws (out of 50,000) from the posterior distribution of the VAR, as the maximum eigenvalue of the associated companion matrix implies explosive dynamics. Around 20,000 draws are retained for inference, on average 1.6 draws (out of 100) from the unitary sphere for each draw from the posterior distribution of the VAR. Without imposing the narrative restrictions, the number of accepted draws increase to around 87,000 draws, on average 2.45 draws from the unitary sphere for each draw from the posterior distribution of the VAR. Finally, without the restriction on the variance decomposition, the number of total accepted draws increases to around 154,000, on average 3.67 draws from the unitary sphere.

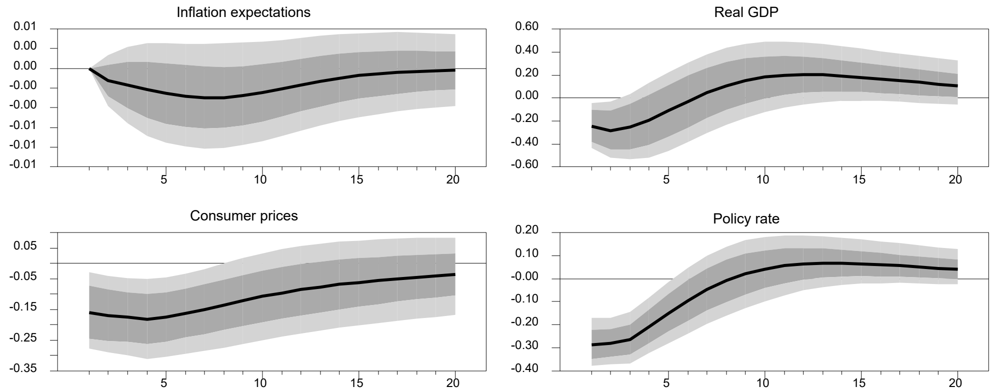
As for the impulse responses (Figures 4 to 7), I report the median (red solid lines) and mean responses (blue dashed lines), the 0.16-0.84 percentiles range (dark grey shaded area) and the 0.05-0.95 percentiles range (light grey shaded area) of the marginal distribution at each step of the impulse horizon. As for the historical decompositions (Figures 8 to 11), I report the mean of the marginal posterior distributions in each quarter.

4.1 Impulse responses

Aggregate demand shock. A negative demand shock causes a decline of consumer prices and leads the ECB to accommodate the shock by lowering the policy rate (Figure 4). The range delimited by the 0.16 and 0.84 percentiles of the posterior distribution of the response of consumer prices is negative for the first six quarters while that of the policy rate is negative up to 4 quarters after the shock. After two years, the probability that prices are below the unshocked path is around 95 per cent.

Figure 4. Impulse response to a negative aggregate demand shock

(*per cent and percentage points; deviation from unshocked path*)



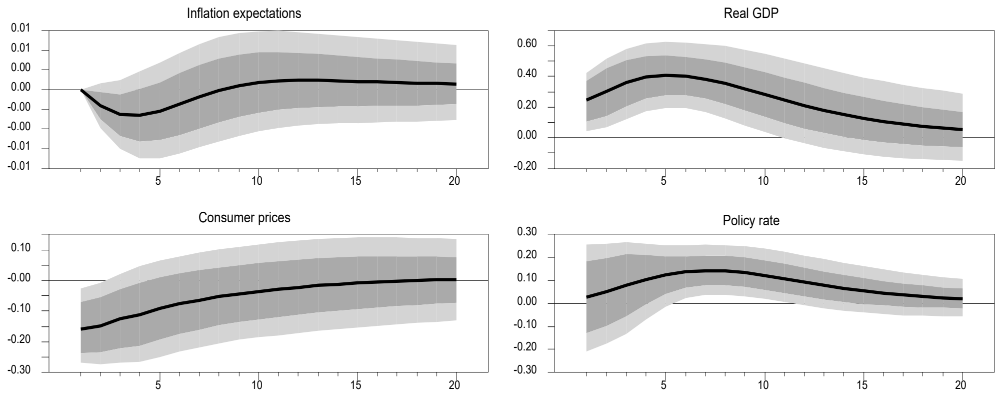
Note: the black solid line refers to the median and the mean of the marginal posterior distributions at each step. The dark grey area denotes the range delimited by the 0.16 and 0.84 percentiles of the posterior distribution. The light grey area denotes the range delimited by the 0.05 and 0.95 percentiles.

The response of real GDP is rather short-lived; it is negative for the first two quarters, according to the 0.16-0.84 range. The fall in inflation expectations is temporary and reaches a minimum after three quarters. At that horizon, the probability that expectations are below the unshocked path is 75 per cent, suggesting that long-term inflation expectations are quite responsive to demand shocks.

Aggregate supply shock. A positive supply shock causes output to increase quite persistently, while the response of consumer prices is very short-lived (Figure 5). The 0.16-0.84 range of the response of output is positive for up to ten quarters.

Figure 5. Impulse response to a positive aggregate supply shock

(*per cent and percentage points; deviation from unshocked path*)

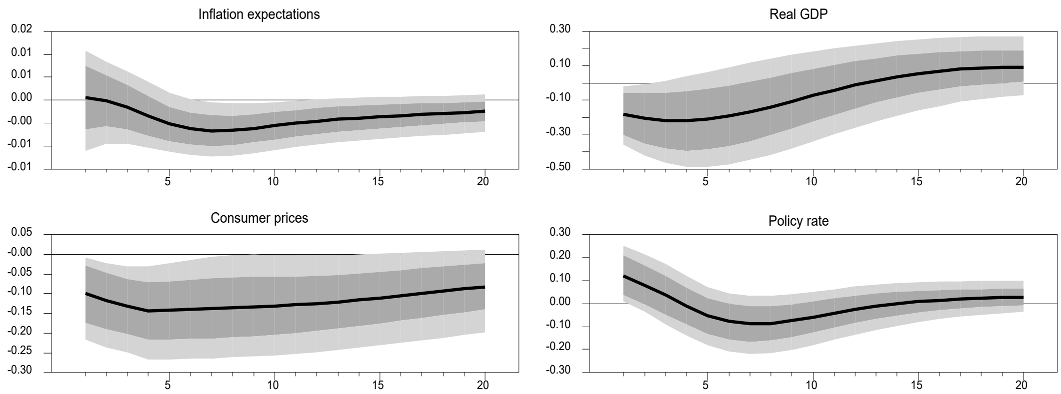


Note: see Figure 4.

The same range for the response of the policy rate is positive in the second year, suggesting a tightening of the monetary policy stance in response to the persistent increase in output, which is not accompanied by inflationary pressures. The 0.16-0.84 range of the response of inflation expectations always includes the zero line, suggesting that supply shocks have no impact on inflation expectations.

Monetary policy shock. A contractionary (positive) monetary policy shock causes a short-lived increase in the policy rate and a persistent decline of consumer prices and inflation expectations (Figure 6). The probabilities that the response of the price level and inflation expectations are negative after 16 quarters are slightly above 90 per cent. Output declines, reaching a minimum after 4 quarters. At that horizon, the probability that the response is negative is around 90 per cent.

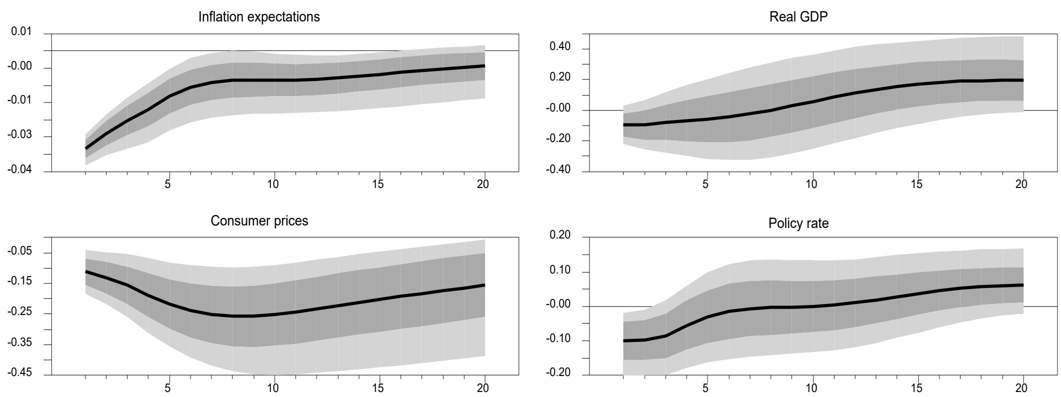
Figure 6. Impulse response to a contractionary monetary policy shock
(*per cent and percentage points; deviation from unshocked path*)



Note: see Figure 4.

Expectation shock. A negative shock to long-term inflation expectations causes consumer prices to fall persistently and the ECB to immediately reduce its policy rate (Figure 7). With a probability of 95 per cent, the response of consumer prices is still negative after four years. This result is highly relevant for assessing the contribution of shocks to expectations to inflation, considering that the sign of the impulse response of inflation is restricted only on impact.

Figure 7. Impulse response to a negative shock to long-term inflation expectations
(*per cent and percentage points; deviation from unshocked path*)



Note: see Figure 4.

López-Salido and Loria (2020) estimate quantile Phillips curve models, which include long-term inflation expectations, and find that a sustained decline in these expectations poses serious downside risks to inflation. This effect is larger in the euro area compared with the U.S.

The probability that output declines on impact is close to 60 per cent; after 10 quarters, the probability that the response of real GDP is positive is 90 per cent. The gradual increase is related to the expansionary monetary policy, which causes a decline in the real policy rate (the policy rate net of current year-on-year inflation).

To sum up, the impulse responses highlight a potential role for shocks to long-term inflation expectations to drive inflation and influence ECB's monetary policy. An expansionary monetary policy can lead to a persistent increase in long-term inflation expectations, which is an important finding in light of the quotation from President Draghi at the beginning of the Introduction. Shocks to long-term expectations account for the largest share of the variance of the forecast error of inflation expectations (close to 90 per cent in the first year and just above 70 per cent after ten years) and explain 45 per cent of that of consumer prices in the long run (Figure D1 in the Appendix).

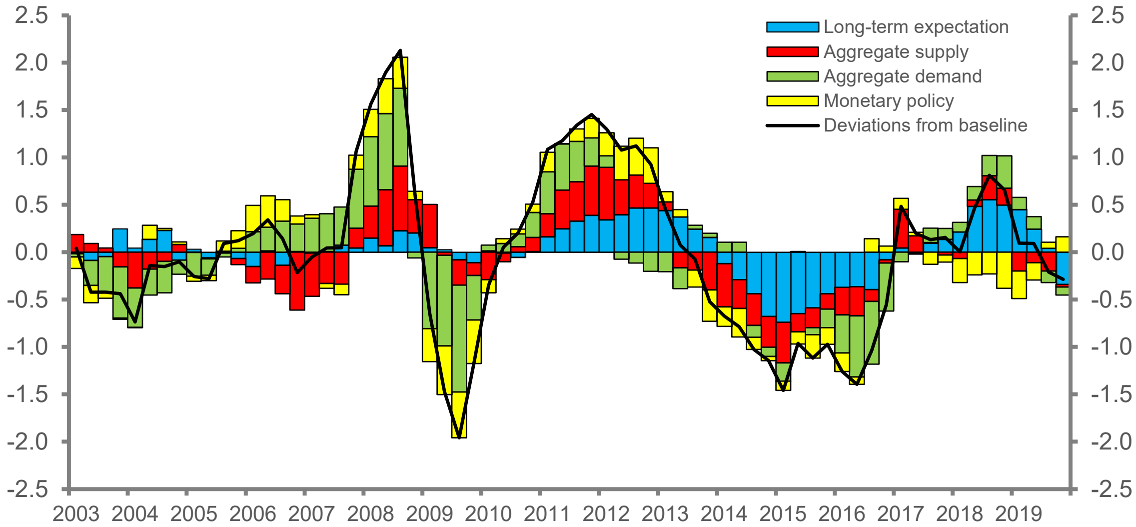
4.2 Historical decompositions

In this section, I discuss the results of the historical decomposition of (year-on-year) inflation and (year-on-year) real GDP growth, the policy rate and long-term inflation expectations, focusing mainly on the period that followed the 2013 disinflation. The charts show the mean values of the posterior distribution of the contributions of the various shocks to each variable in each quarter of the period 2003-2019. For readability and in line with common practices, I do not report the percentiles of the posterior distribution of the contributions.

In the "low inflation" period, which began in early 2013, inflation was pushed below the baseline by all shocks, although shocks to aggregate supply and to long-term inflation expectations played a major role (Figure 8).

Figure 8. Historical decomposition: inflation

(*percentage points; deviation from the baseline*)



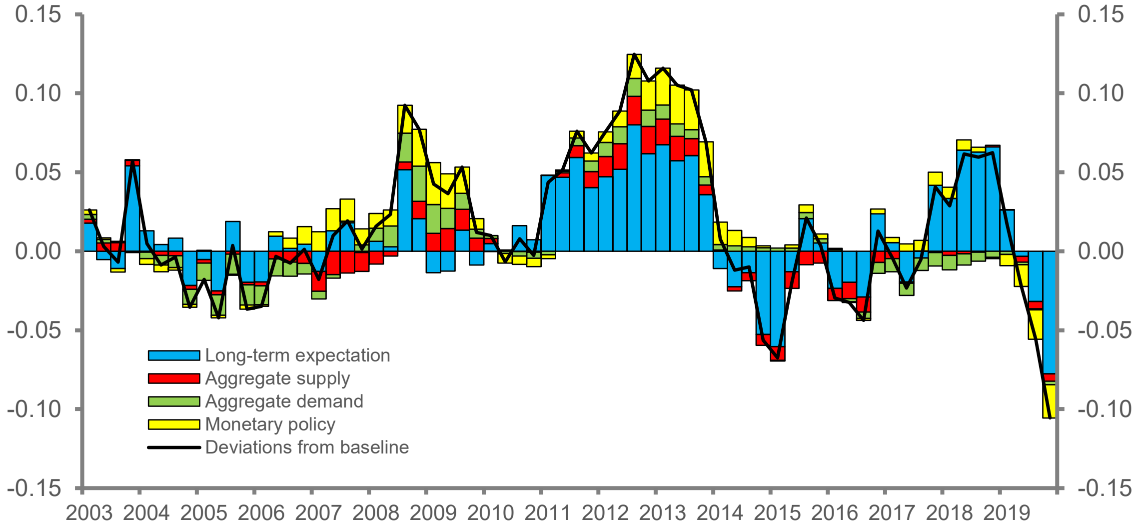
Note: the contribution of each shock to the deviation from the baseline is the mean of the posterior distribution in each quarter.

Monetary policy shocks also exerted a negative downward pressure on inflation between late 2013 and early 2016, with a maximum negative contribution of 0.25 percentage points in 2015:Q3. Afterwards, negative shocks to long-term inflation expectations exerted a persistent downward pressure on inflation, which lasted until late 2016. The maximum impact of shocks to inflation expectations during the 2013-2014 disinflation was reached in 2015:Q1 (-0.7 percentage points). In 2019:Q4, the contribution of negative shocks to inflation expectations to inflation was around -0.35 percentage points. Positive shocks to long-term expectations had a positive effect on inflation in 2018 and in the first half of 2019. Positive shocks to expectations pushed inflation upward in 2011 and 2012. Bobeika and Jarocinski (2019) estimate a VAR and find that domestic factors explain much of the euro-area inflation dynamics during the 2012-14 missing inflation episode. Conti, Neri and Nobili (2017) find, using a VAR, that shocks to aggregate demand and monetary policy shocks played an important role in bringing inflation at low levels during the 2013-14 disinflation. In that period, the lower bound to the ECB's policy rates turned conventional monetary policy de facto contractionary.

Shocks to long-term expectations are the major driver of inflation expectations throughout the whole sample (Figure 9). The fall in expectations between late 2013 and mid-2015 is mainly the result of shocks to expectations, as it is the case in the period of recovery of the expectations in 2017 and 2018. Large negative shocks occurred also in the second half of 2019. Negative aggregate demand shocks kept inflation expectations low in 2016 and 2018. Monetary policy shocks exerted a positive impact on long-term inflation expectations in most of the quarters of the sample.

