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Jonas Dovern, Geoff Kenny

The long-term distribution of expected inflation in the euro area: what has changed since the great recession?

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

The research is carried out in three workstreams:

1) Drivers of Low Inflation;

2) Inflation Expectations;

3) Macroeconomic Effects of Low Inflation.

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

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

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

Abstract: This paper analyses the distribution of long-term inflation expectations in the euro area using individual density forecasts from the ECB Survey of Professional Forecasters. We exploit the panel dimension in this dataset to examine whether this distribution became less stable following the Great Recession, subsequent sovereign debt crisis and period when the lower bound on nominal interest rates became binding. Our results suggest that the distribution did change along several dimensions. We document a small downward shift in mean long-run expectations toward the end of our sample although they remain aligned with the ECB definition of price stability. More notably, however, we identify a trend toward a more uncertain and negatively skewed distribution with higher tail risk. Another main finding is that key features of the distribution are influenced by macroeconomic news, including the ex post historical track record of the central bank.

JEL Classification: *E31, E58*

Keywords: *inflation expectations, density forecasts, ECB, euro area*

Non-Technical Summary

Like many other major central banks, the European Central Bank (ECB) is committed to the objective of price stability. In the case of the ECB, this objective is defined as an annual increase in the Harmonised Index of Consumer Prices (HICP) that is "below but close to 2.0%" and it is intended that this target is achieved over the medium run. Maintaining a solid anchoring of medium- to long-term inflation expectations is commonly seen as crucial for steering inflation toward this objective without suffering substantial economic costs. During recent years, volatile inflation rates, large macroeconomic and financial shocks, and the fact that policy rates were lowered to the effective lower bound (ELB) led to concerns about whether long-term inflation expectations are still anchored in the major currency areas. In particular, in the case of the euro area, several years of very low inflation in the wake of the Great Recession and sovereign debt crisis have led to concerns about persistently too low inflation or even deflationary risks and an associated departure of inflation expectations from levels consistent with the ECB's objective (e.g. Draghi (2014) highlights "the risk that a too prolonged period of low inflation becomes embedded in inflation expectations"). In this paper we study the key properties of the long-term distribution of inflation expectations and the forces that have helped shape them. Our primary purpose is to assess the extent to which the Great Recession and its aftermath led to any perceptible changes in this distribution. Our main findings fall into four broad categories:

First, in contrast to most existing studies which have focused on mean expectations only, our analysis jointly targets the first four moments of the long-term distribution. Hence, we can provide additional information about how long-term inflation uncertainty, the balance of long-term inflation risks and the risk of extreme inflation events may have changed since the Great Recession. A key result is that we find significant breaks in each of the first four moments of this distribution and all of them point toward a heightened risk of lower inflation outcomes. Although we document a small downward shift in the mean long-run expectations toward the end of our sample, they remain aligned with the ECB definition of price stability. However, the analysis of higher moments of the distribution points to a substantial increase in uncertainty about long-run inflation prospects compared with the period prior to the Great Recession and also a tendency towards negatively skewed long-term density forecasts with some small increase in tail risk. Our finding of a negatively skewed long-term distribution is precisely what is predicted by macroeconomic models which incorporate a lower bound constraint on nominal interest rates. Taken together, these distributional changes imply that the levels at which euro area inflation expectations are anchored has not changed substantially following the Great Recession. In particular, the level of long-term inflation expectations remains aligned with the ECB's quantitative definition of price stability. However, the shifts in higher moments indicate a change in the degree to which inflation expectations are anchored, i.e. in how tightly they are anchored at that level.

Second, we uncover significant co-movement between the first two moments of the long-term distribution and various macroeconomic indicators, including indicators capturing the effects of monetary policy. Such co-movement implies that the process governing the long-term distribution is far away from a simple stylized case where the inflation objective is a universal constant and where there is "blind faith" in the ability of the central bank to achieve this objective. Instead, the co-movements that we identify are more in line with theories emphasising uncertainty about the monetary policy transmission mechanism in which agents update their long-run beliefs in response to relevant shocks. For example, we find that long periods of below-expected inflation may eventually lead to lower long-term expectations. In this sense, long-term inflation expectations may not be completely forward looking. Ultimately, they tend to be influenced by the ex post historical track record of the central bank relative to its announced objective. Such results provide strong support for recent concerns about inflation remaining “too low for too long” and unconventional monetary policies aimed at avoiding a persistent undershooting of the price stability objective. Regarding our central question, however, these mechanisms existed also prior to the Great Recession and, overall, they do not appear to have strengthened in its aftermath. Rather it appears to be the persistence of the underlying shocks and the repeated downward revisions in medium-term inflation expectations that have given rise to the small decline in mean long-run expectations.

Thirdly, our analysis sheds light on how forecasters update their assessment of long-run inflation uncertainty in response to macroeconomic developments. Factors which influence this assessment include the volatility in recent inflation rates and perceptions of increased inflation uncertainty at shorter horizons. Also, our results suggest that longer-term uncertainty about the real economy – both about growth and unemployment – spills over into increased uncertainty about long-term inflation. Such mechanisms help explain the large upward shift in long-term inflation uncertainty following the Great Recession in the euro area. They point to a world in which private agents “worry” about the ability of the central bank to hit its target. In this respect, we identify significant counteracting, i.e. uncertainty reducing, effects associated with standard monetary policy instruments. However, this effect is driven by the data in the sample prior to the Great Recession. Concerning the role of more recent non-standard monetary policies, our sample is such that we must limit ourselves to an assessment of how inflation uncertainty responded to key monetary policy announcements. We find that the announcement dates for non-standard measures were generally followed by an increase in inflation uncertainty. Such a result must be interpreted with caution, however. On the one hand, it might reflect elements that our regressions have failed to control for and which simultaneously led to an increase in uncertainty in these quarters. On the other hand, it may point to the fact that forecasters have little historical experience with such measures and their transmission to inflation, highlighting an important communication challenge for monetary policy.

Finally, many models which allow for the lower bound on nominal interest rates highlight the possibility of multiple equilibria. Such models place a large weight on central bank communication and the role of a credible price stability objective in helping to coordinate potentially heterogeneous expectations of different agents. We have therefore also explored our individual level dataset for possible heterogeneity to assess whether forecasters from countries that were proportionately more impacted by the crisis or forecasters working in the financial sector behave differently from others. The main finding is that our key results described above are often shared across these different groups of forecasters. If anything, forecasters from the financial sector appear more sensitive to the lower bound on nominal interest rates and the risk associated with low inflation. However, the mean expectations of forecasters from the financial sector remain fully aligned with the ECB definition of price stability. Another interesting finding is that the long-run inflation expectations of forecasters from countries proportionately more impacted by the Crisis appear to co-move with long-run expectations for growth and unemployment, while this effect is not observed for forecasters from other countries in our panel.

1 Introduction

Like many other central banks, the European Central Bank (ECB) is committed to achieve a particular rate of consumer price inflation. In the case of the ECB, this objective is defined as an annual increase in the Harmonised Index of Consumer Prices (HICP) that is "below but close to 2.0%" and it is intended that this target is achieved over the medium run. Maintaining a solid anchoring of medium- to long-term inflation expectations is commonly seen as crucial for steering inflation toward this objective without suffering substantial economic costs. During recent years, volatile inflation rates, large macroeconomic and financial shocks, and the fact that policy rates were lowered to the effective lower bound (ELB) led to concerns about whether long-term inflation expectations are still anchored in the major currency areas. In particular, in the case of the euro area, several years of very low inflation in the wake of the Great Recession and sovereign debt crisis have led to concerns about persistently too low inflation or even deflationary risks and an associated departure of inflation expectations from levels consistent with the ECB's objective (e.g. Draghi (2014) highlights "the risk that a too prolonged period of low inflation becomes embedded in inflation expectations").

In considering the degree to which private expectations about inflation remain aligned with a central bank's objective, economic theory clearly highlights the importance of analysing the entire probability distribution surrounding such expectations. In particular, while mean expectations play a key anchoring role, theoretical considerations also highlight how shifts in the variance of this distribution, its skewness or tail risk may offer additional evidence of any change in agents' beliefs about future inflation over the longer term and the factors that may be shaping them.[1] To date, however, the empirical literature has almost entirely focussed on measures of mean long-term expectations and has largely ignored higher moments of this distribution. Moreover, there has been little analysis thus far of possible heterogeneity in people's beliefs about future inflation over the long run, as also reflected in such higher moments of the distribution. In this paper, drawing on a rich micro dataset of probabilistic assessments from professional forecasters, we contribute new empirical evidence that focusses on the full distribution of long-term expectations.[2] Using the individual density forecasts from the ECB Survey of Professional Forecasters (SPF), we investigate whether this distribution has become less anchored in the euro area and whether the behaviour of forecasters has changed in the wake of the Great Recession of 2008-2009, the euro area sovereign debt crisis and since the introduction of unconventional monetary policy tools. The SPF provides an ideal source of information to analyse this question because it surveys individual density forecasts for inflation at horizons of five years ahead in addition to the one- and two-year-ahead

[1] Mehrotra and Yetman (2014) highlight the importance of the full distribution, noting that there are "at least two dimensions to anchoring […] both the level at which expectations are anchored and how tightly expectations are anchored at that level". Only the full distribution can speak directly to the latter aspect.

[2] A brief word on terminology: By the distribution of long-term expectations we are referring to the probability assessments of economic agents that relate to all possible future inflation outcomes. This distribution contrasts with the cross-sectional distribution of long-term mean expectations that are held by economic agents. The standard deviation of the cross-sectional distribution provides a measure of disagreement about future inflation that has often been used as a proxy for uncertainty about future inflation. An important virtue of our dataset is that it provides agent-specific measures of uncertainty as opposed to imperfect proxies (Giordani and Söderlind, 2003; Lahiri and Sheng, 2010) that rely on the cross-sectional distribution.

expectations.[3] Using a panel data set on surveyed individual density forecasts allows us to analyse the entire distribution of forecasts at a micro level which may contain more information about the process governing long-run inflation expectations than average point or even average density forecasts. Indeed, the SPF provides a rich source of evidence about the question at hand that complements more indirect indicators extracted from financial assets or derivative markets. The latter have a number of clear advantages compared with survey data, in particular their high frequency and timeliness. However, such measures are potentially distorted by idiosyncratic features in specific financial markets, including market liquidity. In contrast, the SPF offers a direct source of information on the main features of the full distribution for long-term inflation expectations that is not encumbered by such influences.

We begin our empirical analysis by looking at evidence for possible shifts or structural breaks in the long-term distribution of expected inflation. In so doing, we examine the empirical stability of key distributional moments such as mean long-term inflation expectations, their variance as well as higher moments such as skewness and tail risk. Shifts in these moments may be particularly informative about the anchoring of inflation expectations in the wake of the Great Recession, including the impact of heightened uncertainty among economic agents about the central bank's ability to meet its objective or about the possible risks of deflationary equilibria which may result from the ELB. Moreover, in testing for such breaks, we explore the possibility of heterogeneity across the expectations of different groups of forecasters such as forecasters domiciled in countries disproportionately impacted by the Great Recession and sovereign debt crisis or forecasters located in the financial sector compared with those outside the financial sector.[4]

Following on from this, our empirical study turns to the factors that might explain shifts in the long-term distribution of inflation expectations and, in particular, considers the co-movement of long-term inflation expectations and long-term inflation uncertainty with other economic variables and macroeconomic news. This mode of analysis helps us to understand the process driving the formation of long-run inflation expectations. In line with the predictions of theories highlighting uncertainty and imperfect information about the central bank's objective or its ability to meet the latter in the medium term, the possible relevance of short-term forecast errors as well as the deviation between a slow moving average of past inflation and the central bank's objective are considered as potential factors explaining changes in long-term inflation expectations. We also study the effects of changing economic structure, such as increased inflation persistence and heightened volatility in short term news about inflation, on both long-term inflation expectations and inflation uncertainty. Our empirical analysis examines whether the relevance of such variables has changed following the Great Recession and during the more recent period when the ELB has been binding and when the central bank has had to employ non-standard monetary policy measures.

[3] Bowles *et al.* (2007) suggested that the inclusion of the five-year horizon in the design of the SPF questionnaire was explicitly motivated by its relevance for the assessment of ECB credibility. In line with this study, we refer to the five-year-ahead expectations as a measure of long-term expectations.

[4] Andreou *et al.* (2016) propose to look at expectations of different households. However, their dataset is qualitative in nature and relates only to mean expectations.