Figure 9. Historical decomposition: long-term inflation expectations

(*percentage points; deviation from the baseline*)

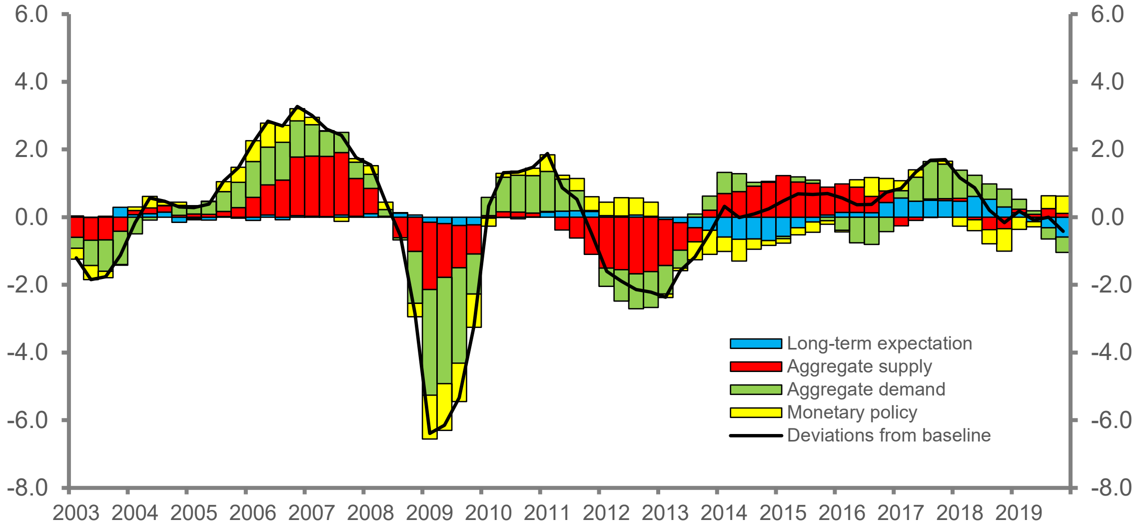


Note: see Figure 8.

Real GDP growth is driven mainly by aggregate demand and aggregate supply shocks (Figure 10). Monetary policy shocks are also an important driver of output fluctuations. After the most acute phase of the sovereign debt crisis, monetary policy shocks exerted a negative and significant impact on real GDP growth until early 2016, when the ECB recalibrated its APP and adopted other policy measures to support economic activity and inflation (Neri and Siviero, 2018). Negative shocks to aggregate demand had a large impact on economic activity between 2012 and 2013. Negative aggregate supply shocks played a major role during the most acute phase of the sovereign debt crisis, while positive shocks raised GDP growth between 2014 and 2017. As I show in Section 7, aggregate supply shocks also capture the impact of oil supply shocks. Finally, shocks to long-term inflation expectations had a negative impact on real GDP growth between 2013 and late 2015 and in 2019.

Figure 10. Historical decomposition: real GDP growth

(*percentage points; deviation from the baseline*)

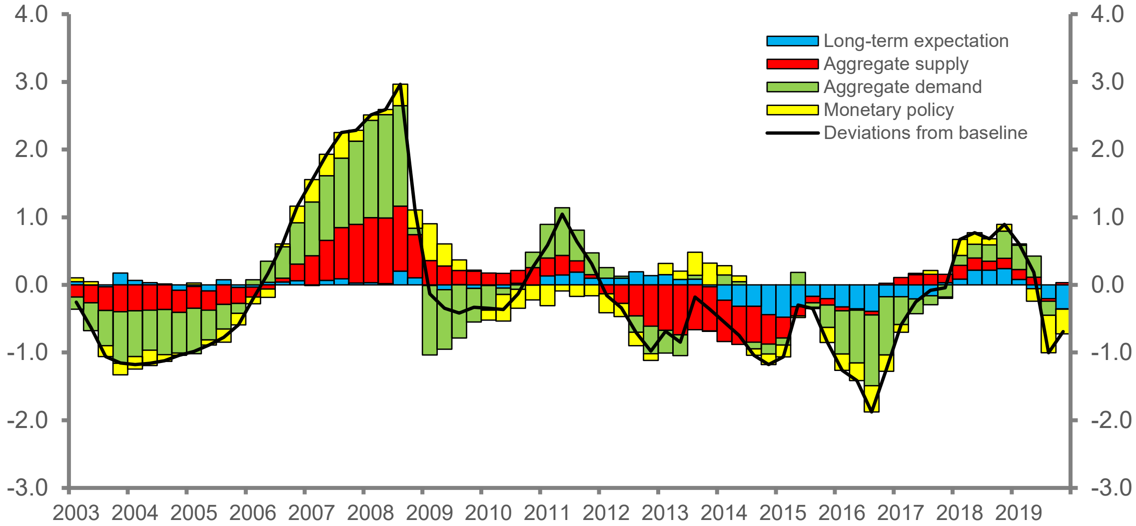


Note: see Figure 8.

Lastly, Figure 11 shows the contribution of the shocks to the policy rate. Positive monetary policy shocks pushed the policy rate above its baseline in 2013 and 2014, providing evidence of a tight monetary policy stance, in line with Conti, Neri and Nobili (2017). It was only in mid-2014, when the ECB adopted a very accommodative monetary stance, that negative monetary policy shocks exerted a downward pressure on the policy rate.

Figure 11. Historical decomposition: policy rate

(*percentage points; deviation from the baseline*)



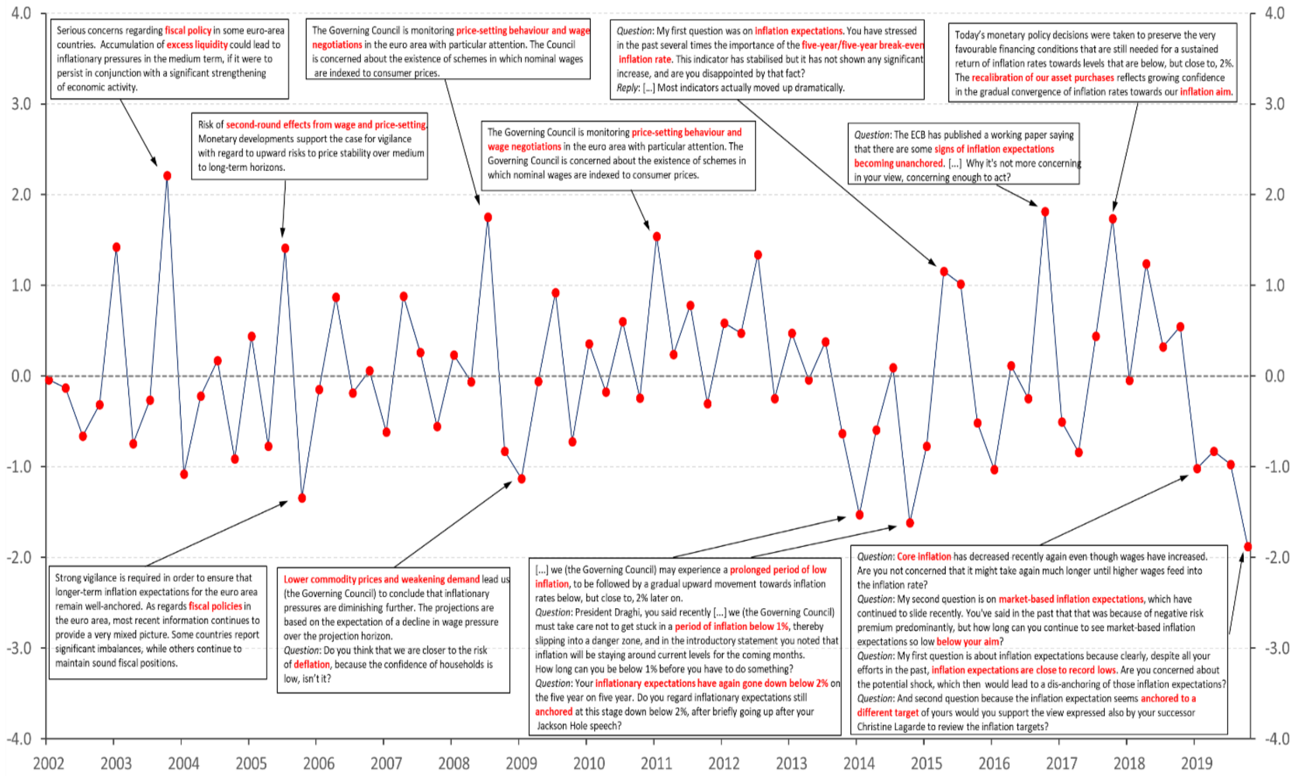
Note: see Figure 8.

Large and persistent negative aggregate demand shocks contributed to keeping the policy rate below the baseline between 2015 and 2017. Negative shocks to long-term expectations led to a decline in the policy rate between 2014 and 2017, suggesting that the ECB's monetary policy responded to the decline in long-term inflation expectations. Shocks to expectations contributed to the negative deviations of the policy rate from its baseline in 2019. These negative deviations deserve particular attention, as the adjustments occurred after the beginning of the normalization of the ECB's accommodative monetary policy stance in 2018.

4.3 Interpreting the identified shocks to long-term inflation expectations

In this section, I offer an interpretation of the identified shocks to long-term inflation expectations (Figure 12). I consider the press conferences following the monetary policy meeting of the Governing Council immediately before the deadline for the submission of forecasters' replies to the SPF questionnaire and I look at both the statement and the questions posed by the attending journalists. I concentrate my attention to the issues that, according to the 2013 and 2018 SPF special questionnaires, influence forecasters' expectations on long-term inflation (Figure 1, panel b). The reason for considering the press conferences is that the participants to the SPF are likely to pay a high degree of attention to the information released by the President of the ECB during the press conference. The objective of the analysis is simply to gather information that may have played a role in shaping SPF participants' long-term inflation expectations.

Figure 12. Shocks to long-term inflation expectations



Note: the chart shows the posterior median (for each quarter) of the identified shocks. Each box contains selected texts from the Introductory Statements preceding the period during which SPF participants replied to the survey. The selected texts are meant to be only a simplified description of the issues touched upon during the press conferences. When relevant, questions from the journalists attending the press conference are also reported. The selection of the topics is based on the results of the special rounds conducted in 2013 and 2018 (Figure 1, panel a). The topics are highlighted in red. Figure D4 in the appendix shows the figure vertically.

Source: Introductory Statements to the press conference; https://www.ecb.europa.eu/press/pressconf/html/index.en.html.

Between 2002 and 2005, positive shocks to long-term expectations may have captured SPF participants' concerns about too loose fiscal policies and excess money and credit growth. The possibility of second round effects in wage and price setting may have led forecasters to revise upward their long-term inflation expectations between 2005 and 2008 and in 2011, resulting in positive shocks. Concerns regarding the existence of schemes in which nominal wages are indexed to consumer prices may have also contributed to the positive shock in 2008:Q3.

After the outbreak of the global financial crisis, the risk of deflation may have pushed inflation expectations downward, resulting in a negative shock in 2008:Q4 and 2009:Q1. In 2014 (Q1 and Q4), concerns about the risk of too low inflation for too long, the persistent decline of market-based indicators of inflation expectations (e.g. the 5y-5y break-even inflation rate), and the risk of the ECB falling behind the curve, may have contributed to large negative shocks. The introduction of the APP in January 2015, and its subsequent recalibrations, led SPF participants to revise upward their long-term inflation expectations (2015:Q2 and 2017:Q4), confident that this measures would allow the ECB to raise inflation to its aim and would contributed to keeping long-term inflation expectations close to the inflation target. The largest shocks between 2015 and 2017 are all positive.

Finally, all shocks in 2019 are negative, possibly capturing participants' concerns about low inflation extending beyond the medium-term after the end of the active phase of the APP in December 2018. The largest negative shock occurred in 2019:Q4. At the September press conference, President Draghi said that "*inflation expectations are not de-anchoring but are re-anchoring at levels between zero and 1.5% which is not our aim*" (see the quotation at the beginning of the Introduction).

5 Assessing the empirical evidence through the lens of a small DSGE model

In this section, I describe the features of a small-scale new Keynesian DSGE model I use for assessing the macroeconomic effects of changes in expectations and the role of monetary policy.

The economy is populated by a representative household, a representative finished-goods-producing firm, a continuum of intermediate-goods-producing firms and a central bank (see, e.g. Clarida et al., 1999 and Woodford, 2003). The two main differences with respect to the standard small-scale models are the use of adjustment costs à la Rotemberg (1982) for introducing price stickiness and the presence of a time-varying perceived inflation target. The central bank sets the policy rate according to a Taylor-type rule. I do not model the zero lower bound and unconventional monetary policies. The counterfactual exercise I carry out with the DSGE model (Section 6.2) does not require modelling the lower bound to the policy rate.

The model is taken from Neri and Ropele (2019), who use it to show that under imperfect information, when the central bank's inflation target is not perfectly observed, favourable cost-push shocks, which would usually raise output, have contractionary effects, as agents erroneously perceive a temporary reduction in the target. Neri and Ropele (2019) also show that this contractionary effect is amplified when monetary policy is constrained by the lower bound on the policy rate. I do not consider an imperfect information set up and I assume that shocks are perfectly observed. Carboni and Ellison (2011) set up a model in which the central bank has better information about its objectives than the private sector, while the latter has better information about the shocks than the central bank.

5.1 The model

The representative household

The representative household lives forever. Her expected lifetime utility is:

$$E_0 \sum_{t=0}^{\infty} \beta^t \{log(C_t - \gamma \bar{C}_{t-1}) - H_t\} \qquad , \tag{3}$$

where E_0 is the expectation operator conditional on time $t=0$ information and $\beta \in (0,1)$ is the discount factor. The instantaneous utility function is increasing in the consumption of a final good (C_t) relative to a level γ of external habit ($\bar{C}_{t-1}$) and decreasing in hours worked (H_t). In each period, the representative household faces the budget constraint:

$$P_t C_t + B_t \leq P_t w_t H_t + (1 + i_{t-1}) B_{t-1} + F_t \tag{4}$$

where P_t is the price of the final good, B_t the holding of bonds offering a one-period nominal return i_t, w_t the real wage, and F_t the firms' profits, which are returned to the representative household.

The representative household's problem is to maximize (3) subject to the sequence of budget constraints in (4). The maximization yields the first order conditions:

$$u_{c,t} = (C_t - \gamma \bar{C}_{t-1})^{-1} \tag{5}$$

$$1 = u_{c,t} w_t \tag{6}$$

$$u_{c,t} = \beta (1 + i_t) E_t \left(\frac{u_{c,t+1}}{P_{t+1}/P_t} \right) \qquad , \tag{7}$$

where $u_{c,t}$ is the marginal utility of consumption.

Final good producers

In each period, a final good Y_t is produced by perfectly competitive firms using a continuum of intermediate inputs $Y_{i,t}$ indexed by $i \in (0,1)$ and a standard CES production function:

$$Y_t = \left[\int_0^1 Y_{i,t}^{(\theta-1)/\theta} di \right]^{\theta/(\theta-1)} \qquad , \tag{8}$$

with $\theta > 1$. Taking prices as given, the final good producer chooses intermediate good quantities $Y_{i,t}$ to maximise profits, which results in the usual demand schedule. The zero profit condition of final good producers delivers the aggregate price index:

$$P_t = \left[\int_0^1 P_{i,t}^{1-\theta} di \right]^{1/(1-\theta)} \qquad . \tag{9}$$

Intermediate goods producers

Intermediate goods $Y_{i,t}$ are produced by a continuum of firms, $i \in (0,1)$, with the following linear technology in labor:

$$Y_{i,t} = H_{i,t} \qquad . \tag{10}$$

Prices are sticky. Intermediate goods producers are monopolistically competitive and set prices taking into account the demand for their goods and the costs for adjusting the prices.

I assume a generalized quadratic adjustment cost mechanism à la Rotemberg (1982), which I borrow from Ireland (2007):

$$\Gamma_{i,t} = \frac{\phi}{2}\left\{\frac{P_{i,t}}{\left[\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}\right]P_{i,t-1}} - 1\right\}^2 Y_t \tag{11}$$

where $\phi \geq 0$ measures the magnitude of the adjustment cost, $\Pi_t \equiv P_t/P_{t-1}$, Π_{t-1} is the (gross) inflation rate between periods *t-2* and *t-1*, Π_t^* denotes firms' perception of the central bank's time-varying inflation target, and $\alpha \in (0,1)$ measures the degree of intermediate firms' price indexation to last period inflation. When α =0, intermediate firms adjust their prices in line with the perceived inflation target and the Phillips curve relation becomes purely forward looking. When α = 1, intermediate firms adjust prices in line with the previous period's inflation rate. In this case, the backward-looking term in the Phillips curve becomes approximately equal in importance to the forward-looking term.

The problem for the intermediate firm *i* is:

$$\max_{\{P_{i,t}\}_{t=0}^{\infty}} E_t \sum_{j=0}^{\infty} \frac{\beta^j u_{c,t+j}}{u_{c,t}}\left\{\frac{P_{i,t+j}}{P_{t+j}}Y_{i,t+j} - MC_{i,t+j}^r Y_{i,t+j} - \Gamma_{i,t+j}\right\} \tag{12}$$

$$\text{subject to: } Y_{i,t+j} = \left[\frac{P_{i,t+j}}{P_{t+j}}\right]^{-\theta} Y_{t+j} \quad ,$$

where $MC_{i,t+j}^r = w_{t+j}$ is the real marginal cost. All the firms face the same problem, and thus will choose the same price and output: $P_{i,t} = P_t$ and $Y_{i,t} = Y_t$ for every *i*. Hence, exploiting the symmetry of the equilibrium, the first-order condition for the maximization problem yields:

$$\theta - 1 = \theta w_t - \phi\left[\frac{\pi_t}{\pi_{t-1}^{\alpha}(\pi_t^*)^{1-\alpha}} - 1\right]\frac{\pi_t}{\pi_{t-1}^{\alpha}(\pi_t^*)^{1-\alpha}} +$$

$$+\beta\frac{u_{c,t+1}}{u_{c,t}}\phi\left[\frac{\pi_{t+1}}{\pi_t^{\alpha}(\pi_{t+1}^*)^{1-\alpha}} - 1\right]\frac{\pi_{t+1}}{\pi_t^{\alpha}(\pi_{t+1}^*)^{1-\alpha}}\frac{Y_{t+1}}{Y_t} \quad . \tag{13}$$

Monetary policy

The central bank sets the policy rate i_t according to the generalized Taylor (1993) rule:

$$1 + \mathrm{i}_t = (1+\bar{\mathrm{i}})\left(\frac{1+\mathrm{i}_{t-1}}{1+\bar{\mathrm{i}}}\right)^{\phi_i}\left(\frac{\pi_t}{\bar{\pi}}\right)^{(1-\phi_i)\phi_\pi}\left(\frac{Y_t}{Y_{t-1}}\right)^{(1-\phi_i)\phi_y} \quad , \tag{14}$$

where $\phi_i \in [0,1]$, $\phi_\pi \in [0,\infty)$ and $\phi_y \in [0,\infty)$. The central bank increases the policy rate whenever inflation is above its target $\bar{\pi}$, which is assumed to be perfectly known by the central bank, and when output increases above its previous level. Provided that $\phi_i \in (0,1]$, the monetary policy rule exhibits inertia. I assume that the central bank knows the inflation target $\bar{\pi}$.

Firms, in setting prices, rely on their perception of the inflation target. Following Gürkaynak et al. (2005), I assume that the perceived target evolves according to the following equation, in which the variables are expressed in terms of deviations from steady state (denoted with a hat):

$$\hat{\pi}_t^* = \rho_{\pi^*}\hat{\pi}_{t-1}^* + \mu\left(\frac{1}{4}\sum_{j=1}^{4}\hat{\pi}_{t-1-j} - \hat{\pi}_{t-1}^*\right) + \varepsilon_{\pi^*,t} \quad , \tag{15}$$

where $\widehat{\pi}_t^*$ represents the perceived target, $\rho_{\pi^*} \in (0,1)$ and $\varepsilon_{\pi^*,t} \sim N(0, \sigma_{\pi^*}^2)$. The parameter μ, the gain, measures the strength with which firms revise their perceptions about the target on the basis of the deviations of past inflation rates from the previous period perceptions. A period of inflation below the perceived target leads agents to revise downward their estimate of the central bank's inflation target. The shock $\varepsilon_{\Pi^*,t}$ captures exogenous changes in firms' perceptions about the target. I assume that the perception about the target is the theoretical counterpart to the long-term inflation expectations used in the VAR analysis.[5] There are other channels, which I do not model, through which changes in long-term inflation expectations affect inflation and economic activity. For example, change in these expectations affect long-term interest rate, thus affecting consumption and investment. The model I use is the simpliest one to rationalize the transmission of shocks to the perception of the target to inflation and output.

5.2 The log-linearized model

The model is closed with a resource constraint, where output is equal to the sum of consumption and to costs paid by the intermediate firms to adjust prices. The equations of the model are log-linearized around the deterministic steady state. For any variable x_t, let $\hat{x}_t = \log(X_t)/\log(\bar{X})$.

The linearized model is given by the following set of equations:

$$\frac{1+\gamma}{1-\gamma}\hat{y}_t = \frac{\gamma}{1-\gamma}\hat{y}_{t-1} + \frac{1}{1-\gamma}y_{t+1|t} - \left(\hat{\imath}_t - \hat{\pi}_{t+1|t}\right) \tag{16}$$

$$(1+\alpha\beta)\hat{\pi}_t = \alpha\hat{\pi}_{t-1} + \beta\hat{\pi}_{t+1|t} + \frac{1}{\phi}\left(\frac{\theta-1}{1-\gamma}\right)(\hat{y}_t - \gamma\hat{y}_{t-1}) + (1-\alpha)(1-\beta\rho_\Pi)\hat{\pi}_t^* \tag{17}$$

$$\hat{\imath}_t = \phi_i\hat{\imath}_{t-1} + (1-\phi_i)\left[\phi_\pi\hat{\pi}_t + \phi_y(\hat{y}_t - \hat{y}_{t-1})\right] + \varepsilon_t^R \ , \tag{18}$$

to which eq. (15) is added. Equation (16) is a standard hybrid IS curve in which current output depends positively on lagged and next period expected output and is inversely related to the ex ante real interest rate. Equation (17) is a hybrid new-Keynesian Phillips curve where current inflation is a function of output, past and future expected inflation, and of the perceived inflation target. While the central bank responds to the deviations of inflation from the target $\hat{\pi}_t$, firms set their prices taking into account their perception of the target, $\widehat{\pi}_t^*$, which differ from the central bank's target. A decline in the perceived target exerts a downward impact on inflation. The central bank responds to the decline in inflation by lowering the policy rate. As the policy rate falls by more than expected inflation, the fall in the real policy rate raises output through the IS curve. The increase in output causes firm to raise their prices, leading to an increase in inflation. Firms revise their perceived target as inflation falls below their previous period perception. The interaction between inflation and the perception of the target, which is in line with the empirical findings in Corsello et al. (2021), can lead to a persistent decline in inflation.

[5] The small size of the model does not allow me to model the perception of the inflation target of households and investors in financial markets.

5.3 Calibration

In this section, we discuss the calibration of the parameters of the DSGE model. The starting point of the calibration is based on Neri and Ropele (2019). I fix some of the parameters to match, from a qualitative point of view, the impulse responses (Matching IRFs) to a monetary policy shock in the model with those of the VAR reported in Figure 6. The matching of the impulse responses is shown in Figure 13.

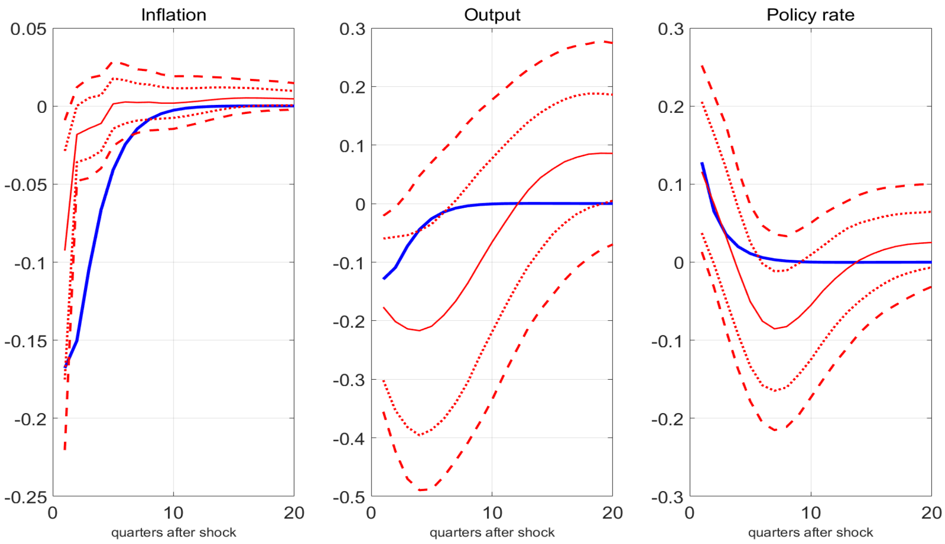
The small size of the model, which has the advantage of being identical to that of the VAR, and the limited set of nominal and real rigidities, make it difficult to achieve a very good matching of the impulse responses, as in Christiano et al. (2005). The comparison between the responses of the model and those of the VAR is mean to discipline the calibration of the parameters and to validate the theoretical model before employing it to assess the role of monetary policy (Section 6). Table 2 reports the parameters.

Table 2. Calibration of parameters

Parameter	*Value*	*Description*	*Source*
β	0.99	Discount factor	Neri and Ropele (2019)
θ	6	Elasticity of substitution among goods	Neri and Ropele (2019)
γ	0.25	Habit formation in consumption	Neri and Ropele (2019)
ϕ	50	Price adjustment cost	Matching IRFs
α	0.3	Indexation of prices to past inflation	Matching IRFs
ϕ_π	2.0	Response to inflation gap in monetary rule	Matching IRFs
$\phi_{\Delta y}$	0.25	Response to output growth in monetary rule	Matching IRFs
ϕ_R	0.80	Monetary policy rule inertia	Matching IRFs
ρ_{π^*}	0.75	Autoregressive coefficient target perceptions	Matching IRFs
μ	0.02	Gain in target perceptions	Gürkaynak et al. (2005)

Figure 13. Impulse response to monetary policy: VAR and DSGE models

(*percentage points; deviation from the baseline – VAR – and steady state – model*)



Note: the blue solid lines denote the responses in the DSGE model. The red dashed lines denote the 0.10 and 0.90 posterior percentiles of the responses in the VAR, the red dotted the 0.16 and 0.84 posterior percentiles, and the red solid line the median response.

A contractionary monetary policy shock raises the ex ante real policy rate, which forces households to reduce consumption. The lower demand for goods causes a decline in inflation. Due to the presence of indexation of prices to the perceived inflation target, which depends on past inflation rates, the fall in inflation is amplified by firms' learning (eq. 15). The calibrated model is able to match from a qualitative viewpoint the impulse responses obtained with the VAR.

The equation describing the formation of agents' perceptions about the inflation target (eq. 15) does not play a major quantitative role in the transmission of the shocks to the perceived target. There are two reasons for this result. First, the gain coefficient is small, which implies that the perceptions adjust very gradually to the four-quarter average of inflation. Second, the coefficient that maps the perceptions about the target on current inflation in the Phillips curve is, *ceteris paribus*, small (around 0.16, based on the calibration in Table 1). This notwithstanding, I prefer to model the perceptions about the target rather than the target itself for two reasons. First, as discussed above, the target perceptions are the theoretical counterpart of the SPF long-term inflation expectations I use in the VAR (see Section 3). Second, modelling the perceptions allows me to assume that the central bank knows its inflation target $\hat{\pi}_t$, while the private sector does not.

6 The role of monetary policy

In this section, I study the effects of a shock to the perceived inflation target and assess the role of monetary policy in influencing the transmission of the shock. I begin carrying out a counterfactual analysis using the impulse responses obtained with the VAR (Section 6.1). I then quantify the impact of the ECB's monetary policy responding to the fall in long-term inflation expectations on actual inflation and real GDP growth in two periods in which expectations fell substantially: 2013-14 and 2019 (Section 6.1.1). Finally, I use the small-scale model to explain the findings with the VAR (Section 6.2).

6.1 The VAR model

In order to highlight the role of monetary policy in stabilizing the macroeconomic effects of shocks to long-term inflation expectations, I construct the counterfactual scenario in the following way. I take the posterior distribution of the responses to a shock to long-term inflation expectations (Figure 7) and I subtract the posterior distribution of the impulse responses to a monetary policy (Figure 6) such that the policy rate does not react on impact to the expectation shock:

$$IRF^{i}_{\pi^e_t|R_0=0} = IRF^{i}_{\pi^e_t} - IRF^{R_0}_{\pi^e_t} * IRF^{i}_{R_t}/IRF^{i}_{R_0} \qquad i = 1, N \quad . \tag{19}$$

In practice, I take the responses to a contractionary monetary policy shock ($IRF^{i}_{R_t}$), normalising them to a unitary shock to the policy rate ($IRF^{i}_{R_t}/IRF^{i}_{R_0}$) and taking into account the size of the impact response of the policy rate ($IRF^{R_0}_{\pi^e_t}$), and subtract the resulting responses from those to a negative shock to long-term inflation expectations ($IRF^{i}_{\pi^e_t}$).[6] Diegel and Nautz (2021) use a similar approach. The resulting impulse responses are reported in Figure 14 and compared with those in Figure 7. The

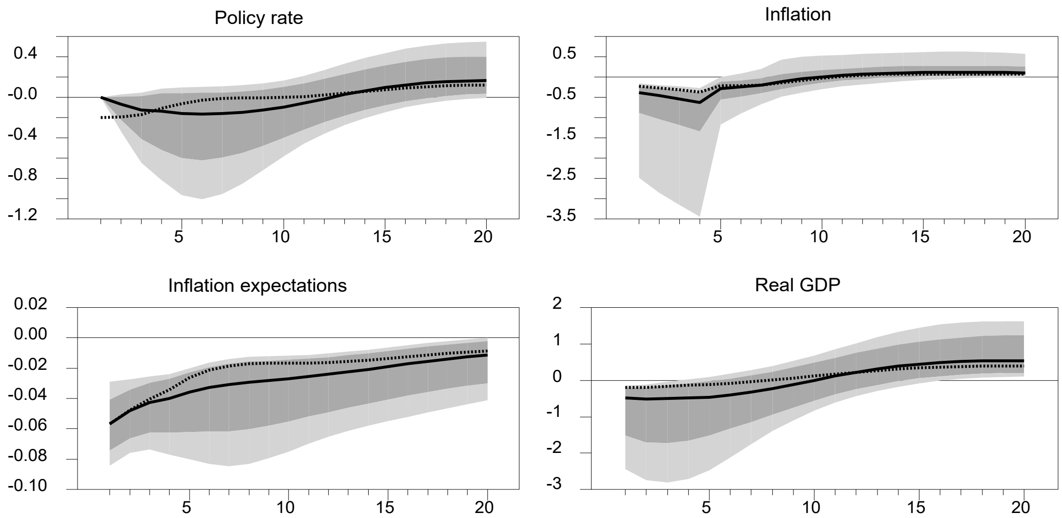
[6] Neri and Ropele (2015) show, by means of a counterfactual, that the accommodative monetary policy stance of the ECB helped to moderate the negative macroeconomic effects of shocks to sovereign spreads in the euro area.

size of the shock to long-term inflation expectations is calibrated to match the decline in 2019:Q1 (6 basis points). Figure D2 in the Appendix shows the 0.16, 0.84 percentiles, the mean and the median of the posterior distribution of the impulse responses in the baseline and in the counterfactual.

In the counterfactual, the policy rate does not respond on impact. Throughout the whole horizon, the 0.16-0.84 posterior range always include the zero line, implying that the policy rate does not respond to the shock. The fact that the ECB does not cut the policy rate to counter the fall in long-term expectations causes inflation to fall by substantially more and leads to a contraction in economic activity. The 0.16-0.84 posterior range for inflation in the counterfactual lies below the median baseline impulse response. The probability of output falling on impact in the counterfactual scenario is 98 per cent and the posterior distribution is skewed towards negative values.[7] After one year, the probability that output is below the baseline is still 90 per cent.

Figure 14. Impulse response to an inflation expectation shock: no monetary policy response

(*per cent and percentage points; deviation from unshocked path*)



Note: the black solid line denotes the median of the marginal posterior distributions of the impulse responses in the counterfactual simulation. The dark grey area denotes the range delimited by the 0.16 and 0.84 percentiles of the posterior distribution. The light grey area denotes the range delimited by the 0.05 and 0.95 percentiles. The black dotted line shows the median impulse response to a negative shock to long-term inflation expectations in the baseline case (Figure 7).

The counterfactual simulation shows clearly that monetary policy plays a key role in the transmission of shocks to long-term inflation expectations to inflation and economic activity. If the central bank fails to act, output falls and inflation declines by more. The absence of an offsetting monetary policy stance amplifies the initial decline in long-term inflation expectations.[8] This result is in line with the mechanism studied in Arias et al. (2016). In Section 6.2, I rationalise the evidence on the role of monetary policy using the small scale model.

[7] The skewness of the impulse responses is due to the normalization by $IRF^{i}_{R_0}$. See footnote 10.
[8] If I assume that long-term inflation expectations fall in response to a contractionary monetary policy shock, the decline in output and inflation in the counterfactual simulation is larger than in the baseline case.

6.1.1 The 2013 and 2019 fall in long-term expectations

In this section, I conduct counterfactual simulations with the VAR to assess the role of the ECB's monetary policy in two selected episodes of marked decline in long-term inflation expectations: the 2013-14 disinflation and the persistent decline in 2019 (Section 2). The simulations allow me tackling the question of how would inflation and real GDP growth have evolved in the two episodes had the ECB not responded to the decline in long-term inflation expectations.

The simulations are constructed as follows. Conditional on a draw from the posterior distribution of the VAR and on draw of the $\mathbf{A}_0$ matrix satisfying the identifying restrictions, I set to zero the aggregate demand and aggregate supply shocks and calibrate the monetary policy shock in each quarter of the simulation in order to perfectly offset the impact of the shock to long-term inflation expectations on the policy rate.[9] Counterfactuals simulations have been used extensively in the literature. Among others, Baumeister and Benati (2013) assess the macroeconomic impact of asset purchases by the Federal Reserve and the Bank of England during the global financial crisis. Kilian and Lewis (2011) study the impact of shocks to oil prices under a scenario in which the Federal Reserve does not respond directly to changes in oil prices.