Our paper, therefore, makes a new contribution to a growing number of recent studies analysing long-term inflation expectations. This literature has yielded the following main conclusions: The degree to which inflation expectation are anchored around a central bank's objective has been dispersed across countries and time and appears to co-move with the degree of credibility of monetary policy (Demertzis *et al.*, 2009; Dräger and Lamla, 2013). Over the last decades, the tendency towards better anchored expectations was stronger in countries with official inflation targets (Gürkaynak *et al.*, 2010; Demertzis *et al.*, 2012; Mehrotra and Yetman, 2014), suggesting that agents use inflation targets as focal points when forming long-term inflation expectations. With respect to the euro area, there is evidence that national inflation expectations are less well anchored for many member states compared to the aggregate expectations for the entire currency area (van der Cruijsen and Demertzis, 2011). Beechey *et al.* (2011) show that on average euro area long-run expectations are more firmly anchored than long-term inflation expectations in the US.

Notwithstanding the above expanding body of literature, the evidence about how the Great Recession and the ensuing period of volatile and low inflation rates may have impacted long-term inflation expectations remains incomplete. Thus far, empirical studies have largely focussed on mean expectations and thus ignored evidence derived from higher moments of the distribution. In general, it is found that long-term mean inflation expectations in the US started to react more strongly to macroeconomic news after the financial turmoil of 2008 (e.g., Galati *et al.*, 2011; Nautz and Strohsal, 2014; Autrup and Grothe, 2014).[5] Indeed, exploiting measures of inflation compensation derived from financial markets, Ciccarelli and Garcia (2015) report evidence that long-term inflation expectations in the US may have become more sensitive to news about long-term inflation expectations in the euro area. Ehrmann (2015) reports evidence of a similar increased sensitivity during periods of low inflation. Overall, the evidence on the stability of long-term expectations in the euro area appears mixed. On the one hand, Galati *et al.* (2011) report evidence for a structural break in the responsiveness of European inflation expectations to macroeconomic news and Lyziac and Palovitta (2016), exploiting the SPF to study the anchoring of long-term inflation expectations in the euro area, conclude that there are "some signs of de-anchoring" in the period since the financial crisis.[6] On the other hand, Strohsal and Winkelmann (2015) as well as Autrup and Grothe (2014) conclude that the degree of anchoring did not change around that time. Also, Speck (2016) uses an event study to analyse mean expectations implicit in inflation-linked swap markets and concludes that medium-term expectations may still be considered firmly anchored.

The remainder of the paper is structured as follows. In Section 2, we review relevant theory for predictions about how the Great Recession and its aftermath might impact on key features of the long-term distribution. In addition, we review the relevant literature highlighting the effects of uncertainty about the central bank's objective and the implications of the ELB for the distribution of long-term inflation expectations. In Section 3, we provide direct evidence about significant shifts in the distribution of long-

[5] Note the contrasting results in Aruoba (2016) who computes the term structure of inflation expectations based on information from different survey sources and concludes that long-term inflation expectations in the US are well anchored also after 2008.
[6] Their analysis examines only aggregate data and the first moment of expectations.

term inflation expectations for the euro area. Then in Section 4 we turn to the analysis of the factors which may have contributed to changes in long-term inflation expectations and uncertainty and whether the role of such factors changed in the wake of the Great Recession. In Section 5, we close by discussing the economic significance of our findings and their implications for monetary policy.

2 The Distribution of Long-term Inflation Expectations: Theory and Testable Implications

In this section we review relevant macroeconomic theory to help structure thinking on the main factors which are likely to impact on either the level at which long-term expectations are anchored or the degree to which they are anchored. We first describe the implications of a stylized canonical monetary business cycle model and, in particular, highlight that it has implications not just for the mean of well-anchored long-term inflation expectations but for the entire distribution surrounding such expectations. We then review more recent literature focussing on two crucial extensions of that model and we highlight their distributional implications. The first concerns possible time variation in the central banks' inflation objective and/or imperfect knowledge on the part of private agents about that objective. The second relates to the implications of the ELB for the distribution of long-term inflation expectations. We then try and tease out the testable implications of these theoretical considerations for our subsequent empirical analysis. Our central insight is that an informed assessment of the extent to which inflation expectations are aligned with a central bank's objective should be derived not solely from an analysis of the mean of the distribution for long-term inflation expectations but also from an analysis of other (higher) moments of this distribution.

2.1 Theory

According to the canonical monetary business cycle model (see, for example, Beechey *et al.*, 2011 for an illustration), if a central bank clearly announces its intention to achieve a particular inflation objective (π^*) over the long-term and if the public believes it has both the commitment and the instruments (i.e. ability) to achieve that objective, then long-term inflation expectations should be stable, or "well-anchored", at the announced objective. In this simplified framework, macroeconomic dynamics are driven by shocks to aggregate demand and supply and the central bank adjusts its policy rate in order to stabilise inflation around its objective. According to the rational expectations assumption, all agents in the economy are assumed to know the model structure and the value of all model parameters, including the central bank's fixed inflation objective. Given these assumptions, the conditional expectation[7] of private agents based on period t information about inflation in the next period reduces to

$$(2.1) \qquad \pi_{t+1|t} = \frac{\alpha\theta}{1-\phi}\pi^* + \frac{1-\phi-\alpha\theta}{1-\phi}\pi_t.$$

[7] At this point we implicitly assume that forecasters have quadratic loss functions or any other loss function that makes it optimal to set the forecast equal to the conditional mean expectation.

The model implies that the expected rate of inflation next period is simply a weighted sum of current period inflation and the central bank's target rate. The weights reflect some of the key model parameters capturing i) the weight on inflation in the central bank reaction function determined by θ ii) the degree of intrinsic persistence in the inflation process determined by $1-\phi$, and iii) how sensitive inflation is to excess demand, i.e. the slope of the Philips curve determined by α). Iterating this equation forward, (see, for instance, Capistrán and Ramos-Francia, 2010), it can be shown that for large h the long-term inflation expectation will converges to π^*, i.e. $E_t\pi_{t+h} = \pi_{t+h|t} = \pi^*$. Thus, in this model, short-term inflation expectations will deviate from the inflation target after temporary shocks have driven inflation away from this target. However, this deviation is decreasing in the forecast horizon and the longer the forecast horizon the smaller should be the reaction of expectations to economic shocks. Precisely what forecast horizon is required to make expectations (virtually) insensitive to macroeconomic shocks? All else equal, the required horizon becomes larger in the presence of (i) a less aggressive central bank who adjusts interest rates more slowly in response to deviations of inflation from the target (i.e. a smaller θ), (ii) less of a weight on expectations in driving current inflation dynamics (smaller ϕ), or equivalently, stronger intrinsic inflation persistence and (iii) less sensitivity of inflation to the output gap (smaller α), i.e., a flatter Phillips curve. In practice, therefore, even if a central bank maintains a firm commitment to its objective, structural changes in the economy such as those that induce a change in ϕ and α can imply an increased sensitivity of long-term expectations to macroeconomic shocks. However, even in such a setting, and as also noted by Dräger and Lamla (2013), the degree of co-movement between long-term expectations and macroeconomic news (e.g., changes in short-term expectations) can be used as a measure of the degree of anchoring or de-anchoring.

In addition to its clear predictions for the behaviour of long-term mean inflation expectations, the above simple framework also yields stark implications for other "higher" moments of the long-term distribution for expected inflation. In particular, in this model, long-term inflation uncertainty – as measured by the long-term forecast error variance – will be equal to the unconditional variance of inflation. To see this, recall that the rational long-term forecast is given by π^*. Consequently, the long-term forecast error is given by $\lim_{h\to\infty} e_{t+h|t} = \pi_{t+h} - \pi_{t+h|t} = \pi_{t+h} - \pi^*$. Since π^* is assumed fixed and perfectly communicated and understood, it follows that

$$(2.2) \qquad Var\left[e_{t+h|t}\right] = Var[\pi_{t+h} - \pi^*] = Var[\pi_{t+h}].$$

Hence, as the target imparts no uncertainty to the long-term inflation outlook, we should also expect to observe a stable variance in the long-term distribution of expected inflation so long-as the unconditional variance of actual inflation is stable.

In reality of course, we may observe changes in the variance of this long-term distribution and such changes may provide useful information on the degree of anchoring of inflation expectations. For example, the recent theoretical literature examining the implications of learning and imperfect information for monetary policy (see, for instance, Orphanides and Williams, 2004 and 2007) identifies such an effect.

For example, Beechey *et al.* (2011) extend the above simple framework and conduct stochastic simulations to examine the effect of more realistic assumptions about how agents form their expectations. In particular, they relax the assumption of a constant and explicit inflation target that is known to all agents but instead consider two extensions. A first extension retains the assumption of a constant objective but introduces imperfect knowledge by requiring agents to infer this constant objective based on the observed reduced-form dynamics of inflation. A second extension considers the possibility of explicit time-variation in the central bank's objective. Under both of these settings, the authors demonstrate that long-term expectations will no longer be fixed at the inflation target but instead will tend to be revised in response to temporary shocks. For instance, for a reference calibration of their model, the response to cost-push shocks of inflation expectations at the five-year horizon nearly doubles when one allows for uncertainty and time-variation in the central bank's objective.[8] Moreover, although long-term expectations will still tend to be less volatile than short-term expectations, such extensions are associated with a sizeable increase in long-term inflation uncertainty, i.e. the forecast error variance of long-run inflation expectations.[9]

Another implicit assumption underlying the model discussed above is that the central bank is always able to adjust its policy rate in response to deviations of inflation from its objective. However, in practice, central banks may be constrained in their ability to do so because of the ELB on nominal interest rates (e.g. Krugman, 1998 and Eggertson and Woodford, 2003). Under such circumstances, models can exhibit multiple equilibria, implying that the long-term distribution of inflation expectations may change and attach non-negligible probabilities to quite distinctive equilibria. Following a period such as the Great Recession, achieving the central bank's inflation objective may therefore become more challenging because, first, the issue of central bank credibility becomes more relevant compared to "normal" times (Bodenstein *et al.*, 2012) and, second, agents may increase their assessment of the duration and the persistence of the ELB regime (Hills *et al*, 2016). For instance, Benhabib *et al.* (2001) highlight the existence of a deflationary equilibrium where the ELB is binding and inflation is stuck below target. More recently, Auroba and Schorfheide (2015) construct a two-regime stochastic equilibrium in which the economy may alternate between a "targeted inflation" and a "deflation" regime.[10] Busetti *et al.* (2014) also study the risks of such a regime in a model with learning and show that it may imply considerable risks of a de-anchoring of long-term inflation expectations and give rise to a period of sustained low growth in real output.[11] Importantly, a key insight from models with multiple equilibria is the importance of how agents

[8] There has been considerable discussion in the wake of the financial crisis about the need for central banks to consider adjusting upwards their inflation objectives. Ball *et al.* (2016), for example, recently make this recommendation as a means to avoid the incidence, severity and costs of hitting the ELB constraint. This discussion is conceptually distinct from other recommendations which have emphasized increasing short-run inflation expectations as a demand management device at the ELB.

[9] With such uncertainty about the objective of the central bank, the last equality in equation (2.2) would no longer hold because $Var[\pi^*] > 0$.

[10] Aruoba *et al.* (2013) find that Japan experienced a switch to such a deflation regime in 1999. Arias *et al.* (forthcoming) also develop a theoretical model to explore the interaction of inflation expectations and actual inflation at the ELB on nominal interest rates.

[11] An equilibrium of weak growth and deflation is central to the recent debate on the risks of secular stagnation which has been reignited by Summers (2014). According to this view, excessive saving acts as a drag on demand reducing growth, inflation and real interest rates.

coordinate their beliefs about future states of the economy or future policy actions. Hence, such models place a strong emphasis on the implications of heterogeneity across agents expectations and the role that central bank communication can play in helping to avoid bad equilibria.[12]

Clearly, the risks of such bad equilibria may tend to show up in increased long-term inflation uncertainty, i.e. in a higher variance of the long-term distribution. However, they may also be reflected in third and fourth moments such as skewness and measures of tail risk. For example, Coenen and Warne (2014) highlight the implications of the ELB for the overall symmetry of the long-term distribution of expected inflation. Employing stochastic simulations of the ECB's New Area-Wide Model to investigate the consequences of the ELB on nominal interest rates for the evolution of risks to price stability following the recent financial crisis, their results highlight how this distribution can become heavily asymmetric and skewed to the downside due to the incidence of the ELB constraint which limits the ability of the central bank to respond to deflationary shocks.[13] Of course, central banks also have access to other tools, such as forward guidance on the future path of short term interest rates or asset purchase programmes and these can help mitigate or even potentially offset completely the effects of the ELB. In particular, such tools may play an important role in helping to stabilise inflation expectations and avoid slipping into a deflationary regime.