Figure 15 show the results. The top left panel focuses on the 2013-14 period, the top right panel on 2019. The red dotted lines denote the median path of the variables in the case that only shocks to inflation expectations are occurring. The blue solid lines depict the path of the variables under the counterfactual that monetary policy shocks offset the impact of the expectation shock on the policy rate. The shaded areas denote the intervals implied by the 0.16 and 0.84 percentiles in the counterfactual simulations. The black dashed-dotted lines show the data. The bottom panels show the difference (the red dotted lines denote the median and the yellow shaded area the 0.16-0.84 range) between the path of the variables in the case the economy is hit by shocks to long-term inflation expectations and the path arising if monetary policy shocks offset the impact of the shocks to expectation on the policy rate.

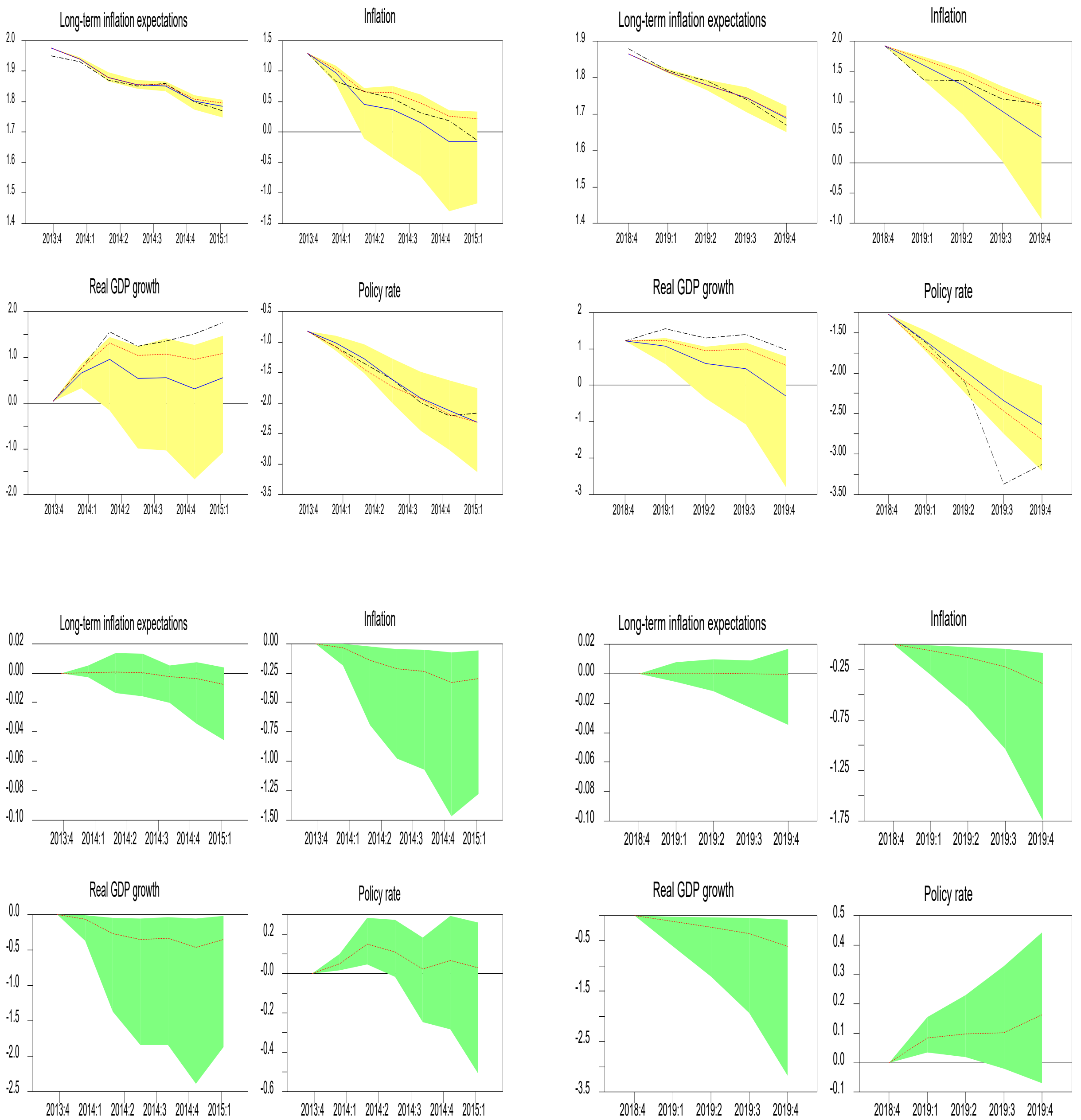
The counterfactuals show that both inflation and real GDP growth in the two episodes would have been lower had the ECB not responded to the shocks to long-term inflation expectations. Inflation and real GDP growth in 2015:Q1 would have been lower by respectively by 0.3 and 0.35 percentage points. The effects are larger in the counterfactual scenario for 2019 (0.4 in the case of inflation and 0.6 in the case of real GDP growth in 2019:Q4), which is due to more negative and larger shocks in the second episode. The distribution of the variables is skewed towards negative outcomes.[10] The ECB would have implemented a tighter monetary policy by not responding to the decline in long-term inflation expectations. The results from the counterfactual for 2019 suggest that

[9] The policy rate does not remain constant since it is influenced by the lagged values of the VAR variables and the trend.
[10] The asymmetry in the distribution is not related to the sign restrictions imposed to identify the monetary policy shock. The posterior distributions are asymmetric also if I impose the long-term inflation expectations fall after a contractionary monetary policy shock. The asymmetry is more related to the construction of the counterfactuals. In particular, the size of the monetary policy shock, ε_t^{mp}, that offsets the shock to long-term inflation expectations, ε_t^{exp}, is calibrated as follows: $\varepsilon_t^{mp} = -\frac{\mathbf{A}_0(4,3)}{\mathbf{A}_0(4,4)}\varepsilon_t^{exp}$, where $\mathbf{A}_0(4,3)$ measures the impact response of the policy rate to inflation expectations and $\mathbf{A}_0(4,4)$ measures the impact response of the policy rate to the monetary shock. The normalization by $\mathbf{A}_0(4,4)$ introduces the asymmetry in the impulse responses (Figure 14) and in the counterfactuals (Figure 15).

the decision of the ECB to restart the APP in September of that year was justified by the need to counter the downward impact of falling long-term inflation expectations on inflation.

Figure 15. Counterfactual simulations: 2013-14 and 2019

(*per cent and percentage points*)



Note: the red dotted lines denote the median of the marginal posterior distributions of the simulations under the assumption the only shocks to long-term inflation expectations are occurring. The blue solid line denotes the median of the posterior distribution in the counterfactual in which the monetary policy shock offset the impact of the expectation shock on the policy rate. The yellow shaded area denotes the interval defined by the 0.16 and 0.84 percentiles of the posterior distribution in the counterfactual. The black dashed-dotted line denotes the data. The green shaded area denotes the interval defined by the 0.16 and 0.84 percentiles of the posterior distribution of the differences between the baseline and the counterfactual.

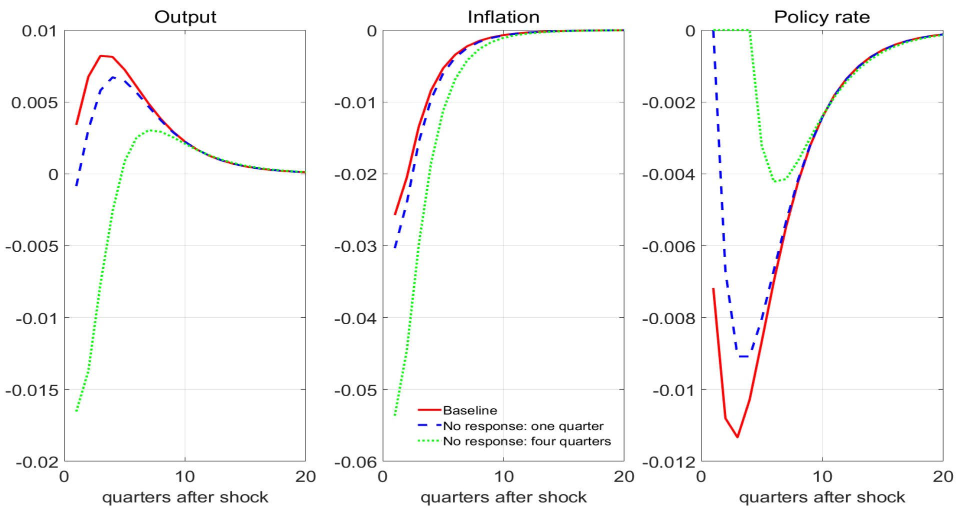
Figure D3 in the appendix compares the monetary policy shocks implemented in the two counterfactuals with the monetary shocks implied by the baseline VAR over the full sample. The chart confirms that the counterfactuals shocks are not large compared with past shocks and thus are plausible. It is unlikely that the policy intervention I implement would lead to changes in the behaviour of agents in the sense of Lucas (1976).[11] In the terminology of Leeper and Zha (2003), the policy interventions I implement are "modest" in the sense that they would not give rise to expectation-formation effects.

6.2 The DSGE model

In this section, I use the model to compute impulse responses to a negative shock to the perceived inflation target. The shock is calibrated to have a similar size to the shock in the baseline case of the VAR counterfactual in Section 6.1. The counterfactual in which the central bank does not respond on impact to the negative shock to the perceived inflation target is obtained using the same approach employed in the VAR (eq. 19). I also consider a counterfactual in which the central bank does not adjust the policy rate for a whole year after the shock. In this case, agents are assumed to know that the policy rate remains at zero for four quarters. Figure 16 shows the results.

Figure 16. Impulse response to an inflation expectation shock: counterfactual with no monetary policy response

(*percentage points; deviation from steady state*)



The model is able to replicate from a qualitative point of view the results obtained with the VAR. The magnitudes of the responses, however, are significantly smaller than in the VAR. In the scenario in which the policy rate cannot be adjusted on impact, output falls marginally on impact and then increases above steady state. When the policy rate is held constant for four quarters, output declines sharply and inflation falls by more compared with the baseline. The differences between the three scenarios are due to the behaviour of the (ex ante) real policy rate: the more the policy rate fails to respond to the shock to perceptions, the larger the increase in the real policy rate. The larger increase amplifies the impact of the shock to the target perceptions on inflation and, through the IS

[11] Baumeister and Benati (2013) note that in the counterfactual simulation they modify the structural shocks, without altering any parameter in the structural VAR. For this reason, the conterfactuals based on alternative path of the shocks are not subject to Sargent's (1979) criticism, which refers to assessing the effects of policy interventions by changing the parameters of the equations describing the policy tools, as there are cross-equation restrictions in the VAR.

curve, on output. In the scenario where the policy rate is not adjusted for a year, the increase in the real rate is twice the increase in the baseline scenario.

6.3 Summing up and discussion

The simulations with the VAR and the DSGE models show that monetary policy can play an important role in the transmission of shocks to inflation expectations/perceptions about the target. If the central bank does not lower the policy rate in response to a negative shock, inflation declines by more and output falls rather than increasing.

The counterfactual simulations are subject to limitations. As such, the results have to be taken with caution. A key limitation, which has been highlighted in the Introduction, is that both models are linear. Changes in long-term inflation expectations/perceptions of the target can arise because of sudden changes in the expectation formation mechanism. In both models, these changes are the result of shocks rather than the consequence of changes in the parameters of the mechanism behind the formation of expectations and perceptions. Another important limitation is that the sign of the shocks to long-term inflation expectations does not matter for their anchoring. Corsello et al. (2021) show that only negative surprises to inflation lead to a de-anchoring in the euro area. Taking into account the different effects of negative and positive shocks would require a non-linear model.

Overcoming the limitations could be the subject of future research. Future research could also aim at improving existing models of expectation formation (Carvalho et al., 2019) by explicitly modelling the lower bound to the policy rate (Armenter, 2018 and Gobbi et al., 2019) and modelling non-standard monetary measures (Burlon et al., 2018, Chen et al, 2012 and Gertler and Karadi, 2011).

7 Robustness

7.1 The VAR

The robustness of the results is tested along the following dimensions: the exclusion of the linear trend and the choice of the prior; the estimation period; the narrative restrictions; the use of core consumer prices; the inclusion of oil prices and the identification of oil supply shocks. The latter robustness check is discussed more extensively in Section 7.1.1. Appendix C reports the results of the various robustness checks.

The estimation of the VAR without a deterministic trend and with a unit root prior yields very similar results.[12] Similar results are also obtained if the VAR is estimated over the sample beginning in 2003:Q3, after the revision of the monetary policy strategy the ECB announced in May of that year. I do not estimate the VAR up to 2020:Q4, as the outbreak of the Covid-19 pandemic and the unprecedented contraction in output may have caused structural changes in the relationship among the variables. As for the identification, removing the narrative restrictions yields similar results. The reason is that the shock to long-term inflation expectations in 2019:Q2 is negative, so that the restrictions are easily satisfied. The historical decomposition of core inflation (Figure C9) shows that

[12] See figures C1 to C3 for the unit root prior, C4 to C6 for the case with the autoregressive prior, the linear trend and no narrative restrictions, and C7 to C9 for the case with core inflation. Figure C10 shows the historical decomposition of inflation in the case of the autoregressive prior/linear trend model estimated on the sample 2003:Q3-2019:Q4.

shocks to long-term inflation expectations play an important role, confirming the results for headline inflation and suggesting the inflation expectations play a role in the pricing of core goods and services.

Oil supply shocks

I have also estimated the baseline VAR, over the same sample period, with the inclusion of oil prices in euro deflated by the consumer price index for the U.S.[13]

The objective of this check is to assess the robustness of the contributions of the shocks to long-term inflation expectations to the identification of oil supply shocks and also to control for oil prices in the transmission of the shocks. I do not aim at providing a detailed decomposition of oil prices into the various shocks considered in the literature (see, for example, Kilian and Murphy, 2012, Lippi and Nobili, 2012, Caldara et al., 2019). I focus on oil supply shocks, as according to Caldara et al. (2019), the oil slump between July 2014 and December 2015 was due mainly to these shocks. This period is characterized by persistently low inflation in the euro area. It is thus important to control for the potential impact of oil supply shocks and the role of long-term inflation expectations.

I maintain the assumptions discussed in Section 3.2 for the shocks identified in the baseline VAR. Table 2 shows the identifying assumptions. I assume that a positive oil supply shock lowers oil prices on impact and leads to a decline in consumer prices and to an increase in real GDP. I also make the following assumptions regarding the impact of the other shocks on oil prices: (*i*) a positive aggregate supply shock causes oil prices to increase; (*ii*) oil prices do not respond on impact to shocks to long-term inflation expectations; (*iii*) the response of oil prices to a monetary policy shock is left unrestricted.

Table 2. Sign and zero restrictions

variable	Aggregate demand	Aggregate supply	Inflation expectations	Oil supply	Monetary policy
Long-term inflation expectations	0	0	-	?	?
Consumer prices	+	-	-	-	-
Oil price	?	+	0	-	?
Policy rate	+	?	-	?	+
Real GDP	+	+	?	+	-

Note: a 0 means that the variable in the row does not respond to the shock in the column. A – means that the response on impact is negative, a + means that it is restricted to be positive. A ? means that the impact response is unrestricted. The sign restrictions are imposed on impact.

As for the impulse responses, the transmission of shocks to long-term inflation expectations is not affected by the inclusion of oil prices (Figure C11). The counterfactual simulation to assess the role of monetary policy yields very similar results to the exercise conducted with the baseline specification of the VAR (Figure C12). The historical decomposition of inflation (Figure C13) is also similar to that obtained with the baseline VAR. Positive oil supply shocks pushed oil prices downward and brought inflation down between 2013 and 2016. The contribution of shocks to long-term inflation expectations to inflation is robust to the inclusion of oil prices and identification of oil supply shocks

[13] Data on U.S. consumer prices are taken from FRED. The series is the following: Consumer Price Index for All Urban Consumers: all items in U.S. City Average, monthly, seasonally adjusted. The series code is CPIAUCSL.

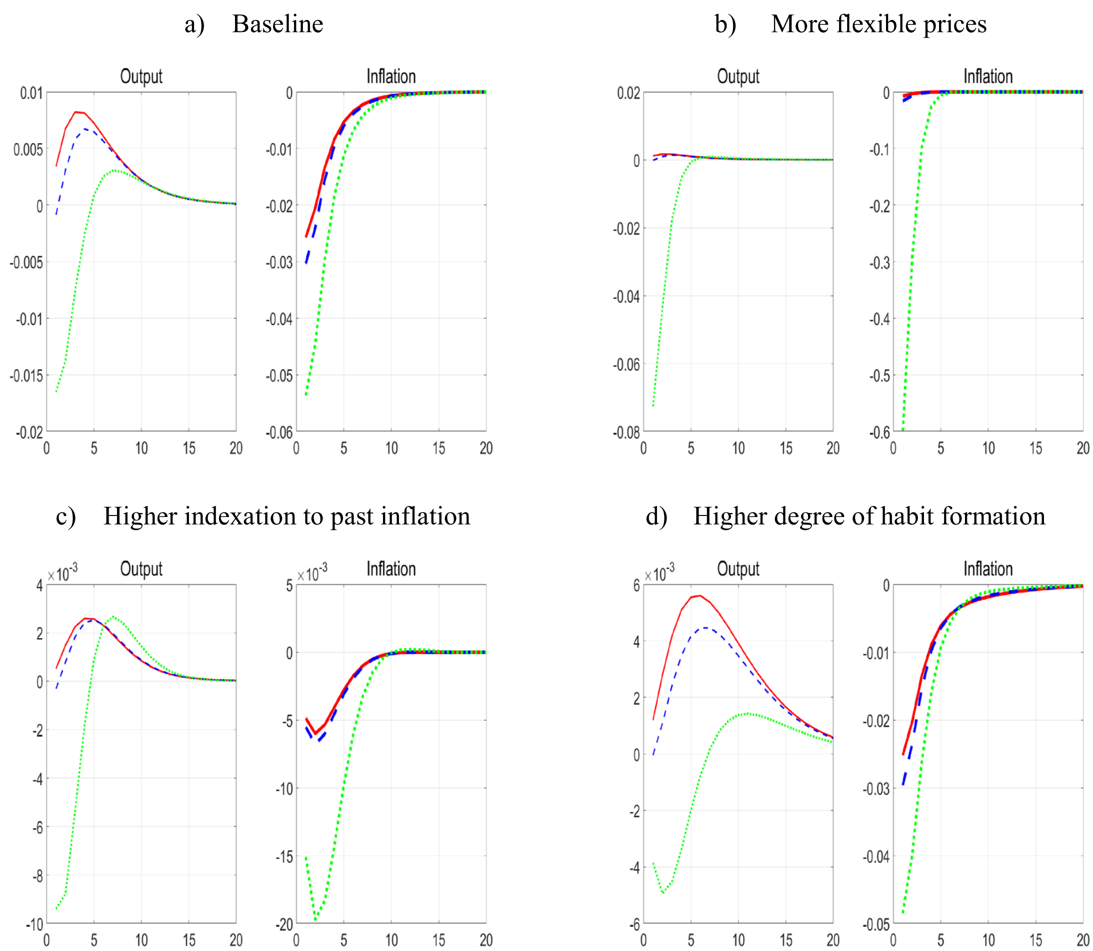
(Figure C14). The contribution of oil supply shocks to inflation is highly correlated with the contribution of aggregate supply shocks in the baseline VAR (correlation = 0.75) and much less with the contribution of the shocks to expectations (0.37), aggregate demand (0.13) and monetary policy shocks (0.09). This result provide some support to the assumption that aggregate supply shocks capture the effects of oil supply shocks on inflation in the baseline VAR.

7.2 The DSGE

The robustness of the results of the counterfactual simulations with the DSGE model is tested along the following dimensions: the role of indexation of prices to the perceived target, the role of price stickiness and the monetary policy rule. Figure 17 shows the impulse responses and the counterfactual scenarios under the different calibrations.

Figure 17. Robustness to selected parameters

(*percentage points; deviation from steady state*)



Note: the red solid lines denote the responses in the baseline case; the blue dashed lines the responses when monetary policy does not respond on impact to the shock to the inflation perceptions; the green dotted lines the case in which the policy rate does not respond for four quarters.

The more prices are flexible (ϕ = 5, compared with ϕ = 60 in the baseline), the larger the contractionary effects of negative shocks to inflation perceptions if the central bank does not respond to the shock for four quarters (panel b). The larger the degree of indexation of prices to past inflation

(α = 0.8, compared with α = 0.2 in the baseline), the smaller the impact of shocks to long-term expectations and the smaller the role of monetary policy (panel c). The larger the degree of habit formation in consumption (γ = 0.8, compared with γ = 0.3 in the baseline), the smaller the effects of shocks to firms' perceptions on output and inflation and the smaller the role that monetary policy plays (panel d). The parameters of the monetary policy rule do not affect the response of output and inflation in the two counterfactuals.

8 Concluding remarks

A widening gap between long-term inflation expectations and the inflation target is a clear sign of de-anchoring, a potentially non-linear phenomenon. In this paper, I have used euro-area data to quantify the macroeconomic consequences of a de-anchoring of (survey-based) long-term inflation expectations from the ECB's inflation target and assess the role of monetary policy in the transmission of shocks to these expectations.

A decline in long-term inflation expectations, which is not countered by the central bank, can lead to a contraction in economic activity, which amplifies the negative effects on inflation. These findings have important policy implications for monetary policy, which must ensure that long-term inflation expectations remain well anchored to the inflation target.

Strong assumptions are required to address the research questions I have posed in this paper. Future research may relax these assumptions and adopt methods that are best suited to capture the non-linearities behind the formation of inflation expectations, including the sign of the shocks, and the implications of the presence of the effective lower bound to the policy rate for monetary policy.

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Appendix A – Data

Long-term inflation expectations

Mean of the point five-year ahead expectations across respondents

Source: ECB Statistical Data Warehouse

Series key: SPF.Q.U2.HICP.POINT.LT.Q.AVG

Harmonized Index of Consumer Prices (HICP)

Overall index (euro area changing composition), quarterly averages of the monthly index, working day and seasonally adjusted

Source: ECB Statistical Data Warehouse

Series key: ICP.M.U2.Y.000000.3.INX

Real Gross Domestic Product (GDP)

Gross domestic product at market prices - euro area 19 (fixed composition) total economy, chain linked volume (rebased), non-transformed data, calendar and seasonally adjusted data

Source: ECB Statistical Data Warehouse

Series key: MNA.Q.Y.I8.W2.S1.S1.B.B1GQ._Z._Z._Z.EUR.LR.N

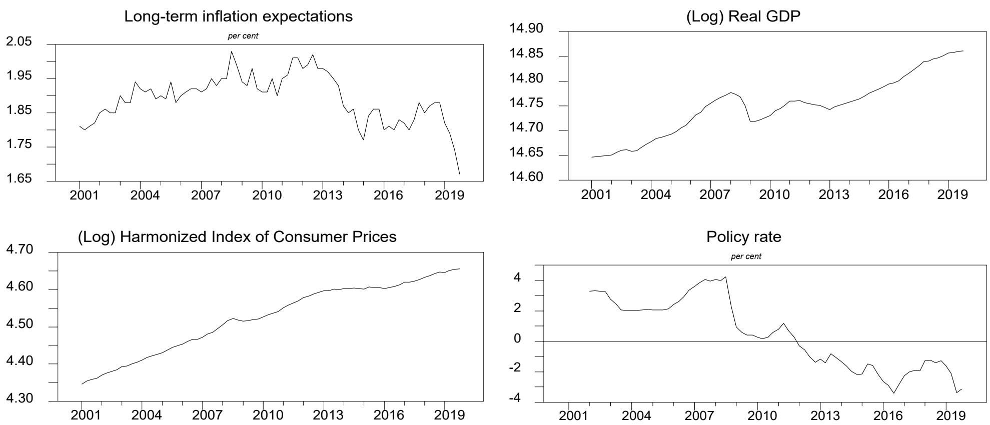
Policy rate

The policy rate is the combination of the Euro OverNight Index Average, EONIA, rate and the shadow rate computed by Krippner (2013). The EONIA rate is the overnight money market rate computed daily by the ECB. The shadow rate is taken from Krippner (2020). The data was downloaded on 29 May 2021 from the following webpage: https://www.ljkmfa.com/test-test/international-ssrs/ and on 24 August 2021 from https://www.ljkmfa.com/visitors/

Source: ECB Statistical Data Warehouse

Series key for EONIA: FM.Q.U2.EUR.4F.MM.EONIA.HSTA

Figure A1. Data



Oil prices in euro

Oil price, Brent crude -1 month forward - Euro

Source: ECB Statistical Data Warehouse

Series key: RTD.M.S0.N.P_OILBR.E

Appendix B – Inference

The prior for the coefficients of the reduced form VAR is assumed to be normal with mean $\bar{B}$ and standard deviation $\boldsymbol{\Upsilon}$:

$$P(\boldsymbol{B}) = N(\overline{\boldsymbol{B}},\boldsymbol{\Upsilon}) \quad .$$

The element i,j of $\overline{\boldsymbol{B}}$ is:

$$\bar{b}_{i,j} = \begin{cases} \rho_i\,, & \text{first own lag}\,, i = j \\ 0, & i \neq j \end{cases}$$

where ρ_i is set on the basis of the estimation of the following equation for each variable:

$$y_t = \alpha + bt + \rho y_{t-1} + \varepsilon_t \ .$$

The elements of the matrix $\boldsymbol{\Upsilon}$ ($\tau_{i,j}$ is the precision) are the following:

$$\gamma_{i,j} = std.dev.(\bar{b}_{i,j}) = \frac{1}{\tau_{i,j}} = \begin{cases} \dfrac{\kappa_1}{l^{-\kappa_3}}\,, \text{lag } l \text{ of the dependent variable} \\ \dfrac{\kappa_1 \kappa_2 s_j}{l^{-\kappa_3} s_r}\,, \text{lag } l \text{ of variable } r \neq j \\ \kappa_1 \kappa_4, \text{constant and linear trend} \end{cases}$$

where κ_1 measures the degree of overall tightness of the prior, κ_1 the relative tightness of the lags of the other variables in each equation, κ_3 the decay rate of lag l and κ_4 the tightness of the prior on the constant and the coefficients of the linear trend. The term $\frac{s_j}{s_r}$ is scale factor that accounts for the different variances of the dependent and explanatory variables.

The prior for the covariance matrix $\boldsymbol{\Sigma}$ is diffuse:

$$P(\boldsymbol{\Sigma}) \propto |\boldsymbol{\Sigma}|^{-\frac{m+1}{2}} \quad ,$$

were m is the number of variables in the VAR. Given the normal likelihood function of the VAR, the posterior density of **B** and $\boldsymbol{\Sigma}$ is normal-inverse Wishart.

Inference is conducted using the Gibbs sampling by partitioning the VAR parameters in the reduced-form coefficients and the covariance matrix of the error terms. The posterior distribution of $\boldsymbol{\Sigma}$ is:

$$P(\boldsymbol{\Sigma}|\mathbf{B}) \sim IW[(Y - X\boldsymbol{B})'(Y - X\boldsymbol{B}), T]$$

and the posterior distribution of **B** is:

$$P(vec\,\boldsymbol{B}|\boldsymbol{\Sigma}) = N\big[(\boldsymbol{\Sigma}^{-1} \otimes X'X + \boldsymbol{\Upsilon})^{-1}\big((\boldsymbol{\Sigma}^{-1} \otimes X'X)vec(\boldsymbol{B}) + \boldsymbol{\Upsilon}\, vec(\boldsymbol{B})\big), (\boldsymbol{\Sigma}^{-1} \otimes X'X + \boldsymbol{\Upsilon})^{-1}\big] \ .$$

Inference is conducted using a modified version of the Gibbs sampling algorithm (see the code gibbsvar.rpf) available at the ESTIMA webpage https://estima.com/procs_perl/800/gibbsvar.rpf .

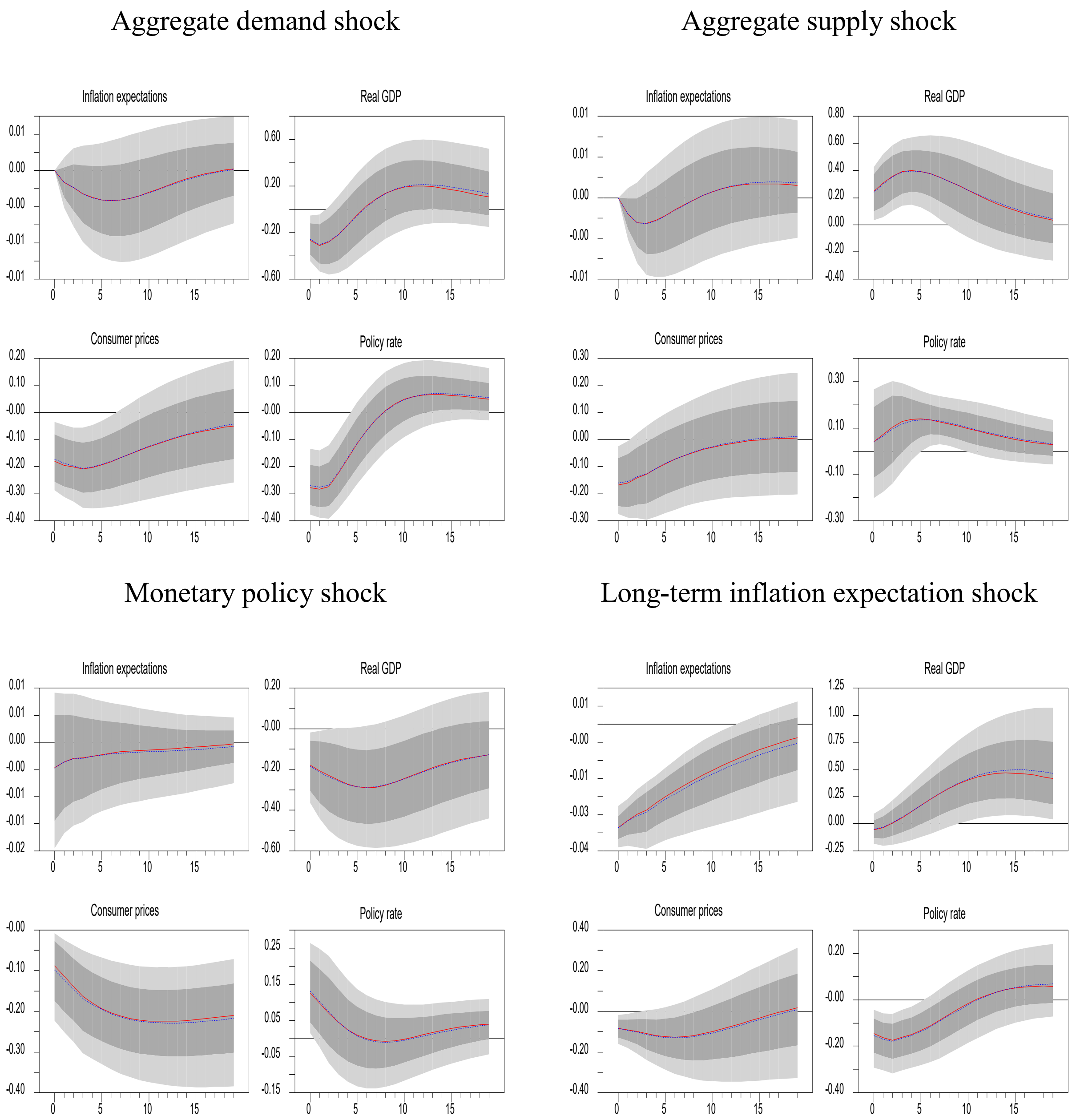
Alternatively, the prior for **B** is assumed to have a mean of 1 on the first own lag and zero in all the other cases. In this case, the VAR does not include a linear trend.

Appendix C – Robustness checks

Unit root prior and no linear trend

The VAR has been estimated without the linear trend and with a unit root prior à la Minnesota. The impulse responses in Figure C1 are based on one million draws from the posterior distribution of the VAR parameters and 100 draws from the unitary sphere. The draws which imply an eigenvalue of the companion matrix larger than one are discarded. The results are based on around 360,000 draws; around 460,000 draws are discarded.

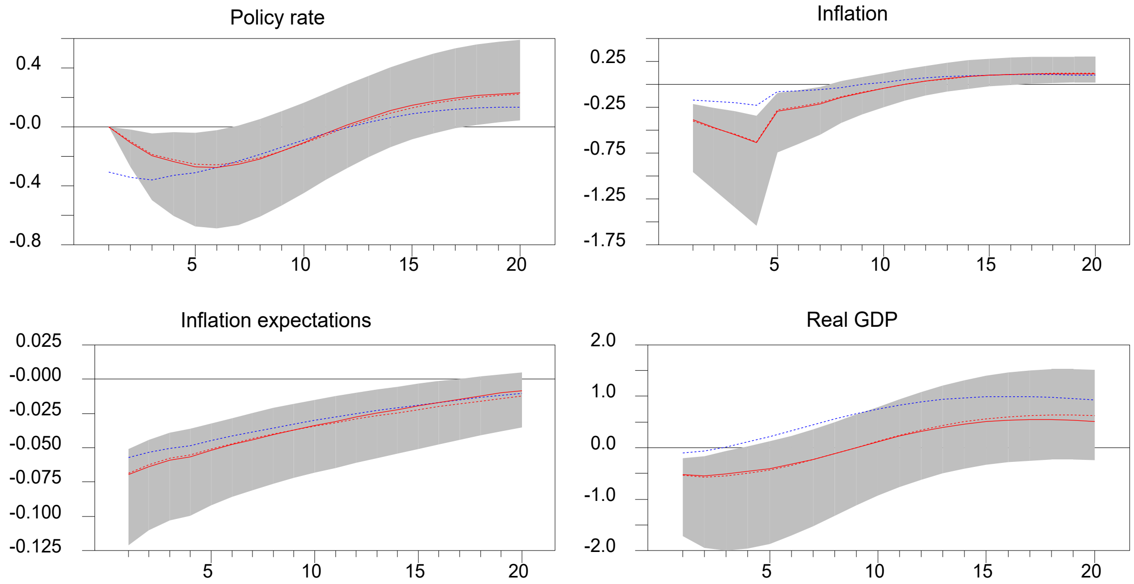
Figure C1 – Impulse responses



Note: the red solid and the blue dotted line refer, respectively, to the median and the mean of the marginal posterior distributions at each step. The dark grey area denotes the range delimited by the 0.16 and 0.84 percentiles of the posterior distribution. The light grey area denotes the range delimited by the 0.05 and 0.95 percentiles.