2.2 Testable Implications

A powerful and *sufficient* condition for perfectly anchored long-term inflation expectations is that they are constant and equal to the central bank's objective. However, in practice, once one allows for the possibility of structural changes in the economy, uncertainty about the central bank's objective, learning on the part of economic agents, or constraints such as the ELB on nominal interest rates, it makes sense to consider the stability of the entire distribution not just mean long-term expectations.[14] We therefore begin our empirical analysis in Section 3 by looking at evidence for possible shifts or structural breaks in this distribution over time. In so doing, we examine the empirical stability of key distributional moments such as mean long-term inflation expectations, mean long-term inflation forecast variance as well as average higher moments such as skewness and tail risk. As highlighted by the discussion above, shifts in these higher moments may be particularly informative concerning increased uncertainty about the central bank achieving its objective, including the possible risk of deflationary equilibria which may result from the ELB. Moreover, we search for any differences in the stability of these moments across agents, singling out forecasters from crisis countries and the financial sector.

[12] The models in Wiederholt (2015) and Andrade *et al.* (2015) emphasise the implications of heterogeneous beliefs in models with a binding lower bound on nominal interest rates.

[13] Earlier papers highlighting the implications of the ELB for the skewness of inflation expectations include Reifshneider and Williams (2000) and Coenen *et al.* (2004). Another relevant strand in this literature, e.g., Hills *et al.* (2016), emphasises how the presence of the lower bound has implications for the economy even when the policy rate is away from zero.

[14] A recent study by Cecchetti *et al.* (2015) also emphasizes the importance considering the full distribution when examining the degree of anchoring of long-term expectations. In particular, they find that negative tail events impacting on short-term expectations have been increasingly channelled to long-term views about inflation.

Following on from this, in Section 4, we turn to the factors that might explain shifts in the long-term distribution of inflation expectations and, in particular, consider the co-movement of key moments with other economic variables and macroeconomic news. In conducting this analysis, we examine whether the relevance of such variables has changed following the great recession and during the more recent period when the ELB has been binding and when the ECB has had to employ non-standard monetary policy measures. Focussing on both long-term expectations and uncertainty, this analysis helps shape our understanding of the degree to which this distribution has remained well anchored and the factors that may have driven any change over time.[15] In line with the predictions of the theory discussed above, we consider a wide range of possible co-variates capturing short-term macroeconomic news and uncertainty, measures of perceived structural change, the central banks historical track record and indicators capturing monetary policy actions and/or announcements.

3 Identifying Breaks in the Distribution of Long-term Inflation Expectations

In this section we report our empirical analysis of possible structural breaks in the distribution of long-term inflation expectations. We first describe our main source of data and our approach to estimating density moments. We then discuss the empirical model used to estimate possible breaks in the distribution before reporting the main findings. The latter are first reported at an aggregate level but we also consider possible heterogeneity across forecasters depending on their sectoral affiliation or country of origin. In particular, we examine whether forecasters strongly affiliated with the financial sector or domiciled in countries which were disproportionately more impacted by the financial crisis exhibit a different behaviour compared with the aggregate.

3.1 Data and Estimation of Density Moments

Before attempting to identify breaks in the long-term distribution of inflation expectations, it is necessary to estimate the key moments summarizing the distribution's location, spread, symmetry, and tail risks. We base our analysis on the densities of individual forecasters as provided by the SPF which is published by the ECB at a quarterly frequency since the beginning of 1999. Since we are interested in long-term inflation expectations, we primarily focus on those forecasts that have a forecast horizon of roughly five years (i.e. twenty quarters or $h = 20$). Our sample period ranges from 1999Q1 to 2015Q2.[16] Appendix I provides a complete description of the SPF and other data sources used in the paper. Reflecting its survey origins, the SPF data set is heavily unbalanced because forecasters leave the panel or enter later and

[15] In the case of mean long-term expectations, this mode of analysis speaks to a necessary but not sufficient condition for them to be well anchored. A lack of co-movement between long-term expectations and other variables is not sufficient to guarantee a perfect anchoring of inflation expectations. For example, it could be that long-term expectations are independent from short-term inflation expectations and current inflation developments but they are influenced by another factor that makes them deviate from the central banks inflation target. For a model that features different shocks to short-term and long-term inflation expectations, see Nautz *et al.* (2016).

[16] Note that during the first two years of the SPF long-term forecasts were only surveyed on an annual basis in 1999Q1 and 2000Q1. We make use of these observations whenever possible (e.g., in the analysis of Section 3.2). However, we have to drop them from the sample whenever we relate long-term expectations to lagged (by one quarter) information from the SPF (e.g., in the regression analysis of Section 4.1).

because they are not required to report their forecasts in every survey round. We focus on the analysis of this unbalanced panel and, in particular, do not attempt to interpolate any missing observations. The number of available long-term inflation forecasts averages 39.5 (and ranges from 30 to 59).

The density forecasts are provided as histograms for which forecasters report probability forecasts that reflect their assessment of the likelihood that future inflation will fall within certain intervals. Formally, denote with $f_{i,t+h|t}^{k}$ the probability that forecaster i ($i = 1, \dots, N$) in survey period t attaches to the event that the inflation rate in period $t+h$ falls into a particular interval k ($k = 1, \dots, K$).[17] To compute mean long-term expectations, the corresponding inflation uncertainty, and higher moments of the density forecasts, we adopt a non-parametric approach which assumes that all the probability mass in a particular interval k is compressed at the midpoint of this interval, which we denote by μ_k. The first four moments are then given by

(3.1) Mean: $$\pi_{i,t+h|t} = \sum_{k=1}^{K} f_{i,t+h|t}^{k} \, \mu_k$$

(3.2) Variance: $$\sigma_{i,t+h|t}^{2} = \sum_{k=1}^{K} f_{i,t+h|t}^{k} \left(\mu_k - \pi_{i,t+h|t}\right)^2$$

(3.3) Skewness: $$s_{i,t+h|t} = \sum_{k=1}^{K} f_{i,t+h|t}^{k} \left(\mu_k - \pi_{i,t+h|t}\right)^3 / \sigma_{i,t+h|t}^{3}$$

(3.4) (Excess) kurtosis: $$k_{i,t+h|t} = \sum_{k=1}^{K} f_{i,t+h|t}^{k} \left(\mu_k - \pi_{i,t+h|t}\right)^4 / \sigma_{i,t+h|t}^{4} - 3$$

For each moment $m = \{\pi, \sigma^2, s, k\}$, we construct the cross-sectional average as $\bar{m}_{t+h|t} = 1/N_{t+h|t} \sum_{i=1}^{N_{t+h|t}} m_{i,t+h|t}$, where $N_{t+h|t}$ denotes the number of density forecasts with a forecast horizon of h quarters available at time t.

3.2 Testing for Breaks in Density Moments

Following on from the discussion in Section 2, a powerful set of conditions for inflation expectations to be fully anchored is that their distribution is stable around the central bank's inflation target. To examine this, we test for evidence of any breaks in the moments estimated above. We employ the method of Bai and Perron (1998, 2003), who consider the linear regression model with a finite number of unknown breaks in the model parameters. Their method yields estimates of the unknown regression coefficients associated with each regime together with estimates of each of the unknown break points. To select the number of significant breaks and to date their occurrence, we apply these methods to a regression model that includes only an intercept. Formally, the considered model is

(3.5) $$\bar{m}_{t+h|t} = \alpha_{m,r} + \varepsilon_{t+h|t}^{m},$$

[17] Note that K changes over time as the survey design was changed at several points in time. We tackle this issue by assigning a probability of 0 to intervals that were not included in a particular survey round.

where $\alpha_{m,r}$ denotes the mean of each moment $m = \{\pi, \sigma^2, s, k\}$ conditional on being in structural regime r = 1, ... R and $\varepsilon_{t+h|t}^{m}$ is an iid error term. Hence for the case of mean long-term expectations ($m = \pi$), the estimate of $\alpha_{\pi,r}$ is an estimate of the average expected rate of long-term inflation in a given regime. Under the assumption that forecasters believe that, in general, the central bank is able to achieve its inflation target in the absence of further shocks such an estimate provides a regime-specific measure of the perceived inflation objective. In the absence of any structural breaks, we have $\alpha_{\pi,r} = \alpha_{\pi}$ and, hence, the long-term expectation for inflation is constant.

In testing for such breaks, a focus on mean expectations from equation (3.1) is justified because it draws on all the probabilities collected from respondents.[18] As such, it may contain more information than the long-term point forecasts that are also collected in each survey round. Figure 1 plots the mean estimated according to equation (3.1) together with two other measures of central tendency taken from the survey. A first such measure is the mode computed as the mid-point of the interval which is assigned the maximum probability, again averaged across the responding forecasters in a given round. The second measure is simply the average point forecast for inflation with the same long-term horizon. Overall, one observes a very clear co-movement and similarity between these three measures of central tendency. In particular, the average point forecast and the estimated mode appear very closely related, suggesting that when they give their point forecasts they may be giving a modal prediction. However, in the period since the financial crisis mean expectations dropped slightly below both the estimated average mode and the reported point forecasts. Given this divergent pattern we therefore expand our analysis of structural breaks to consider also the estimated mode of the probability distributions.

[Insert Figure 1 about here]

In a similar way to the analysis of the long-term mean, for each of the other three higher order moments, the estimate for $\alpha_{m,r}$ is an estimate for the average perceived future variance, skewness and tail risk embodied in the long-term distribution in any given regime. Breaks of these higher-order moments may signal changes in the degree to which the long-term distribution for expected inflation is anchored, i.e. in how tightly expectations are anchored around a given mean.

In implementing the Bai-Perron procedure it is necessary to specify a *minimum* required distance between any two potential break dates. We set this minimum distance between breaks at a relatively conservative level of eight quarters in order to avoid overfitting and possibly finding an implausibly large number of spurious breaks for each moment. As suggested by Bai and Perron (1998), we use the sequential test to determine the number of structural breaks.[19]

[18] Note that a measure for $\pi_{i,t+h|t}$ is also available directly from the reported long-term point forecasts. However, we focus primarily on the mean of the reported densities to ensure consistency of our results across the different moments. Furthermore, García and Manzanares (2007) provide evidence that the density forecasts from the SPF are more reliable than the point forecasts.

[19] The sequential test is based on the idea of sequentially testing the null hypothesis of l breaks versus $l + 1$ breaks until the null hypothesis can no longer be rejected. In particular, given a set of l break points, Bai and Perron (1998) suggest to apply $l + 1$ tests

3.3 Breaks in the Mean

Using the approach outlined in the previous section, we analyse whether there have been any substantial regime changes in the distribution of long-term inflation expectations. Figure 2 shows the evolution of the modal expectation discussed above together with the first four moments given by equations (3.1) to (3.4). In each panel of Figure 2, the regime-specific conditional estimates $\hat{\alpha}_{m,r}$ are also plotted. The break-point analysis of density moments is further detailed in Table 1. In particular, in the upper part of Table 1 (All Forecasters) we report a list of the estimated break dates and the corresponding *t*-statistics indicating the statistical significance of each break.

[Insert Figure 2 about here]

[Insert Table 1 about here]

For the mean expectations, we find two significant breaks in 2005Q2 and then again in 2013Q2. The earlier break indicates an upward shift in inflation expectations compared with the data before 2005. Interestingly, this upward shift came in the wake of the ECB's 2003 clarification of its primary mandate which aimed to clarify the ECBs goal of achieving a rate of inflation that is "below but close to" 2.0%. Hence the upward shift in expectations around this time can be interpreted as evidence of a successful central bank communication which brought expectations more in line with how the ECB itself interpreted its price stability mandate. Prior to this clarification, private agents may have interpreted the ECB definition of price stability as being consistent with a slightly lower rate of inflation on average. The second break in mean long-term expectations is downward and occurs in the wake of the Great Recession and euro area sovereign debt crisis. Although quantitatively modest (the regime specific mean falls to 1.80% from 1.92% prior to 2013Q2), it more than reverses the upward shift in 2005. Given the low volatility of the time series, it is found to be statistically significant despite its small magnitude. It is also of interest to consider the equivalent analysis for the long-term modal expectations also reported in Table 1. Although in this case the analysis identifies three break points, the broad findings are very similar. In particular, over the first half of the sample, modal expectations also initially adjusted upwards but generally remained at levels that were below but close to 2.0%. Following the Great Recession, in the second half of the sample, this pattern was reversed. The identified break date for this downward shift in modal expectations coincides precisely with the corresponding date for the mean.

Our results above point to a quantitatively modest but noteworthy decline in long-run mean inflation expectations toward the end of our sample. At the same time, as highlighted in Engelberg *et al.* (2009), it must be acknowledged that our moment estimates are subject to measurement error due to random variation in response rates, panel composition and the assumptions we make regarding the allocation of

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of the null hypothesis of no structural break against the alternative hypothesis of a single structural break to the $l + 1$ segments of a time series defined by the l breaks.

probability mass to the mid-points of the surveyed intervals. Mean inflation expectations also remain in a range that is fully consistent with price stability as defined by the ECB's mandate. Hence, our analysis provides no grounds to think that euro area long-run mean inflation expectations have become unanchored. The recent break in the SPF also goes in the same direction as previous signals of a downward movement in mean expectations from other sources, although the decline in the survey-based measure remains very modest compared to the decline in market-based measures (Figure 3). Studies using such data, e.g. Strohsal and Winkelmann (2015), Autrup and Grothe (2014) and Speck (2016), have also concluded that expectations did not become unanchored.

[Insert Figure 3 about here]

3.4 Breaks in the Variance

Figure 2 and Table 1 also report equivalent results for higher moments. In the case of long-term inflation uncertainty, we identify two breaks each capturing an increase in uncertainty about long-term inflation. In contrast to the analysis of the mean, the shifts in long-term inflation uncertainty are quantitatively more noticeable. For example, following the second break in 2009Q2, i.e. in the immediate wake of the Great Recession, average uncertainty about the long-term inflation at 0.65 percentage points (pp) had increased by about 40% compared with its level in the pre-crisis regime (0.47 pp). Following this increase, long-term inflation uncertainty has been quite stable at the new level and has shown no tendency to decline. This pronounced and persistent increase in the variance of the long-term distribution signals that forecasters perceive the long-term inflation outlook to be more uncertain now than before the Great Recession.[20] As a result, the distribution has become less concentrated around levels that are consistent with the definition of price stability. The increase correlates well with an increase of the unconditional variance of annual inflation rates in the euro area when computed recursively based on an expanding sample; the latter increases from about 0.2 in 2007 to a little below 0.6 in 2014.[21] Thus, it seems as if forecasters anticipate that the increase in inflation volatility which emerged after the Great Recession will be highly persistent – or even permanent – rather than being relevant only to recent years or the short-term outlook.

Overall, the identified upward shift in the variance could be taken to imply that the *degree* to which the long-term distribution is anchored has diminished. The shift in the variance is also consistent with macroeconomic theories highlighting the implications of increased uncertainty surrounding the central bank's objective (Beechey *et al.*, 2011) and, in particular, the potential effects of the lower bound on nominal interest rates (Benhabib *et al.*, 2001). However, the higher variance is also consistent with the view that forecasters believe it may take longer for the central bank to achieve its price stability objective, e.g. as a result of more persistent and volatile shocks in the future or a perceived change in the transmission of monetary policy. It does not necessarily imply that they have reduced their belief in the

[20] It is noteworthy that the upward adjustment came quite soon after the Great Recession and the sovereign debt crisis was not associated with any further rise in long-run inflation uncertainty.
[21] We use an expanding sample starting in 1997.

ECB's ability to ultimately achieve that objective over a longer horizon than the five years to which our survey data relate. Nonetheless, our findings highlight an important challenge for monetary policy and its communication in order to maximise the effectiveness of policy and to limit further the rise of uncertainty surrounding long-term inflation prospects.

3.5 Breaks in Symmetry and Tail Risk

Figure 2 and Table 1 also report the results of the break analysis for the overall skewness and tail risk in the long-term distribution for expected inflation in the euro area. The time path of the average skewness in Figure 2 provides insight on possible changes in the overall symmetry of the distribution and may thus signal concerns among forecasters about long-term inflation risks either to the upside or the downside. The plot suggests that, since 2010Q2, the forecast densities are negatively skewed whereas prior to this date they were broadly symmetric. This means that since the Great Recession forecasters have been more concerned about deviations in the direction of lower inflation and less concerned about deviations in the direction of higher inflation. Such a finding of a negatively skewed long-term distribution is precisely what is predicted by macroeconomic models which incorporate a lower bound constraint on nominal interest rates as discussed in Section 2 (e.g., Coenen and Warne, 2014). Interestingly, according to the test results reported in Table 1, the break in skewness occurred relatively soon after the Great Recession and prior to the break in mean expectations. For the kurtosis, we find one significant and rather small shift depicting an increased probability mass in the tails of the distribution in the second half of the sample. Interestingly, the increase in tail risk is estimated to have occurred in 2006Q4 and therefore anticipated the Great Recession although for forecasters from non-crisis countries the break date is later in 2008Q2. The estimated fourth moments indicate that the long-term inflation density is platykurtic, which means that forecasters believe that, relative to a normal distribution, less of the inflation uncertainty is associated with infrequent tail events.[22]

Together with the increased variance, the above distributional changes that we have identified imply a marked rise in the probability of very low future inflation rates at long horizons. Figure 4 provides a summary of how the shape, symmetry and tail risk implicit in the survey indicators have changed over time. The left plot shows how much probability weight the forecasters attributed, on average, to long-term outcomes of inflation below 0.0%, below 1.0%, and above 3.0%. It is clear that while the risk of a sustained outright deflation with a falling price level is still perceived as being very low, the perceived probability that inflation will be below 1.0% has climbed steadily from very low levels prior to 2007 to around 10.0% in more recent years. According to Figure 4, the probability that inflation will be above 3.0% is also somewhat higher than before 2007 but the increase is not nearly as strong and it has been declining toward the end of the sample. The right plot shows the inflation-at-risk measure that is proposed by Andrade *et al.* (2012). For each wave of the survey, this indicates the 5^{th} and 95^{th} percentiles of the

[22] This is a well know finding in the literature exploiting such data. It is a direct consequence of the fact that many participants in the SPF attach positive probabilities to only a very limit number of the provided bins (see Kenny *et al.*, 2015).

reported long-term density forecasts for inflation.[23] Again, while the 95th percentile (that is informative about the upper tail of the distribution) is currently more or less unchanged compared to its value in 2007, the 5th percentile (that is informative about the lower tail of the distribution) declined from above 1 percent in 2007 to 0.7 percent in the second quarter of 2015.[24] Overall, forecasters see more risks on the downside which corresponds to our finding of a structural break in the skewness of long-term forecast densities after 2010.

[Insert Figure 4 about here]

3.6 Heterogeneity across Forecaster Groups

To analyse whether these changes in the long-term distribution differ across specific groups of forecasters, we use additional data that allow us to classify forecasters according to different characteristics. We focus on two different classifications. First, forecasters from the financial sector might differ from those from non-financial institutions due to different incentive structures, different emphasis on financial sector developments, or the reliance on different types of macroeconomic models. To see whether they reveal any differences, we split our sample into financial-sector forecasters (Financial) and forecasters from outside the financial sector (Non-Financial). In our sample, the number of financial and non-financial sector forecasters averages about 25 and 13, respectively. Second, local developments might influence forecasters' perceptions about the euro area as a whole (see, e. g., Berger *et al.*, 2009). Given that the Great Recession has been associated with a high degree of economic divergence across countries, one hypothesis is that forecasters from the crisis countries could have different views about the long-term development of the euro area than forecasters from the other member states. Therefore, we consider a different grouping, for which we merge forecasters from Greece, Ireland, Italy, Portugal, Spain, and Cyprus into one group (Crisis), which on average includes 8.5 forecasters, and all other forecasters into a second group (Non-Crisis) that comprises on average about 21.5.

Figure 5a depicts the equivalent information to Figure 2 but distinguishing forecasters from crisis and from non-crisis countries, while the second and third parts of Table 1 report the corresponding detailed results from implementing the Bai-Perron procedure. In general, the results of this analysis point to large similarities in the findings for different groups (and therefore confirm the above conclusions from the analysis of the full sample). Although the precise timing of the breaks can differ across each group, following the Great Recession, we observe the previously identified small downward shift in mean expectations and a persistent rise in inflation uncertainty and negative skewness. The downward shift in mean expectations appears to have occurred earlier in crisis countries (2009Q1) than in non-crisis

[23] To extract these percentiles, we follow Engelberg *et al.* (2009) and use the approximation of the true density forecasts derived by fitting the generalized Beta distribution. The 5th and 95th percentiles are then computed as the average across all individual forecaster.

[24] This means that forecasters, on average, expect inflation five years ahead to fall below 0.7 percent with a probability of 5 percent.

countries (2013Q2). Also, forecasters from crisis countries perceive persistently higher inflation tail risk in the *euro area as a whole* compared with forecasters from non-crisis countries.

Turning to the comparison between financial sector and non-financial-sector forecasters in Figure 5b, we see a very strong co-movement of the moments for the two groups. Two modest differences are nonetheless worth highlighting. First, following the break in 2013Q2 which resulted in a downward shift for both groups, financial-sector forecasters have mean expectations approximately 10 basis points below non-financial-sector forecasters. Second, the overall increase in long-term inflation uncertainty appears to have been stronger in the group of financial-sector forecasters and, at the sample end, is slightly higher for this forecaster group. On balance, although the quantitative differences are small, financial-sector forecasters appear modestly more sensitive to the risk of a downward de-anchoring of the distribution compared with non-financial sector forecasters.[25] Such increased sensitivity may derive from their institutional and sectoral proximity to the challenges associated with the financial and sovereign debt crises.

[Insert Figure 5a about here]

[Insert Figure 5b about here]

4 Explaining Changes in Distributional Moments

The previous section provided evidence that the distribution of long-term inflation expectations in the euro area may have changed in the period since the Great Recession. In particular, our analysis shows that, in the aftermath of the Great Recession and the euro area sovereign debt crisis, this distribution experienced a modest downward shift in its mean, a more sizeable increase in its variance and a persistent negative skewness. Moreover, we also identified a small increase in tail risk which occurred in anticipation of the Great Recession. In this section, we attempt to analyse the underlying factors that may have potentially contributed to these changes. In particular, we try to answer the following questions: What are the factors that influence (or at least co-move with) key moments of the long-term distribution? Did the role of such factors change after 2007, the year in which the financial crisis began to unfold? Do forecasters respond more or less strongly to certain developments than they used to do before the crisis? And eventually, can we attribute the major shifts in the long-term distribution to particular developments such as changes in the persistence of inflation, the hitting of the ELB on nominal interest rates or the introduction of non-standard monetary policies?[26] In addressing these questions, we focus on the first two moments since mean expectations and the surrounding inflation uncertainty are the variables for which we can readily

[25] This increased sensitivity of financial sector forecasters to low inflation risks may also help explain why the measures of inflation expectations extracted directly from financial markets (e.g. inflation linked swap markets as depicted in Figure 3) responded more quickly to the recent period of low inflation than other indicators.

[26] Pasaogullari (2015) examines the impact of quantitative easing on long-term inflation expectations in the US. Focussing on the potential risk of an upward de-anchoring of expectations and risks of hyperinflation, he finds no evidence in either financial market indicators or in the expectations of professional forecasters.

identify potential co-variates.[27] We first present an analysis of the factors which can explain movements in long-term inflation expectations and subsequently turn to the sources of changes in inflation uncertainty.

4.1 Inflation Expectations

To analyse empirically how long-term inflation expectations change jointly with other variables, we use the following regression approach: Let $\Delta\pi_{i,t+20|t} = \pi_{i,t+20|t} - \pi_{i,t-1+20|t-1}$ denote the change in the long-term inflation expectation of an individual forecaster. We regress this change on forecaster-specific fixed effects and a set of covariates, denoted by $X_{i,t}$, which can contain matched forecaster-specific variables (e.g. expectations for other variables by the same forecaster) as well as common variables (e.g. past inflation rates observed by all forecasters). The linear panel regression is given by:[28]

(4.1) $\Delta\pi_{i,t+20|t} = \alpha_i + X_{i,t}\beta + \varepsilon_{i,t}$,

where $\varepsilon_{i,t}$ is an error term that we allow to exhibit both spatial and temporal correlation (Driscoll and Kraay 1998).[29] The parameter vector β measures the extent to which long-term expectations co-move with the other variables. For perfectly anchored inflation expectations, we would expect $\beta = 0$ to hold. This would imply that they do not co-move with other economic factors at all, which constitutes a *necessary* but not a sufficient condition for anchored inflation expectations.

When estimating equation (4.1), we consider the following sets of variables in $X_{i,t}$:

i. *Short-term macroeconomic news*: This includes individual-specific information such as the change in short- and medium-term (h=4 and h=8 quarters) inflation expectations ($dE[\pi(1y)]$ and $dE[\pi(2y)]$) as well as recent short- and medium-term inflation forecast errors ($\pi - \mathrm{E}[\pi(1y)](t-4)$ and $\pi - \mathrm{E}[\pi(2y)](t-8)$). Also, we include common information such as the recently observed change in the inflation rate ($d\pi(t-1)$) and in oil prices ($dOil(t-1)$) which can capture shocks to the inflation process itself.[30]

ii. *Short-term macroeconomic uncertainty*: Recent literature has emphasised the role of uncertainty as a source of business cycle fluctuations – either as a primitive source of such

[27] We would nonetheless consider that modelling either the skewness or measures of tail risk in the long-term inflation distribution constitutes a potentially interesting area for future research.