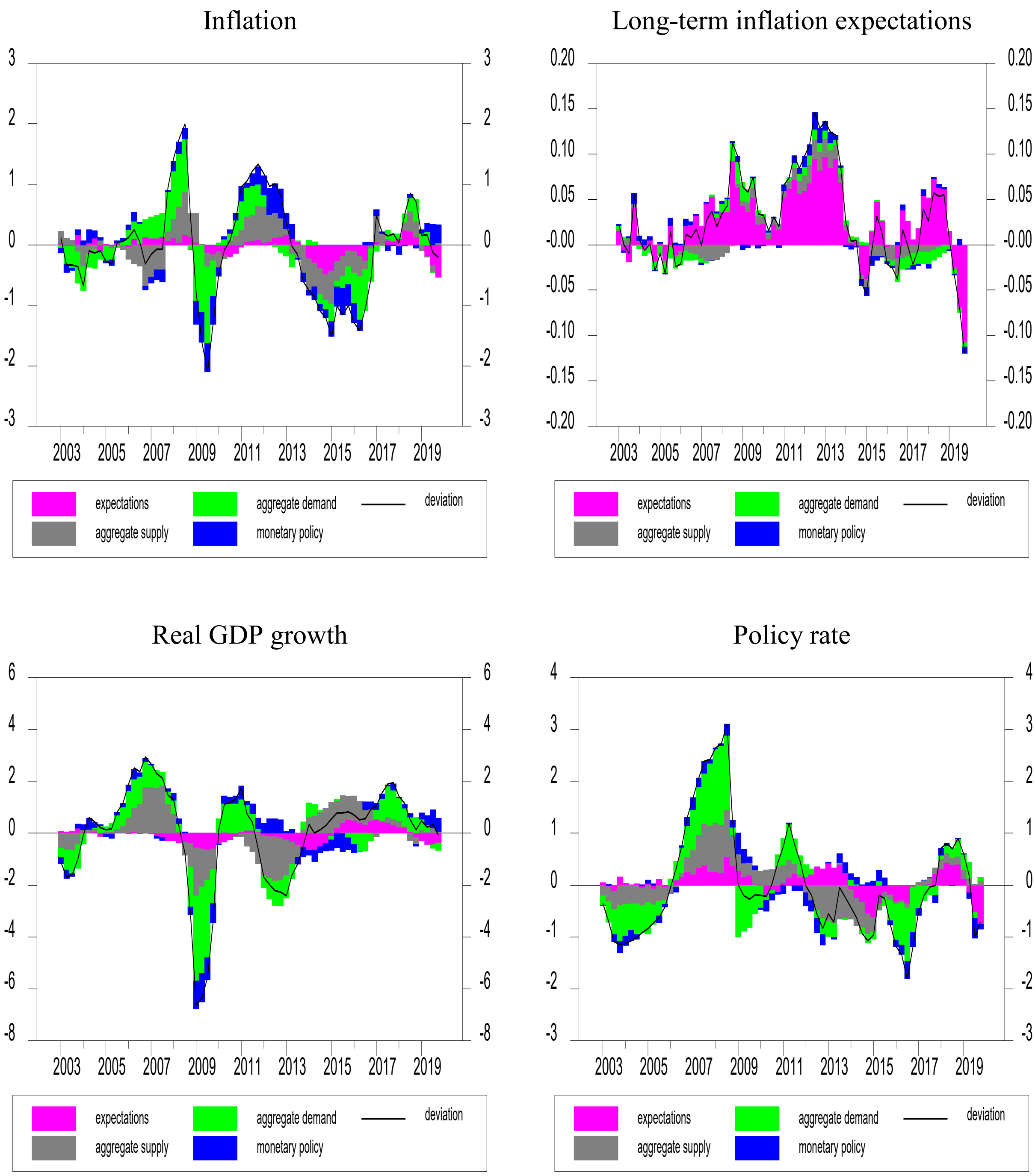
Figure C2. Impulse response to an inflation expectation shock: counterfactual with no monetary policy response

(*per cent and percentage points; deviation from unshocked path*)



Note: the red solid and red dotted lines (which are perfectly overlapping in this case) denote, respectively, the median and the mean of the marginal posterior distributions of the impulse responses at each step in the counterfactual simulation. The dark grey area denotes the range delimited by the 0.16 and 0.84 percentiles of the posterior distribution. The blue dotted line shows the median impulse response to a negative shock to long-term inflation expectations in the baseline case (Figure 7).

Figure C3 – Historical decomposition



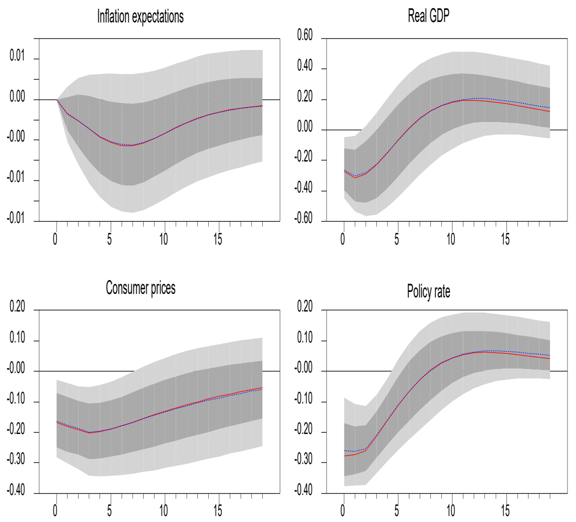
Note: the contribution of each shock to the deviation of year-on-year inflation from the baseline is the mean of the (marginal) posterior distribution in each quarter. The first observation for the computation of the contributions is 2002:Q1 and the last one is 2019:Q4. In the chart, the decomposition starts in 2003:Q1 since 4 observations are lost in the computation of the inflation rate and 4 are lost due to the number of lags of the VAR.

Autoregressive prior, linear trend and no narrative and variance decomposition restrictions

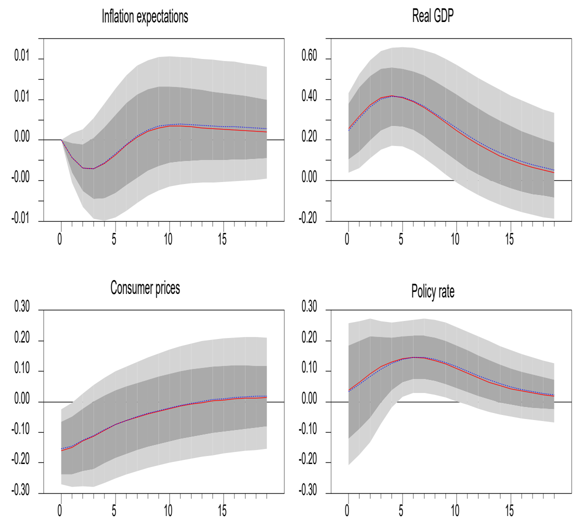
The baseline VAR (linear trend and with autoregressive priors) has been estimated and shocks have been identified without imposing the narrative restrictions and the restriction on the variance decomposition of long-term inflation expectations. The impulse responses in Figure C4 are based on 200,000 draws from the posterior distribution of the VAR parameters and 100 draws from the unitary sphere. The draws which imply an eigenvalue of the companion matrix larger than one are discarded. The results are based on around 168,000 draws; around 25,000 draws are discarded.

Figure C4 – Impulse responses

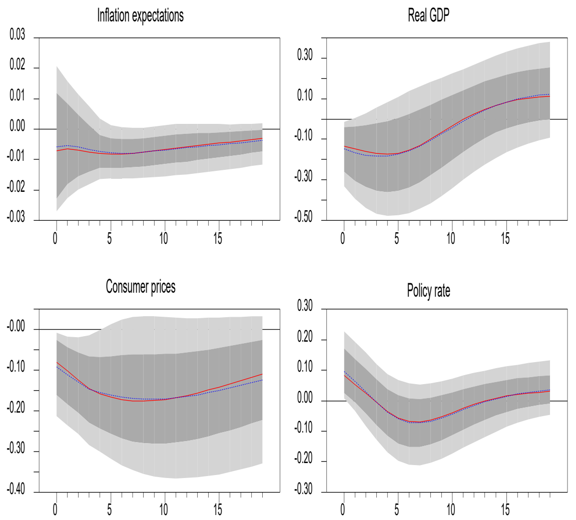
Aggregate demand shock



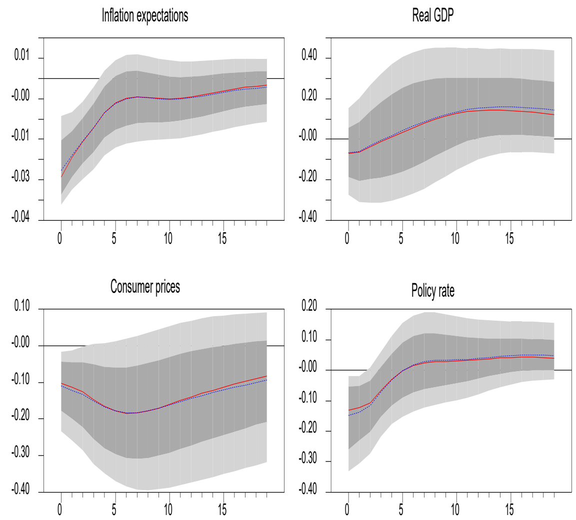
Aggregate supply shock



Monetary policy shock



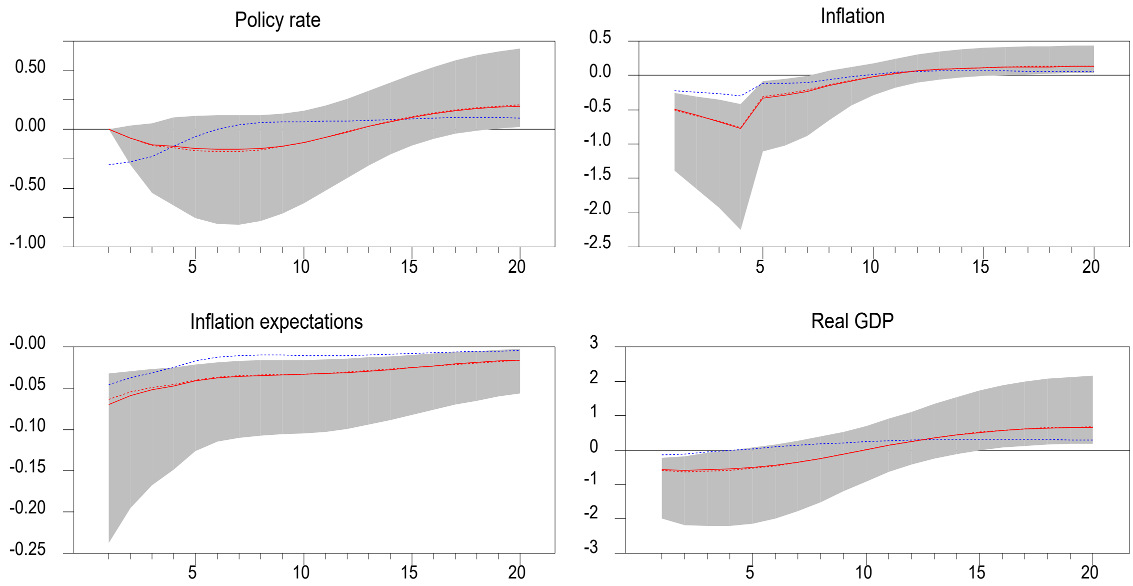
Long-term inflation expectation shock



Note: the red solid and the blue dotted line refer, respectively, to the median and the mean of the marginal posterior distributions at each step. The dark grey area denotes the range delimited by the 0.16 and 0.84 percentiles of the posterior distribution. The light grey area denotes the range delimited by the 0.05 and 0.95 percentiles.

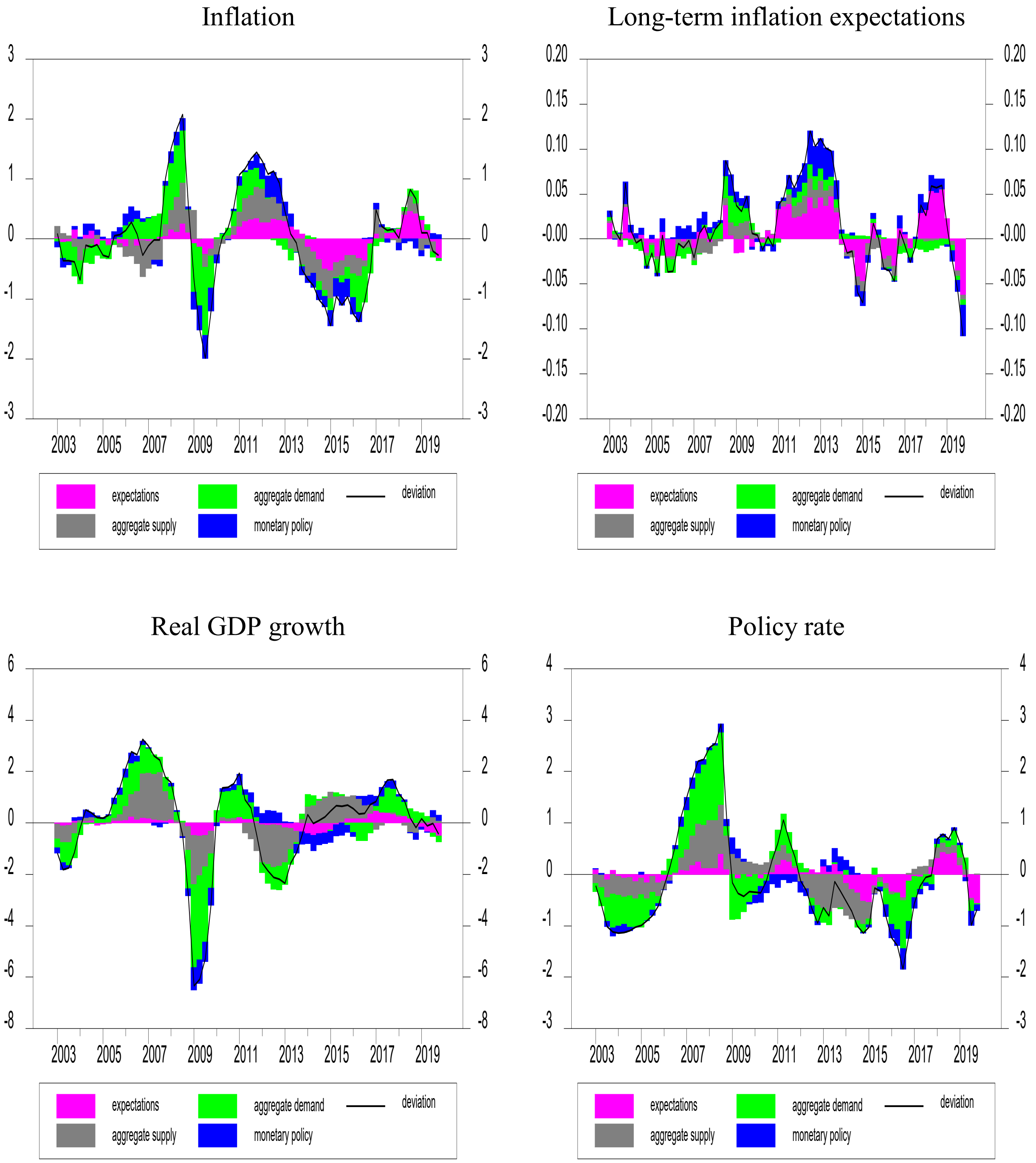
Figure C5. Impulse response to an inflation expectation shock: counterfactual with no monetary policy response

(per cent and percentage points; deviation from unshocked path)



Note: the red solid and red dotted lines (which are perfectly overlapping in this case) denote, respectively, the median and the mean of the marginal posterior distributions of the impulse responses at each step in the counterfactual simulation. The dark grey area denotes the range delimited by the 0.16 and 0.84 percentiles of the posterior distribution. The blue dotted line shows the median impulse response to a negative shock to long-term inflation expectations in the baseline case (Figure 7).