[28] We also considered whether augmenting equation (4.1) with interaction terms using a measure of inflation persistence or with non-linear terms is able to better capture changes in the density moments. We present results for the regressions taking the time-varying level of inflation persistence into account in Appendix II. Overall, these show that the level of inflation persistence is an important driver for the degree to which long-term expectations co-move with other variables. The results underline the correspondence of our empirical results with the predictions of theoretical models discussed in Section 2. Concerning non-linear terms, we first analysed whether the sign/direction of movements of the covariates matter. Second, we check whether including quadratic terms of all covariates helps to track changes in long-term inflation expectations better. Finally, we allow for different effects of realizations of the covariates that are far out in the tails of the distribution of these variables. Overall, we do not find any evidence of large and significant non-linear effects either in the case of long-term expectations or in the case of long-term inflation uncertainty.

[29] Given that forecasters form their predictions simultaneously and that professional forecasts are usually found to be subject to information rigidities (Coibion and Gorodnichenko, 2012; Dovern *et al.*, 2015), which cause forecast revisions to be autocorrelated, both features are important. Ignoring them and assuming independently distributed error terms is likely to result in an underestimation of the true long-term covariance.

[30] Beechey *et al.* (2011) and Badel and McGillicuddy (2015) document a substantial co-movement of long-term US inflation expectations with oil prices.

fluctuations or as a key amplification mechanism (see, for example, Bloom 2014 for a recent survey). It is well known that such indicators increased substantially in the wake of the Great Recession. We therefore consider the change in the variance ($dV[\pi(1y)]$) of individual short-term inflation expectations and the change in the variance of short-term expectations for GDP growth ($dV[GDP(1y)]$) and the unemployment rate ($dV[U(1y)]$) as additional regressors.

iii. Measures of *perceived structural change*: In addition to the impact of news and uncertainty measures at short-term business cycle frequencies, more structural and long-term supply-side considerations represent an additional potential driver of shifts in mean long-term expectations. To capture the effects of perceived or actual structural change on long-term inflation expectations we include the change in long-term expectations for GDP growth ($\mathrm{dE}[\mathrm{GDP}(5\mathrm{y})]$) and the unemployment rate ($\mathrm{dE}[\mathrm{U}(5\mathrm{y})]$). The inclusion of these measures speaks to the theme of possible deflationary equilibria and secular stagnation as highlighted by the discussion in Section 2. In particular, to the extent that we can explain the recent drop in long-term inflation expectations as linked to expectations for weaker growth or higher unemployment this may point to evidence of a mutually reinforcing deterioration in long-term real prospects and long-term inflation expectations.

iv. A measure of *central bank performance*: Another potential source of shifts in long-term mean expectations is the central bank's own historical track record. The latter should, of course be assessed over the medium run given that the central bank cannot be expected to fully counteract all short-term shocks to inflation. We therefore derive an inflation "performance gap" as the difference between recent long-term expectations and a (five-year) moving average of past inflation ($\mathrm{MA}(\pi) - \mathrm{E}[\pi(5\mathrm{y})](\mathrm{t}-1)$): the inclusion of this indicator is in the spirit of Levin *et al.* (2004) who show that long-term inflation expectations in the US and the euro area were highly correlated with a slow moving average of inflation over the period 1994 to 2003. It also speaks to the theoretical models on learning discussed in Section 2 as such models normally imply that agents will infer a central bank's true objective from its ex-post performance. Finding a significant co-movement between this performance indicator and long-term expectations would mean that missing the price stability objective for a considerable period of time leads to revisions in long-term expectations.

v. *Monetary policy* indicators: The final class of variables that we consider relates to the effects of both standard interest rate policy and also, more recent, non-standard measures such as asset purchases.[31] To capture the potential effects of interest rate policy, we include a variable that measures the distance between the 3-month Euribor rate and the corresponding Taylor rate ($Taylor\ deviation\ (t-1)$) that forecasters observed in the

[31] A recent paper by Andrade *et al.* (2016) suggest that quantitative easing in the euro area helped to "guide long-run inflation expectations closer to [the ECB's] price stability objective".

quarter prior to forming a new long-term inflation expectation.[32] All other things equal, relatively tight (loose) interest rate policy might lead forecasters to revise their long-term inflation expectations downward (upward). To capture measures associated with recent quantitative easing, we include the change in the (log-) volume of the ECB's balance sheet ($\mathrm{dCBBS}(\mathrm{t}-1)$) with the expectation that an expansion of the balance sheet might potentially lead agents to change their estimate of long-term inflation rate upwards. For example, given the downward shift in mean expectations that we observe following the Great Recession, balance sheet expansion may have helped to raise inflation expectations towards the inflation target and therefore may have contributed positively to the change in expectations *ceteris paribus*. Finally, we also include variables aimed at capturing any announcement effects from recent non-standard monetary policy changes. To do so, we construct a dummy for survey rounds that follow the announcement of important monetary policy actions ($MPA\ dummy$). We include this to analyse whether, controlling for other influences, the announcement/implementation of expansionary monetary policy actions over recent years may have been followed by an upward revision in inflation expectations[33] Finally, we construct a dummy to identify possible impact effects when the ELB was hit ($ELB\ dummy$). This variable takes a value of unity for the first survey rounds that follow the dates when the ELB was reached for the ECB deposit rate (on July 11, 2012) and for the main financing rate (on June 5, 2014), respectively, and zero otherwise.

Table 2 lists the results of estimations of equation (4.1). Colum 1 reports full sample results; Columns 2 and 3 report results for the pre- and post-crisis samples respectively; Columns 4 and 5 compare the groups of financial-sector and non-financial-sector forecasters. Finally, Columns 6 and 7 compare the groups of forecasters from crisis countries and from non-crisis countries.

Looking first at the full sample results, we observe some significant co-movement with several of the variables included in the regression with an overall R^2 of 0.24. The results suggest that changes in medium-run expectations at the two-year horizon and observed two-year-ahead inflation forecasting errors move positively with mean long-term expectations. The effect is strong, supporting evidence from US household expectations provided by Dräger and Lambla (2013). For example, long-term inflation expectations are revised by roughly 0.19 pp, on average, when two-year-ahead expectations move by 1 pp. Such a positive co-movement implies that persistent shocks to the shorter term inflation outlook can have a tendency to spill over into long-term inflation expectations (see also Andrade *et al.*, 2016). The full-sample results also highlight an important role for the medium-run central bank performance indicator.

[32] The parameters of the Taylor-type interest rate rule were estimated over the sample 1999Q1 to 2011Q4 to intentionally exclude the period with (almost) binding ELB. Details are given in Appendix I.
[33] The events are: the introduction of enhanced credit support on May 7, 2009; the introduction of the Security Market Program (SMP) on May 10, 2010; the introduction of the Outright Monetary Transaction (OMT) program on August 2, 2012; the introduction of forward guidance on July 4, 2013; and the introduction of the enhanced asset purchase program (APP) on January 22, 2015.

This is in line with macroeconomic theories which allow for uncertainty about the central bank objective and/or learning on the part of private sector agents. According to the estimated coefficient, a deviation of long-term expectations from this slowly moving average of past inflation by 1.0 pp leads forecasters to revise their long-term expectations by just below 0.2 pp. We also observe some quantitatively less important but significant co-movement with the change in actual inflation.[34] Turning to the monetary policy indicators, we find very little significant co-movement with our measure of mean long-term expectations. An exception is, however, a significant and negative sign for the parameter capturing the sensitivity to the change in the ECB balance sheet. Such a result appears counterintuitive because it implies that long-term expectations decrease after a balance sheet expansion. However, this effect appears mainly driven by the variation in the data prior to the financial crisis and not by the more recent experience with non-standard monetary policies (see also Column (3) and the further discussion below). Hence, we would not conclude from this result that the expansion of the ECB balance sheet - which has mainly taken place in the second half of our sample and after the financial and subsequent sovereign debt crisis in the euro area - has contributed to the downward movement in mean expectations that was identified in Section 3.[35]

[Insert Table 2 about here]

This broad conclusion tends to be confirmed when we split our sample into a pre- and post- Great Recession period in Columns 2 and 3. In both samples, we observe the same strong positive co-movement with two-year-ahead expectations and the central bank performance indicator. However, the overall co-movement of long-term expectations with the variables considered is broadly stable across sub-samples with the regression R^2 being more or less the same in both sub-samples. Looking at individual parameter estimates, we do not observe increased sensitivity to most of the above-mentioned co-variates: the parameters on two-year-ahead expectations, the observed two-year forecast errors, and the central bank performance all decline in the post Great Recession sample (Column 3) compared with the earlier sample (Column 2). Column 2 also reports the estimated coefficient on the balance sheet for the sample only including data prior to 2007Q4. This sample yields a strongly negative and significant estimate, suggesting that this period also drives the full-sample results.[36] However, focussing only on the sample since 2007Q4, the impact is insignificant, suggesting that the negative co-movement does not relate to balance sheet policies implemented since the Great Recession.[37] Another interesting effect in the post crisis sample is a negative impact on mean inflation expectations from an increase in short-term unemployment expectations. Following the financial crisis there was a substantial increase in unemployment and according to the estimated parameter this shock appears to have weighed negatively on mean long-run

[34] This is in contrast to Beechey *et al.* (2011) who find a response of long-term inflation expectations to inflation news for the US but not for the euro area.
[35] Given that the large program of asset purchases was announced only at the very end of our sample, a longer run of data would be needed to detect such effects.
[36] Given that changes in the size of the balance sheet during this period were largely determined endogenously by the demand for currency and the minimum reserve requirements, the observed correlation should not be interpreted as a genuine "policy effect".
[37] These results are clearly a reflection of the major structural break in the balance sheet data after the onset of the financial crisis; changes in the balance sheet size were small and regular before 2007 and larger and also more volatile afterwards.

inflation expectations. The impact is however quantitatively very small compared with the other co-movement.

Overall the co-movement identified above suggests that the process governing the mean of the long-term distribution for expected inflation is far away from a simple stylized case where the inflation objective is a universal constant and where there is “blind faith” in the ability of the central bank to achieve this objective. Instead, this process is more in line with theories emphasising uncertainty about the monetary policy transmission mechanism in which agents update their long-run beliefs in response to relevant shocks. However, there is no evidence of a generalized increased sensitivity to the main co-variates following the Great Recession. Hence, the small downward shift in the mean identified more recently appears driven by developments in the underlying co-variates themselves rather than an increased sensitivity to these co-variates.

Columns 4 to 7 report the results of our panel analysis for the four groups of forecasters discussed earlier. The results generally confirm some of the main findings based on the full sample regression, although there are also some noteworthy differences that can be identified. For both financial-sector and non-financial-sector forecasters as well as for forecasters from crisis and non-crisis countries, we observe the strong impacts from changes in two-year-ahead inflation expectations and also from the central bank performance indicator. One interesting difference is that for financial sector forecasters we obtain a downward impact from our dummy variable capturing the hitting of the ELB. The negative sign implies that hitting the ELB resulted in a drop in mean long-term inflation expectations of close to 4 basis points. Such a drop in mean expectations could be explained by perceptions about a more challenging environment confronting monetary policy and an associated lengthening of the period over which monetary policy would be able to return the rate of inflation to levels consistent with the definition of price stability (see, for example, Arias *et al.*, 2016). A second interesting difference is a co-movement with real variables (such as short-term GDP uncertainty and long-term unemployment expectations) in the case of financial sector forecasters and this is not observed for forecasters outside the financial sector. Instead, the long-term inflation expectations of the latter group appear to co-move more with recent actual changes in inflation and oil prices.

Columns (6) and (7) also reveal insightful differences between forecasters from crisis and non-crisis countries. One important difference is that the group-specific regressions include a significant negative impact of long-term GDP growth and unemployment rate expectations on mean inflation expectations in the case of forecasters from crisis countries. The coefficients imply that a reduction in long-term growth expectations and an increase in long-term unemployment expectations both weaken long-term inflation expectations. For example, in the case of the unemployment rate, the coefficient estimates imply that a 1.0pp increase in the expected unemployment rate five years ahead would be associated with a 4 basis point drop in mean long-term inflation expectations. Such effects bring to mind the hypothesis of secular stagnation discussed in Section 2 whereby the economy can potentially shift to a low-growth-high-unemployment equilibrium with undesirably too low inflation (see, for example, the analysis in Busetti *et al.*, 2014).