Figure C6 – Historical decomposition



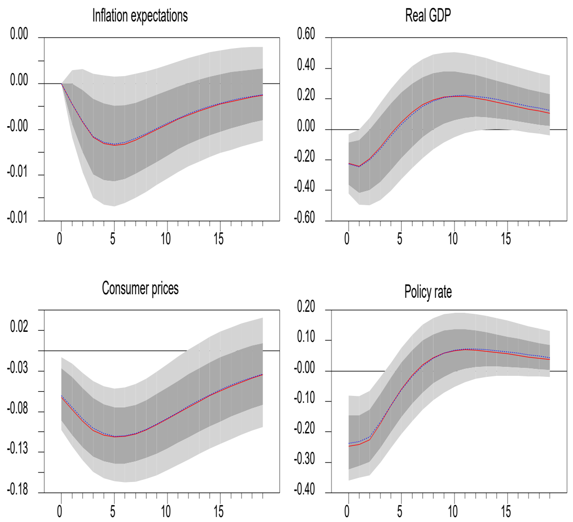
Note: the contribution of each shock to the deviation of year-on-year inflation from the baseline is the mean of the (marginal) posterior distribution in each quarter. The first observation for the computation of the contributions is 2002:Q1 and the last one is 2019:Q4. In the chart, the decomposition starts in 2003:Q1 since 4 observations are lost in the computation of the inflation rate and 4 are lost due to the number of lags of the VAR.

Autoregressive prior, linear trend and narrative restrictions: core inflation

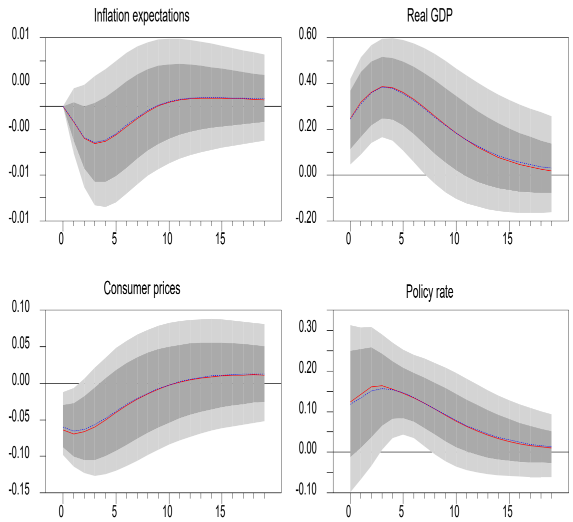
The baseline VAR (linear trend and with autoregressive priors) has been estimated using core inflation instead of headline inflation. Shocks have been identified imposing the narrative restrictions. The impulse responses in Figure C7 are based on one million draws from the posterior distribution of the VAR parameters and 100 draws from the unitary sphere. The draws which imply an eigenvalue of the companion matrix larger than one are discarded. The results are based on nearly 89,000 draws; around 58,000 draws are discarded.

Figure C7 – Impulse responses

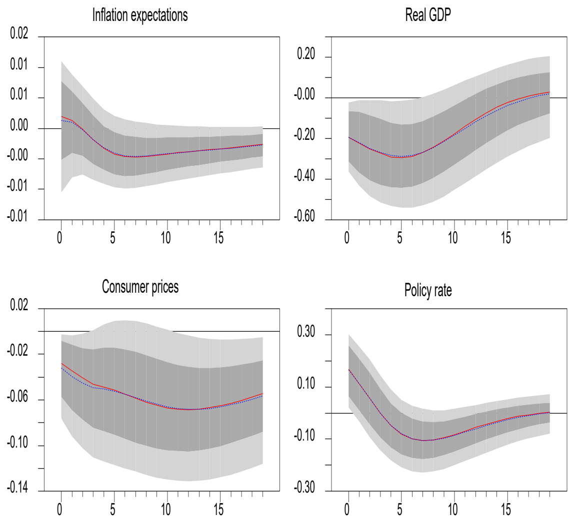
Aggregate demand shock



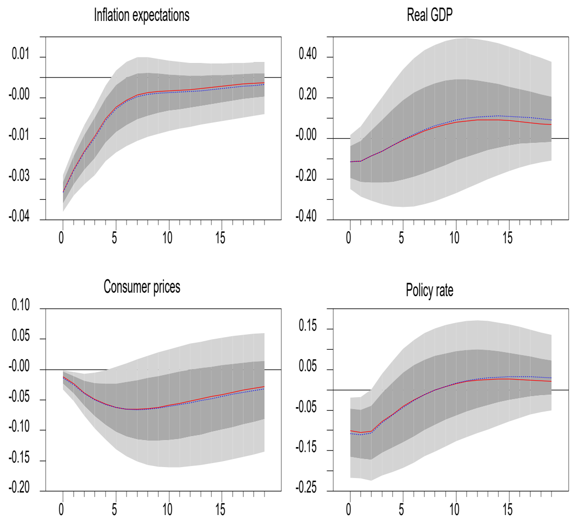
Aggregate supply shock



Monetary policy shock



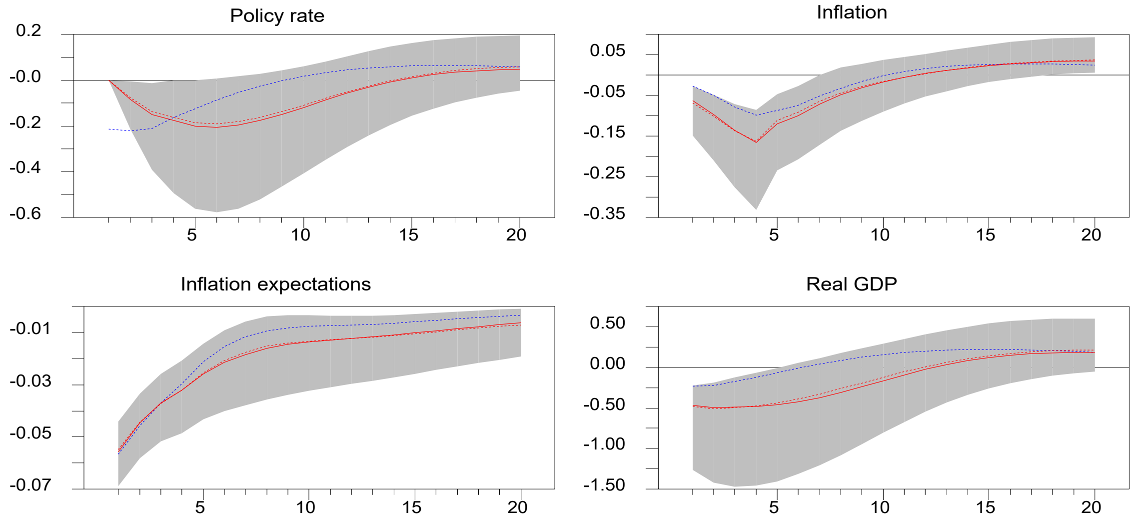
Long-term inflation expectation shock



Note: the red solid and the blue dotted line refer, respectively, to the median and the mean of the marginal posterior distributions at each step. The dark grey area denotes the range delimited by the 0.16 and 0.84 percentiles of the posterior distribution. The light grey area denotes the range delimited by the 0.05 and 0.95 percentiles.

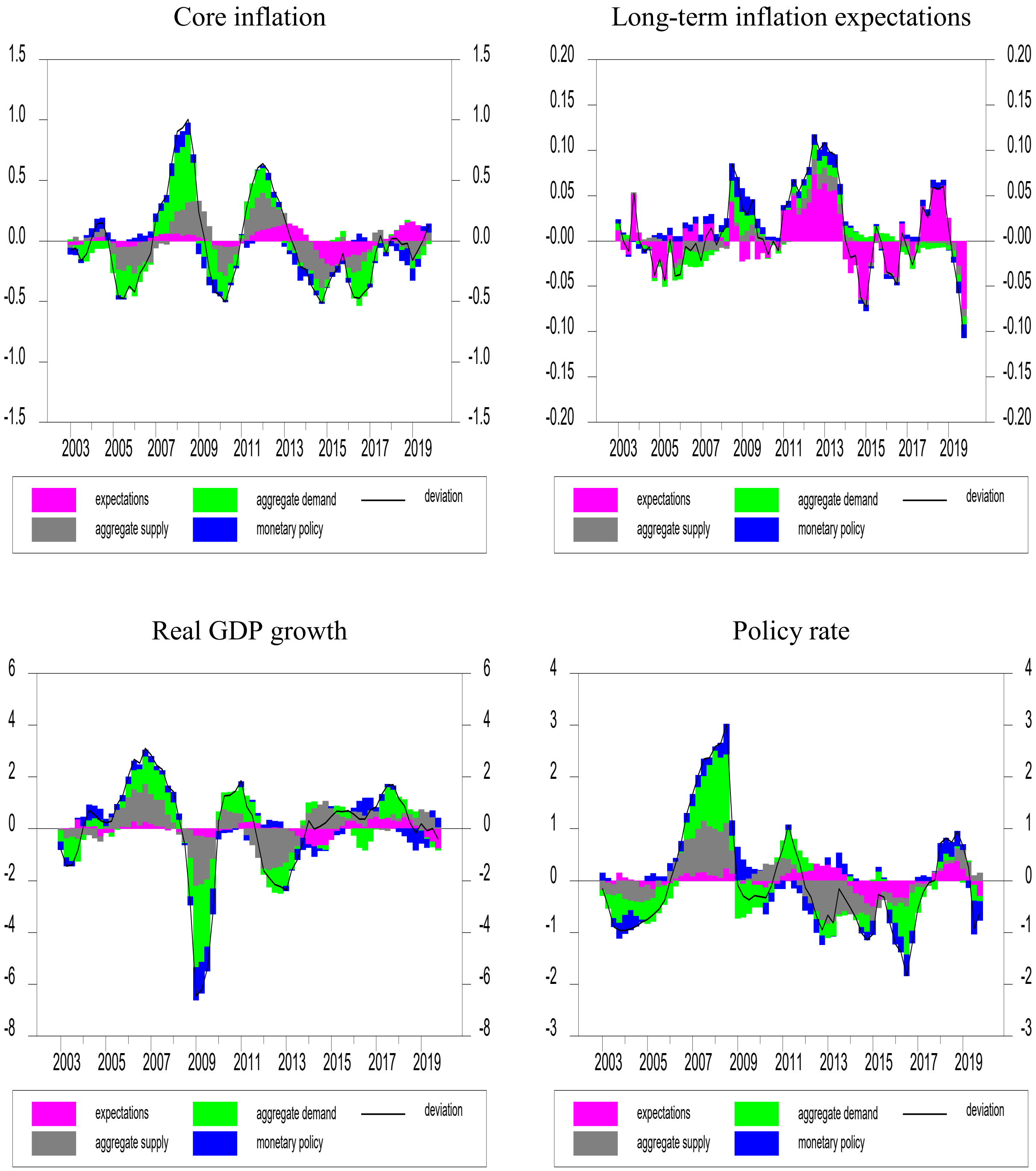
Figure C8. Impulse response to an inflation expectation shock: counterfactual with no monetary policy response

(*per cent and percentage points; deviation from unshocked path*)



Note: the red solid and red dotted lines denote, respectively, the median and the mean of the marginal posterior distributions of the impulse responses at each step in the counterfactual simulation. The dark grey area denotes the range delimited by the 0.16 and 0.84 percentiles of the posterior distribution. The blue dotted line shows the median impulse response to a negative shock to long-term inflation expectations in the baseline case (Figure 7).

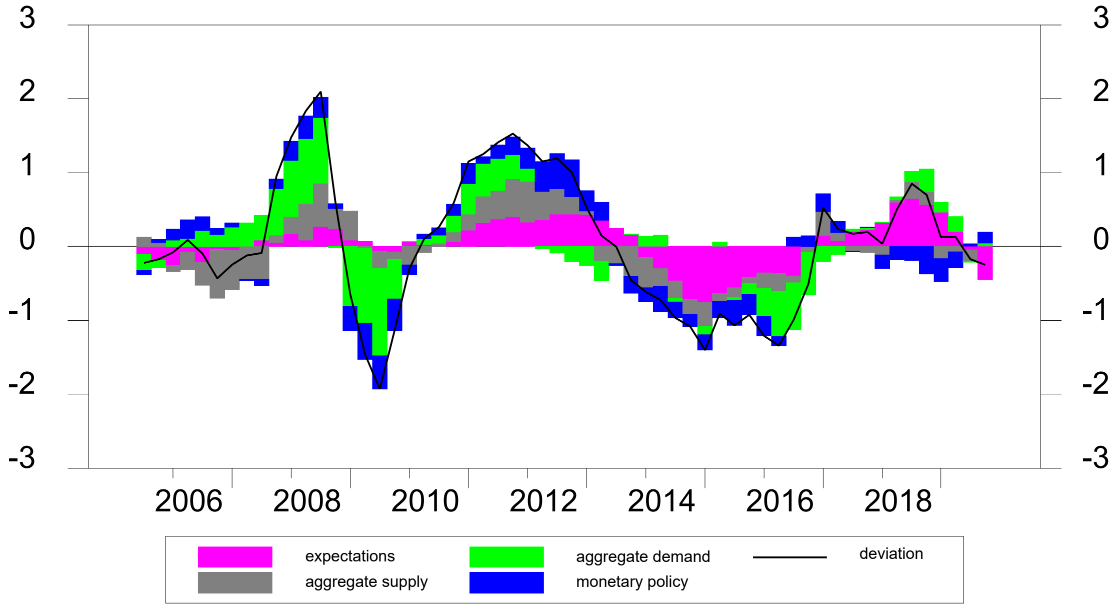
Figure C9 – Historical decomposition



Note: the contribution of each shock to the deviation of year-on-year inflation from the baseline is the mean of the (marginal) posterior distribution in each quarter. The first observation for the computation of the contributions is 2002:Q1 and the last one is 2019:Q4. In the chart, the decomposition starts in 2003:Q1 since 4 observations are lost in the computation of the inflation rate and 4 are lost due to the number of lags of the VAR.

Figure C10. Historical decomposition: inflation

(*percentage points; deviation from the baseline*)

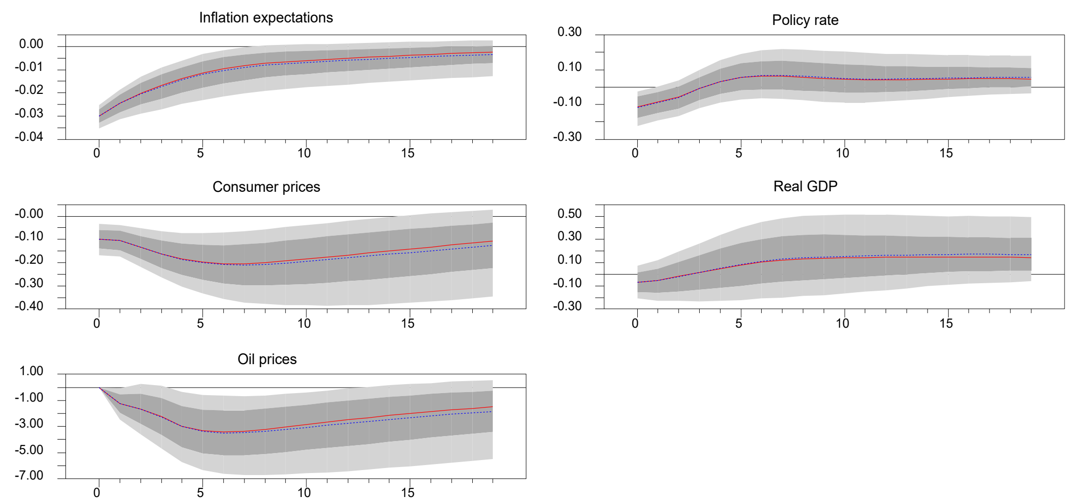


Note: the contribution of each shock to the deviation of annual inflation from the baseline is the median of the posterior distribution at each quarter (marginal posterior). The first observation is 2003:Q3 and the last one is 2019:Q4. The first observation in the chart refers to 2005:Q3. The chart is based on one million draws from the posterior distribution of the VAR parameters and 100 draws from the unitary sphere.

Autoregressive prior, linear trend and narrative restrictions: oil supply shocks

The baseline VAR with the autoregressive prior has been estimated using headline inflation, including oil prices in euro (normalized by the U.S. CPI) and identifying oil supply shocks. Shocks have been identified imposing also the narrative restrictions. The impulse responses in Figure C11 are based on one million draws from the posterior distribution of the VAR parameters and 100 draws from the unitary sphere. The burn-in sample is set at 250,000 draws. The draws which imply an eigenvalue of the companion matrix larger than one are discarded. The results are based on around 135,000 accepted draws; around 200,000 draws are discarded.

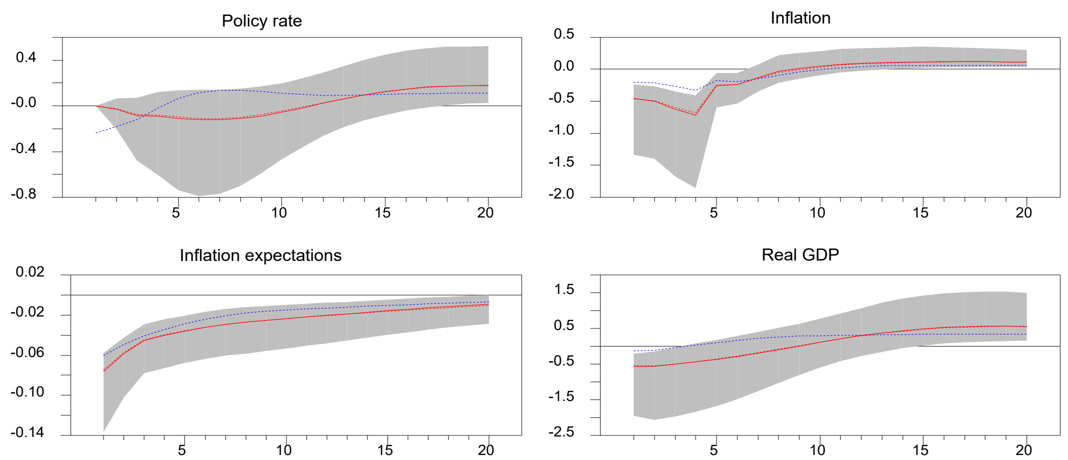
Figure C11 – Impulse responses to a shock to long-term inflation expectation



Note: the red solid and the blue dotted line refer, respectively, to the median and the mean of the marginal posterior distributions at each step. The dark grey area denotes the range delimited by the 0.16 and 0.84 percentiles of the posterior distribution. The light grey area denotes the range delimited by the 0.05 and 0.95 percentiles.