4.2 Inflation Uncertainty

In this section, we explore the possible drivers behind the shifts in long-term inflation uncertainty identified in Section 3. We use a similar approach to that described above for mean expectations, regressing long-term inflation uncertainty at the individual forecaster level, given by $\sigma^2_{i,t+20|t}$, on a host of candidate forecaster-specific and common co-variates. Denoting by $\Delta\sigma^2_{i,t+20|t} = \sigma^2_{i,t+20|t} - \sigma^2_{i,t-1+20|t-1}$ the change in the long-term inflation uncertainty of an individual forecaster, we use - analogously to equation (4.1) - the following panel specification

(4.2) $$\Delta\sigma^2_{i,t+20|t} = \alpha^*_i + X^*_{i,t}\,\beta^* + \varepsilon^*_{i,t},$$

where $X^*_{i,t}$ denotes the set of covariates. When estimating equation (4.2), we focus on similar information to that included for inflation expectations but appropriately transformed to ensure a clear interpretability of the parameter estimates. In more detail, we include the following variables in $X^*_{i,t}$:

i. *Short-term macroeconomic uncertainty and news*: We consider possible transmission of short-term business cycle uncertainty to long-term inflation uncertainty by including changes in short- and medium-run (h=4 and h=8) inflation uncertainty ($\mathrm{dV}[\pi(1y)]$ and $\mathrm{dV}[\pi(2y)]$) and the corresponding measures for short-term growth and unemployment expectations ($\mathrm{dV}[\mathrm{GDP}(1y)]$ and $\mathrm{dV}[\mathrm{U}(1y)]$). We also include the *absolute value* of the recently observed change in the actual inflation rate ($\mathrm{abs}(\mathrm{d}\pi(t-1))$) of the change in oil prices ($\mathrm{abs}(\mathrm{dOil}(t-1))$), and of recent short- and medium-run inflation forecast errors ($\mathrm{abs}(\pi - \mathrm{E}[\pi(1y)](t-4))$ and $\mathrm{abs}(\pi - \mathrm{E}[\pi(2y)](t-8))$).

ii. *Long-term real uncertainty:* In an analogous manner to the analysis of mean expectations, we consider the change in the perceived long-term variance for GDP growth ($\mathrm{dV}[\mathrm{GDP}(5y)]$) and the unemployment rate ($\mathrm{dV}[\mathrm{U}(5y)]$) taken from the corresponding rounds of the SPF. In line with the discussion in Section 2, a strong link with these variables may capture movements in inflation uncertainty associated with a re-assessment of the perceived future level of real economic volatility.

iii. *Central Bank Performance*: We include the absolute value of the inflation performance gap analysed in the previous section ($\mathrm{abs}(\mathrm{MA}(\pi) - \mathrm{E}[\pi(5y)](t-1))$) because large persistent deviations of inflation from the long-term expectation in either direction might cause forecasters to increase their reported long-term inflation uncertainty.

iv. *Monetary Policy Indicators:* We include the absolute value of the change in the (log-) volume of the ECB's balance sheet ($\mathrm{abs}(\mathrm{dCBBS}(t-1))$) because large changes in the balance sheet might signal uncertainty about monetary policy and thereby contribute to higher long-term inflation uncertainty. We also include the absolute value of the deviation of the short-term interest rate from its level implied by a Taylor rule which may capture any impact of (unsystematic) monetary policy on uncertainty. Lastly, we include the same two dummy variables capturing monetary policy events discussed in relation to the analysis of mean expectations.

Table 3 lists the results of estimations of equation (4.2). Overall and compared to mean expectations, a higher share of variation of long-term inflation uncertainty can be explained by the covariates considered (R^2 of 0.36 over the full sample). The main takeaways concerning the co-movement of long-term inflation uncertainty with other variables are as follows: First, long-term inflation uncertainty is highly correlated with inflation uncertainty at a two-year horizon. Second, absolute changes in the current inflation rate are positively correlated with long-term inflation uncertainty although this result appears driven mainly by the pre Great Recession sample period. Thirdly, we find a strong and highly significant positive relationship with the perceived uncertainty about long-term growth rates and the long-term unemployment rate. This observed correlation is quantitatively important and significant both over the full sample and in each of our sub-sample regressions.

[Insert Table 3 about here]

The panel regressions for uncertainty also reveal some interesting co-movement with the indicators linked to monetary policy. In the full specification, active monetary policy – associated with large changes in the volume of the assets held by the ECB or large deviations from the Taylor interest rate – tend to be associated with, on average, a reduction in long-term inflation uncertainty. This result suggests that monetary policy has, in absolute terms, contributed to reducing inflation uncertainty over our sample. However, when one considers the persistent rise in long-term uncertainty highlighted in Section 2, monetary policy was not able to fully insulate long-run inflation uncertainty from the other factors discussed above. Looking at the coefficients corresponding to the monetary policy dummies, however, we find that the announcement dates for non-standard measures were generally associated with an increase in inflation uncertainty although this effect is quantitatively less important than the above-mentioned downward effects. On the one hand, this might indicate that those monetary policy actions, as a side effect, led to a slight increase in long-term inflation uncertainty because forecasters had no historical experience on which to assess the long-term implications for inflation. On the other hand, it might reflect elements that our regressions have failed to control for and which simultaneously led to an increase in uncertainty in these quarters.

Table 3 also provides important insights into possible changes in the co-movement of long-run inflation uncertainty with key variables before and after the Great Recession. Overall, many of the above effects are common to both sub-samples and the estimated coefficients do not change dramatically. One notable difference is that since 2008, we also find a positive spillover from very short-term one-year-ahead inflation uncertainty that was not observed prior to the Great Recession. Second, the uncertainty reducing effects associated with the central bank balance sheet and deviations of short-term interest rates from the Taylor rate are both no longer significant in the later sample period.

Columns (4) to (7) of Table 3 report the group-specific panel regressions for the behaviour of long-term inflation uncertainty. Some of the main findings above are shared across the groups considered, in particular the observed nexus between real uncertainty at long horizons and inflation uncertainty at long horizons. There are also some noteworthy differences: one result is that financial-sector forecasters tend to significantly adjust their estimates of long-term inflation uncertainty in response to the size of current changes in the inflation rate while this is not true for other forecasters. In addition, the positive spill-over from two-year-ahead inflation uncertainty to long-term inflation uncertainty is significant for financial-sector forecasters but not for forecasters from other sectors. Perhaps the starkest difference is that the above-mentioned positive association between long-term inflation uncertainty and the announcement of unconventional monetary policy actions is only observed in the case of non-financial-sector forecasters and those forecasters from non-crisis countries.

5 Discussion and Conclusions

In this paper we have studied the key properties of the long-term distribution of inflation expectations and the forces that have helped shape them. Our primary purpose has been to assess the extent to which the Great Recession and its aftermath, including the onset of a period in which the lower bound on nominal interest rates has started to bind, has led to any perceptible changes in this distribution. Our main findings fall into four broad categories which we discuss below.

First, and in contrast to most existing studies which have focused only on mean expectations, our analysis jointly targets the first four moments of this distribution. Hence, we can provide additional information about how long-term inflation uncertainty, the balance of long-term inflation risks and the risk of extreme inflation events may have changed since the Great Recession. A key result is that we find significant breaks in each of the first four moments of this distribution and all of them point toward a heightened risk of lower inflation outcomes. Although we document a small downward shift in the mean long-run expectations toward the end of our sample, they remain aligned with the ECB definition of price stability. However, the analysis of higher moments of the distribution points to a substantial increase in uncertainty about long-run inflation prospects compared with the period prior to the Great Recession and also a tendency towards negatively skewed long-term density forecasts with some small increase in tail risk. Our finding of a negatively skewed long-term distribution is precisely what is predicted by macroeconomic models which incorporate a lower bound constraint on nominal interest rates (e.g., Coenen and Warne, 2014). Taken together, these distributional changes imply that the levels at which euro area inflation expectations are anchored has not changed substantially following the Great Recession. In particular, the level of long-term inflation expectations remains aligned with the ECB's quantitative definition of price stability. However, the shifts in higher moments indicate a change in the degree to which inflation expectations are anchored, i.e. in how tightly they are anchored at that level.

Second, our study has uncovered significant co-movement between the first two moments of the long-term distribution and various macroeconomic indicators, including indicators capturing the effects of monetary policy. Such co-movement implies that the process governing the long-term distribution is far away from a simple stylized case where the inflation objective is a universal constant and where there is “blind faith” in the ability of the central bank to achieve this objective. Instead, the co-movements that we identify are more in line with theories emphasising uncertainty about the monetary policy transmission mechanism in which agents update their long-run beliefs in response to relevant shocks (Orphanides and Williams, 2004 and 2007). For example, we find that persistent periods of lower than expected inflation over the short-term may eventually lead to lower long-term expectations as well. In this sense, long-term inflation expectations are not completely forward looking. Ultimately, they are influenced by the ex post historical track record of the central bank relative to its announced objective. Such results provide strong support for recent concerns about inflation remaining “too low for too long” and unconventional monetary policies aimed at avoiding a persistent undershooting of the price stability objective. Regarding our central question, however, these mechanisms existed also prior to the Great Recession and, overall, they do not appear to have strengthened dramatically in its aftermath. Rather it appears to be the persistence of the underlying shocks and the repeated downward revisions in medium-term inflation expectations that have given rise to the small decline in mean long-run expectations. Our results therefore add to the evidence provided in Autrup and Grothe (2014), Strohsal and Winkelmann (2015), and Speck (2016).

Thirdly, our analysis sheds light on how forecasters update their assessment of long-run inflation uncertainty in response to macroeconomic developments. Factors which influence this assessment include the volatility in recent inflation rates and perceptions of increased inflation uncertainty at shorter horizons of two years. Also, our results suggest that longer-term uncertainty about the real economy – both about growth and unemployment – spills over into increased uncertainty about long-term inflation. Such mechanisms help explain the large upward shift in long-term inflation uncertainty following the Great Recession in the euro area. They point to a world in which private agents “worry” about the ability of the central bank to hit its target. In this respect, we identify significant counteracting, i.e. uncertainty reducing, effects associated with standard monetary policy instruments. However, this effect is driven by the data in the sample prior to the Great Recession. Concerning the role of more recent non-standard monetary policies, our sample is such that we must limit ourselves to an assessment of how inflation uncertainty responded to key monetary policy announcements. We find that the announcement dates for non-standard measures were generally followed by an increase in inflation uncertainty. Such a result must be interpreted with caution, however. On the one hand, it might reflect elements that our regressions have failed to control for and which simultaneously led to an increase in uncertainty in these quarters. On the other hand, it may also point to the fact that forecasters have little historical experience with such measures and their transmission to inflation.

Finally, many models which allow for the lower bound on nominal interest rates highlight the possibility of multiple equilibria. Such models (e.g. in Wiederholt, 2015 and Andrade *et al.*, 2015) place a large weight on central bank communication and the role of a credible price stability objective in helping to coordinate potentially heterogeneous expectations of different agents. We have therefore also explored our individual level dataset for possible heterogeneity to assess whether forecasters from countries that were proportionately more impacted by the crisis or forecasters working in the financial sector behave differently from others. Our main finding is that key results are often shared across these different groups of forecasters. If anything, forecasters from the financial sector appear to be more sensitive to the lower bound on nominal interest rates and a heightened risk of lower inflation outcomes. However, the mean expectations of forecasters from the financial sector also remain aligned with the ECB definition of price stability. Another interesting finding is that the long-run inflation expectations of forecasters from countries proportionately more impacted by the financial crisis appear to co-move with long-run expectations for growth and unemployment, while this effect is not observed for forecasters from other countries in our panel.

In conclusion, by focussing on the full distribution and by exploiting individual level data, we have been able to make an innovative contribution to the empirical literature trying to understand the process governing the formation of long-term inflation expectation. The availability of microdata has also helped us shed light on possible heterogeneity in this process across different groups of economic agents. Nonetheless, a number of open questions remain for future research. These include a careful analysis of how the different measure implemented more recently by the ECB will impact on key feature of the long-term distribution and an analysis of whether expectations of other agents (as, e.g., private households, financial markets participants) show the same tendencies as the ones that we have identified. Lastly, many of our findings are well-predicted by macroeconomic theory stressing the effects of uncertainty about monetary policy, either in terms of its target or the effectiveness of its instruments, including the implications of constraints such as the lower bound on nominal interest rates. However, further work is needed to jointly model monetary policy, the business cycle, and the formation of inflation expectations in ways which can help identify more precisely the mechanisms that may be behind our empirical results.

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Appendix I – Data Sources

SPF data: The SPF panel of point and probability forecasts for euro area GDP, HICP inflation and the unemployment rate at long, medium, and short horizons were obtained from the ECB website (which is accessible via http://www.ecb.europa.eu/stats/prices/indic/forecast/html/index.en.html). The website also contains a detailed description of the dataset.

Oil prices: Data on the price of oil (Brent) in US dollar were downloaded from Datastream. We include the most recent change over three months (approximated by the log difference) that was known to the forecasters at the time they submitted their forecasts to the SPF.

ECB Balance Sheet: We include the most recent change of the total volume of the ECB's assets and liabilities over a period of three months that was known to the forecasters at the time they submitted their forecasts to the SPF. Data were obtained from Datastream.

Output Gap: The measures of the output gap used in the estimation of the Taylor rule are based on an average of the estimated euro area output gaps from the European Commission (EC), the International Monetary Fund (IMF) and the Organization for Economic Co-operation and Development (OECD). As these series are annual, we use a simple linear interpolation so as to exploit other quarterly data for short-term interest rates, inflation and inflation expectations in the Taylor rule.