Figure C12. Impulse response to an inflation expectation shock: counterfactual with no monetary policy response

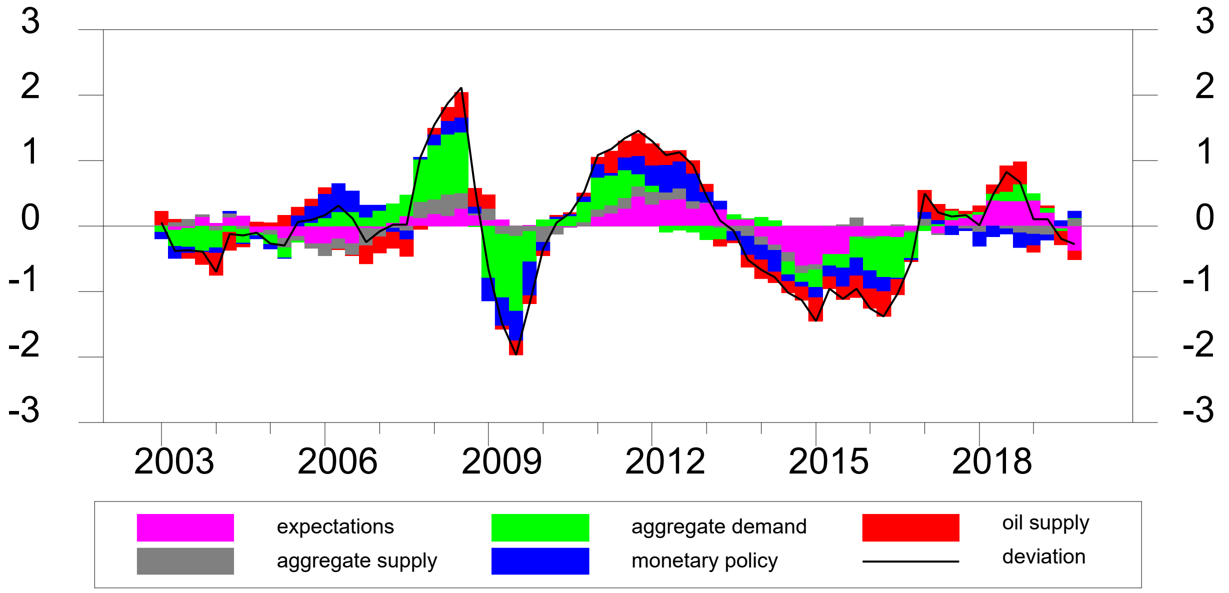
(*per cent and percentage points; deviation from unshocked path*)



Note: the red solid and red dotted lines denote, respectively, the median and the mean of the marginal posterior distributions of the impulse responses at each step in the counterfactual simulation. The dark grey area denotes the range delimited by the 0.16 and 0.84 percentiles of the posterior distribution. The blue dotted line shows the median impulse response to a negative shock to long-term inflation expectations in the baseline case (Figure 7).

Figure C13 – Historical decomposition of inflation

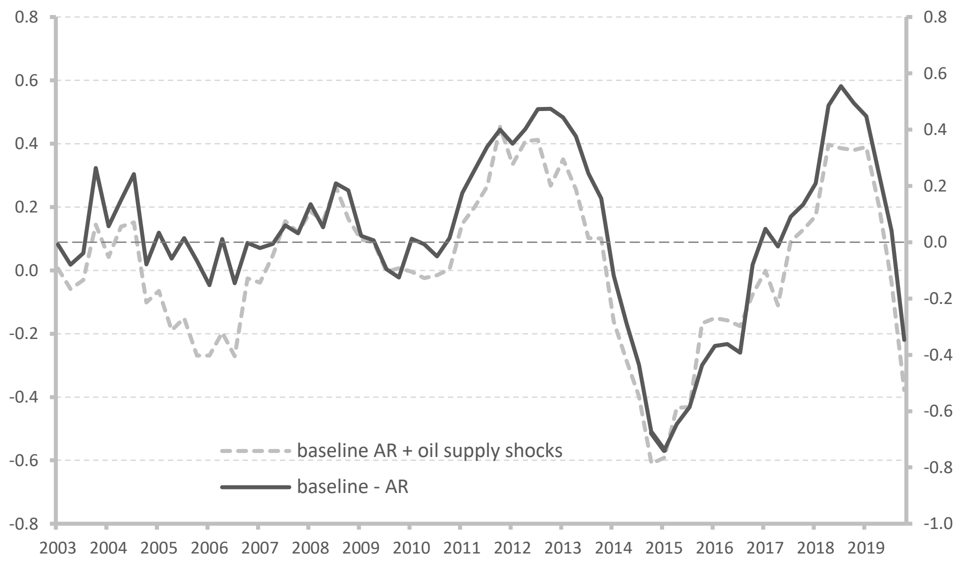
(*percentage points; deviation from the baseline*)



Note: the contribution of each shock to the deviation of annual inflation from the baseline is the median of the posterior distribution at each quarter (marginal posterior).

Figure C14. Contribution of shocks to long-term expectations to inflation

(*percentage points; deviation from the baseline*)

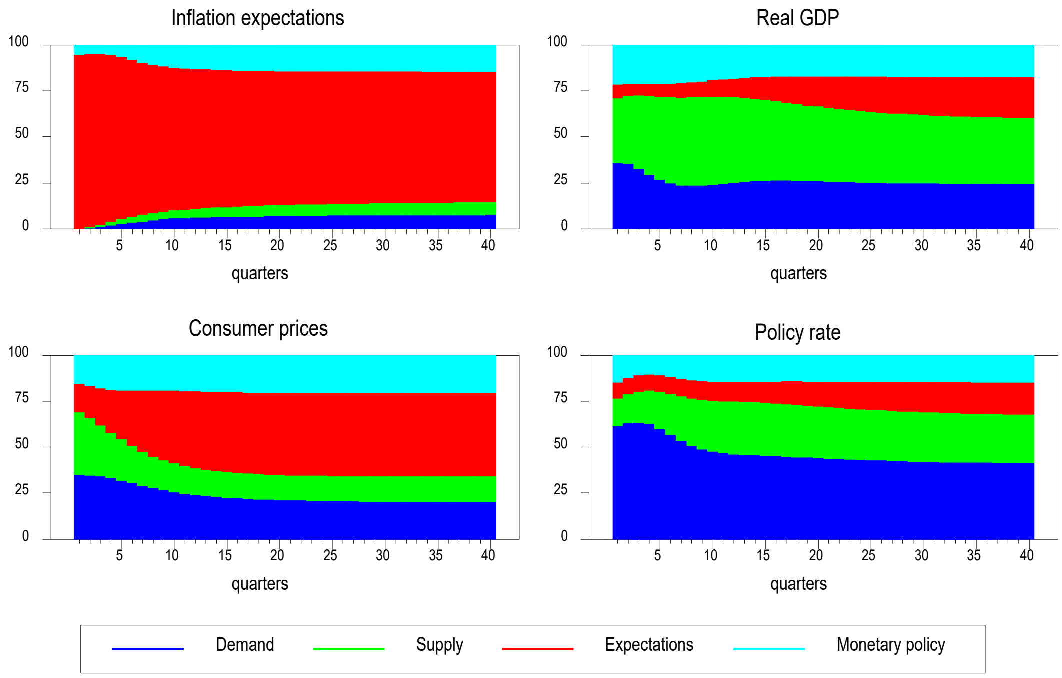


Note: the contribution of the shock to the deviation of annual inflation from the baseline is the median of the posterior distribution at each quarter (marginal posterior).

Appendix D – Additional figures

Figure D1. Variance decompositions

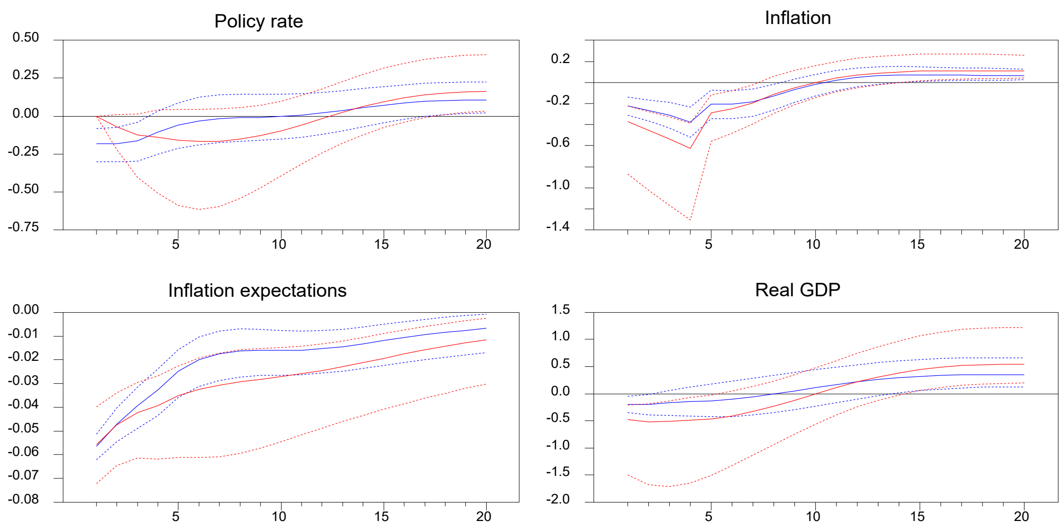
(*percentage points*)



Note: the chart shows the median of the posterior distribution of the variance decomposition in each quarter.

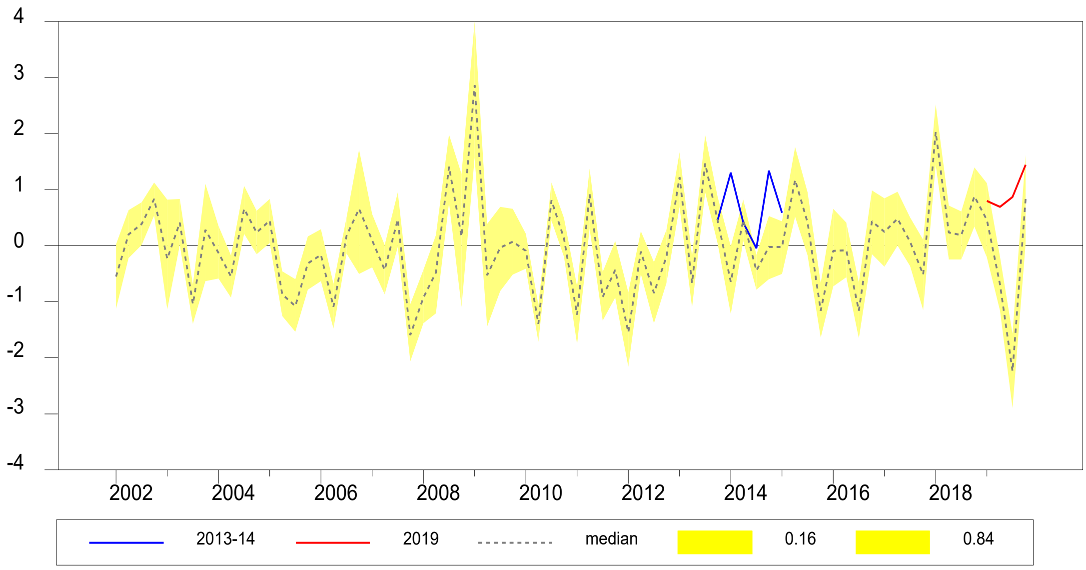
Figure D2. Impulse response to an inflation expectation shock: no monetary policy response

(*per cent and percentage points; deviation from unshocked path*)



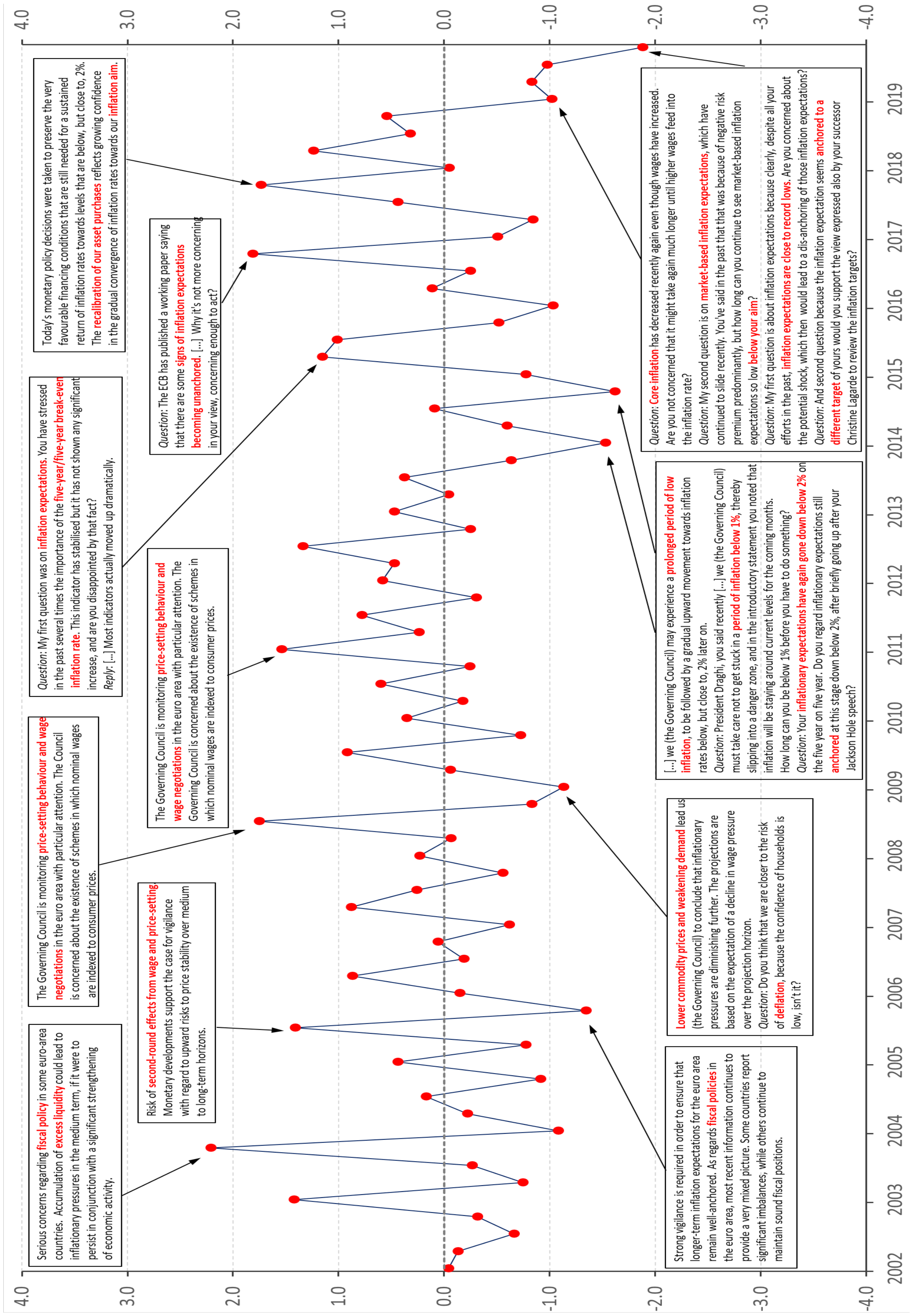
Note: the blue dashed lines denotes the 0.16 and 0.68 percentiles of the posterior distribution of the impulse responses at each step in the counterfactual simulation; the blue solid line denotes the median response. The red dashed lines denotes the 0.16 and 0.68 percentiles of the posterior distribution of the impulse responses at each step in the baseline simulation; the red solid line denotes the median.

Figure D3. Monetary policy shocks: full sample and counterfactuals



Note: the grey dotted line denotes the median of the posterior distribution of the monetary policy shocks in the VAR with autoregressive prior and lianer trend, in which the shocks are identified with sign an narrative restrictions. The yellow shaded area represents the interval defined by the 0.16 and 0.8 percentiles of the posterior distribution of the monetary policy shocks. The light blue and red solid lines denotes the median of the posterior distribution of the monetary policy shocks implemented in the counterfactuals for, respectively, 2013-14 and 2019.

Figure D4. Shocks to long-term inflation expectations



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