Inflation rate: In the regressions and for estimating the Taylor rule, we use inflation rates based on the Harmonised Index of Consumer Prices (HICP). Data were obtained from Datastream. In the regressions, we use the most recent change of the annual inflation rate over a period of three months that was known to the forecasters at the time they submitted their forecasts to the SPF.

Short term interest rates: We use the three months Euribor rate to estimate the Taylor rule. Data were obtained from Datastream.

Taylor rule: We estimate a simple (one-year-ahead) forward looking version of the Taylor rule

$$r_t = (1-\rho)\alpha + (1-\rho)\beta\pi^e_{t+3} + (1-\rho)\gamma(y_t - \bar{y}_t) + \rho r_{t-1} + \varepsilon_t$$

over the period 1999Q1 to 2012Q4 by GMM (instruments are four lags of the annual inflation rate, the output gap, the interest rate, and the quarterly changes of oil prices respectively). The obtained point estimates are $\hat{\rho} = .75, \hat{\alpha} = -2.75, \hat{\beta} = 2.95,$ and $\hat{\gamma} = .67$ with $R^2 = .97$.

Appendix II – The Impact of Inflation Persistence

As shown in Section 2, there might be a certain degree of responsiveness of long-term inflation expectations to transitory developments for finite forecast horizons due to changes in the persistence of inflation. In particular, the higher the persistence of inflation (the smaller ϕ is in equation (2.1)) the more do medium-run expectations react to transitory shocks. Thus, we should empirically observe that long-term inflation expectations co-move more strongly with some of the above co-variates when inflation persistence is high. We analyse whether this is indeed the case by adding to the regression framework of Section 4 interaction effects of all variables with a measure of inflation persistence. Inflation persistence is measured by the degree of first-order autocorrelation of monthly changes in the log HICP over rolling windows of 36 months.[38]

Table A.1 reports the results of the panel regressions for long-term mean expectations and long-term inflation uncertainty including these interactions with our measure of inflation persistence. Focusing first on the interaction with mean expectations, we observe that the co-movement between long-term expectations and two-year-ahead inflation expectations is stronger when inflation persistence is high. Furthermore, forecasters react more strongly to past medium-run forecast errors when inflation persistence is high. A word of caution is warranted at this point: a revision in inflation expectations might themselves lead to higher inflation persistence, causing problems of reverse causality in our context. This would not change, however, our basic conclusion that the degree of co-movement of some variables with long-run inflation expectations seems to be positively correlated with the persistence of inflation.

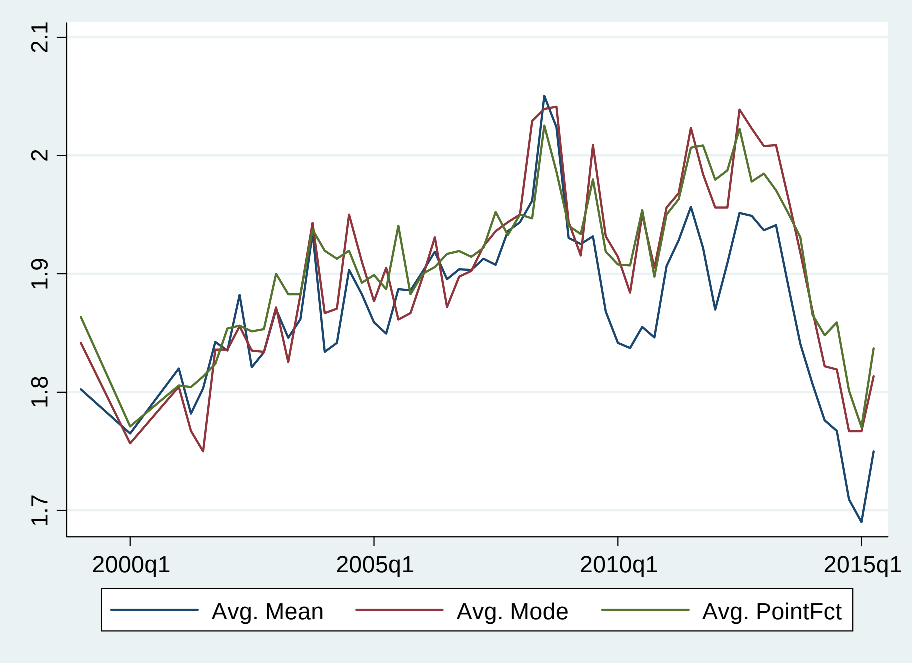
[Insert Table A.1 about here]

Table A.1 also reveals some interesting impacts of inflation persistence on the degree to which long-term inflation uncertainty co-moves with the variables that we consider. In particular, the positive correlation between long-term inflation uncertainty and one-year-ahead growth uncertainty becomes smaller when inflation persistence is higher. Second, the downward impact of standard monetary policy surprises (Taylor Deviations) on long-term inflation uncertainty is mitigated when inflation persistence is high.

[38] We average the values for all months of a quarter to construct a time series that matches the frequency of the SPF data set.

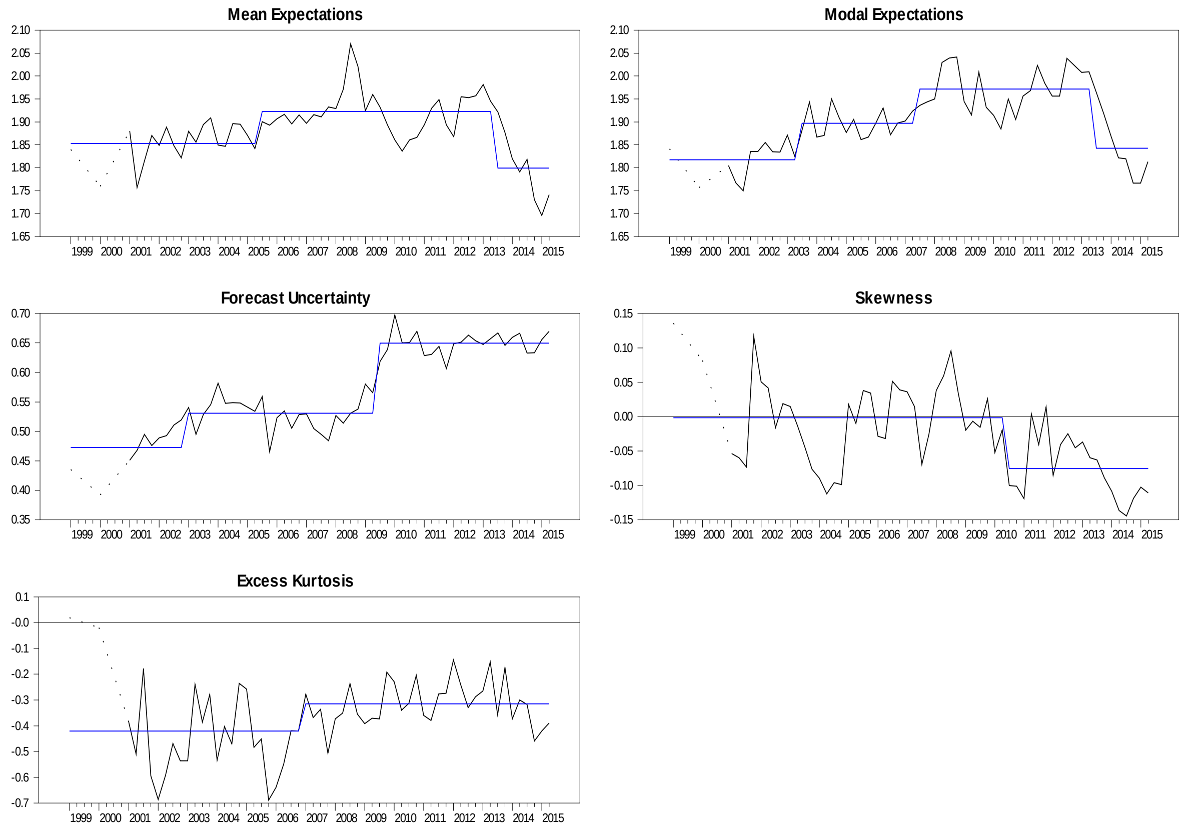
Figures and Tables

Figure 1 – Different measures of central tendency of long-term inflation expectations



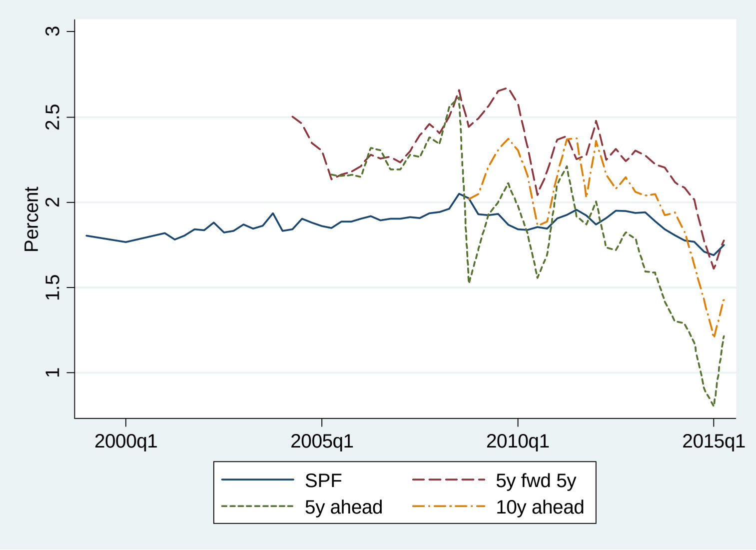
Notes: Average mean expectations and average modal expectations are computed based on the reported density forecasts. The average point forecasts are computed based on the reported individual point forecasts.

Figure 2 – Break points for moments of density forecasts



Notes: Based on the test by Bai and Perron (2003). The black lines refer to the average moments of the density forecasts of the individual SPF participants. The blue lines show the unconditional means with breaks as selected based on the sequential supF tests. The minimum distance between two break points was set to eight quarters.

Figure 3 – Selected measures of long-term inflation expectations for the euro area



Notes: The average SPF expectations are computed based on the density forecasts which are used throughout the paper. "5y fwd 5y" refers to the five year forward five-year-ahead inflation-linked swap rate; "5y ahead" refers to the five-year-ahead inflation-linked swap rate; "10y ahead" refers to the ten-year-ahead inflation-linked swap rate.

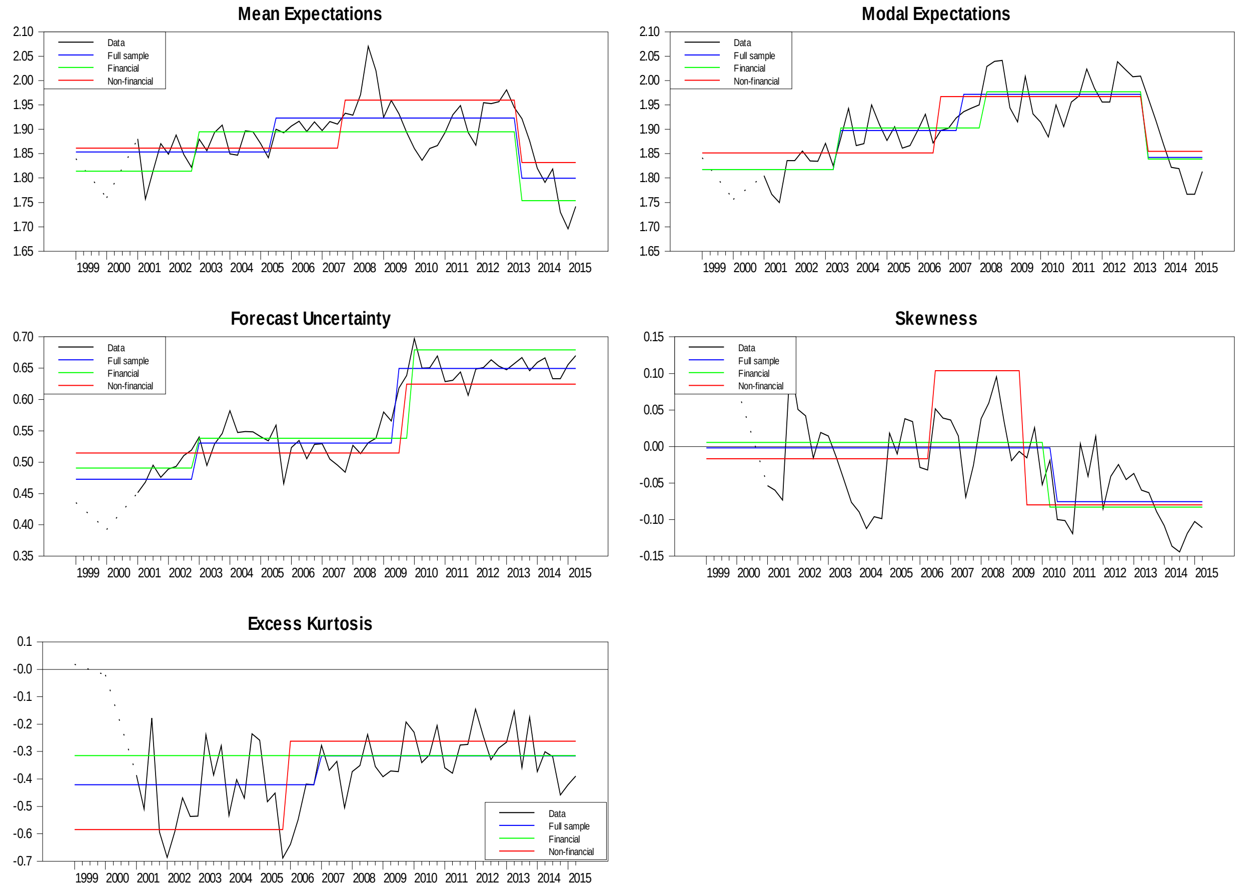
Figure 4 – Long-term expectations about tail inflation events

Notes: The left plot refers to the average probability mass assigned to the respective bins from the surveyed histograms. The right plot shows the 5th and 95th percentile of the long-term inflation density forecasts, averaged across individual panellists. The method is taken from Andrade *et al.* (2012).

Figure 5a – Break points for moments of density forecasts (crisis vs. non-crisis)

Notes: Based on the test by Bai and Perron (2003). The black lines refer to the average moments of the density forecasts of all individual SPF participants. The blue lines show the unconditional means with breaks as selected by the sequential supF tests. The minimum distance between two break points was set to eight quarters. The green lines show the corresponding unconditional means for the sample of forecasters from the crisis countries while the red lines show the corresponding unconditional means for the sample of forecasters from all other countries.

Figure 5b – Break points for moments of density forecasts (financial vs. non-financial)



Notes: Based on the test by Bai and Perron (2003). The black lines refer to the average moments of the density forecasts of all individual SPF participants. The blue lines show the unconditional means with breaks as selected by the sequential supF tests. The minimum distance between two break points was set to eight quarters. The green lines show the corresponding unconditional means for the sample of forecasters from the financial sector while the red lines show the corresponding unconditional means for the sample of forecasters from non-financial institutions.

Table 1: Break points for average moments of density forecasts

Mean expectation			Modal expectation			Forecast uncertainty			Skewness			Excess Kurtosis		
Date	**t-stat**	**Mean**	**Date**	**t-stat**	**Mean**	**Date**	**t-stat.**	**Mean**	**Date**	**t-stat.**	**Mean**	**Date**	**t-stat.**	**Mean**
All Forecasters														
-	-	1.85	-	-	1.82	-	-	0.47	-	-	-0.00	-	-	-0.42
2005Q2	4.85	1.92	2002Q2	4.59	1.90	2002Q4	5.80	0.53	2010Q2	4.86	-0.08	2006Q4	2.95	-0.32
2013Q2	6.23	1.80	2007Q2	5.07	1.97	2009Q2	15.73	0.65						
			2013Q2	6.98	1.84									
Forecasters from Crisis Countries														
-	-	1.84	-	-	1.84	-	-	0.49	-	-	0.05	-	-	-0.38
2007Q1	5.02	1.96	2008Q1	4.35	1.92	2008Q2	7.21	0.59	2002Q4	4.24	-0.09	2006Q2	2.14	-0.23
2009Q1	5.30	1.84				2011Q4	3.99	0.66	2004Q4	5.56	0.08			
									2008Q4	5.54	-0.05			
Forecasters from Non-Crisis Countries														
-	-	1.82	-	-	1.82	-	-	0.52	-	-	-0.03	-	-	-0.49
2003Q3	7.17	1.93	2003Q3	8.12	1.95	2009Q2	11.10	0.64	2005Q3	3.16	0.03	2008Q2	3.51	-0.36
2013Q2	7.56	1.79	2011Q1	5.30	2.05				2010Q1	6.26	-0.09			
			2013Q2	7.79	1.87									
Forecasters from Financial Sector														
-	-	1.81	-	-	1.82	-	-	0.49	-	-	0.01	-	-	-0.31
2002Q4	4.32	1.89	2003Q2	4.32	1.90	2002Q4	4.36	0.54	2010Q1	5.21	-0.08			
2013Q2	6.89	1.75	2008Q1	4.34	1.98	2009Q4	16.66	0.68						
			2013Q2	6.15	1.84									
Forecasters from Non-Financial Sector														
-	-	1.86	-	-	1.85	-	-	0.51	-	-	-0.02	-	-	-0.58
2007Q3	5.35	1.96	2006Q3	6.11	1.97	2009Q3	7.13	0.62	2006Q2	4.32	0.10	2005Q4	5.89	-0.26
2013Q2	4.71	1.83	2013Q2	4.10	1.85				2009Q2	6.58	-0.08			

Notes: Based on the test by Bai and Perron (2003). Dependent variables are the average moments of the density forecasts of the individual SPF participants. Dates refer to periods in which we observe a significant change in the unconditional mean of the different moments. The number of breaks and their location is selected based on the sequential supF test and the minimum distance between two breaks is set to eight quarters.

Table 2: Co-movement of long-term expectations with other variables

Dep. Var.: dE[π(5y)]		All Forecasters		Financial	Non-financial	Crisis	Non-crisis
	Full sample	<07q4	≥07q4	Full sample	Full sample	Full sample	Full sample
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
dE[π(1y)]	0.016	-0.002	0.010	0.026	-0.019	0.011	0.015
	(0.020)	(0.037)	(0.022)	(0.023)	(0.037)	(0.025)	(0.022)
dE[π(2y)]	0.186***	0.194***	0.149***	0.176***	0.232***	0.169***	0.205***
	(0.033)	(0.054)	(0.026)	(0.042)	(0.072)	(0.052)	(0.042)
π-E[π(1y)](t-4)	-0.010	-0.003	-0.019	-0.002	-0.033	-0.008	-0.011
	(0.013)	(0.023)	(0.012)	(0.016)	(0.024)	(0.018)	(0.019)
π-E[π(2y)](t-8)	0.031**	0.047	0.037***	0.024	0.054**	0.027	0.034
	(0.015)	(0.032)	(0.013)	(0.018)	(0.022)	(0.020)	(0.021)
dE[GDP(1y)]	0.007	0.006	0.012	0.010	-0.005	0.011	0.003
	(0.007)	(0.013)	(0.009)	(0.009)	(0.015)	(0.014)	(0.009)
dE[U(1y)]	0.019	0.119***	-0.032*	0.040*	-0.007	0.052**	-0.011
	(0.021)	(0.039)	(0.017)	(0.023)	(0.036)	(0.021)	(0.028)
Dπ(t-1)	0.028*	0.063**	0.022	0.029	0.033**	0.042*	0.012
	(0.015)	(0.030)	(0.015)	(0.018)	(0.016)	(0.023)	(0.015)
dOil(t-1)	-0.031	-0.201***	0.005	-0.006	-0.139**	-0.060	-0.011
	(0.043)	(0.069)	(0.039)	(0.047)	(0.064)	(0.066)	(0.031)
dV[π(1y)]	-0.056	-0.019	-0.063	0.002	-0.110	0.069	-0.137
	(0.053)	(0.113)	(0.046)	(0.041)	(0.125)	(0.054)	(0.090)
dV[GDP(1y)]	0.042	0.098	0.040	0.077**	-0.064	-0.026	0.095**
	(0.026)	(0.071)	(0.032)	(0.038)	(0.073)	(0.042)	(0.036)
dV[U(1y)]	0.047	0.088	0.037	0.062	0.023	0.023	0.054
	(0.047)	(0.127)	(0.044)	(0.061)	(0.094)	(0.067)	(0.056)
dE[GDP(5y)]	0.015	0.033	-0.012	0.038	0.005	0.071*	-0.030
	(0.034)	(0.039)	(0.057)	(0.036)	(0.063)	(0.042)	(0.052)
dE[U(5y)]	-0.014	-0.033	-0.013	-0.036*	0.019	-0.040**	-0.001
	(0.012)	(0.024)	(0.013)	(0.020)	(0.016)	(0.017)	(0.014)
MA(π)-E[π(5y)](t-1)	0.187***	0.309***	0.262***	0.167***	0.245***	0.162***	0.208***
	(0.021)	(0.047)	(0.037)	(0.023)	(0.045)	(0.031)	(0.032)
dCBBS(t-1)	-0.309***	-1.581***	-0.164	-0.320***	-0.415**	-0.388**	-0.266**
	(0.113)	(0.427)	(0.098)	(0.118)	(0.178)	(0.150)	(0.131)
Taylor deviation(t-1)	0.016	0.100**	-0.012	0.006	0.045	0.024	0.008
	(0.027)	(0.039)	(0.028)	(0.028)	(0.048)	(0.023)	(0.037)
MPA dummy	0.004		-0.008	-0.005	0.022	-0.017	0.018
	(0.009)		(0.012)	(0.017)	(0.052)	(0.027)	(0.024)
ELB dummy	-0.012		-0.011	-0.040*	0.012	-0.023	-0.008
	(0.018)		(0.021)	(0.023)	(0.039)	(0.030)	(0.028)
Constant	-0.022**	-0.002	-0.032***	-0.026**	-0.003	-0.018	-0.023***
	(0.009)	(0.012)	(0.011)	(0.010)	(0.011)	(0.014)	(0.008)
Observations	985	481	504	719	266	449	536
R-squared	0.239	0.299	0.305	0.263	0.267	0.246	0.265

Notes: Dependent variable is the change in long-term inflation expectations. All models include fixed effects for each forecaster. The constant is identified by restricting the average of the fixed effects to equal 0. Standard errors are computed using the method by Driscoll and Kraay (1998) and are robust against general forms of spatial and temporal dependence. See Section 4.1 for a description of the variable labels.

Table 3: Co-movement of long-term inflation uncertainty with other variables

Dep. Var.: dV[π(5y)]	All Forecasters Full sample (1)	All Forecasters <07q4 (2)	All Forecasters ≥07q4 (3)	Financial Full sample (4)	Non-financial Full sample (5)	Crisis Full sample (6)	Non-crisis Full sample (7)
dV[π(1y)]	0.067	-0.013	0.129*	0.094*	0.022	0.094*	0.028
	(0.058)	(0.081)	(0.071)	(0.050)	(0.146)	(0.052)	(0.074)
dV[π(2y)]	0.263***	0.431***	0.181***	0.281***	0.234	0.202***	0.324***
	(0.055)	(0.090)	(0.037)	(0.052)	(0.179)	(0.037)	(0.100)
abs(π-E[π(1y)](t-4))	0.007	0.007	0.007	0.005	0.014	-0.002	0.018
	(0.007)	(0.018)	(0.007)	(0.008)	(0.016)	(0.007)	(0.012)
abs(π-E[π(2y)](t-8))	-0.005	-0.010	-0.003	-0.005	-0.007	-0.001	-0.012
	(0.007)	(0.016)	(0.007)	(0.007)	(0.015)	(0.007)	(0.013)
dV[GDP(1y)]	-0.013	0.015	-0.023	-0.011	0.012	0.033	-0.046
	(0.023)	(0.045)	(0.020)	(0.026)	(0.037)	(0.025)	(0.034)
dV[U(1y)]	-0.002	-0.072	0.022	0.001	-0.013	0.004	-0.008
	(0.032)	(0.076)	(0.027)	(0.041)	(0.048)	(0.042)	(0.046)
abs(Dπ(t-1))	0.021**	0.027***	0.007	0.022*	0.016	0.008	0.030**
	(0.009)	(0.008)	(0.013)	(0.012)	(0.023)	(0.011)	(0.013)
abs(dOil(t-1))	0.011	0.006	0.046	0.012	0.021	0.021	0.013
	(0.025)	(0.046)	(0.027)	(0.025)	(0.071)	(0.027)	(0.039)
dV[GDP(5y)]	0.243***	0.281***	0.182***	0.237***	0.233**	0.245***	0.242***
	(0.044)	(0.053)	(0.050)	(0.055)	(0.091)	(0.052)	(0.059)
dV[U(5y)]	0.097***	0.083***	0.106***	0.081***	0.146***	0.068**	0.123***
	(0.022)	(0.030)	(0.031)	(0.024)	(0.043)	(0.030)	(0.041)
abs(MA(π)- E[π(5y)](t-1))	0.016	0.003	0.022	0.016	0.010	0.008	0.020
	(0.016)	(0.017)	(0.032)	(0.015)	(0.033)	(0.024)	(0.023)
abs(dCBBS(t-1))	-0.094*	-0.273	-0.062	-0.079	-0.153	0.061	-0.214**
	(0.049)	(0.213)	(0.046)	(0.052)	(0.103)	(0.052)	(0.080)
abs(Taylor deviation(t-1))	-0.038***	-0.106***	-0.020	-0.043***	-0.027	-0.040***	-0.035**
	(0.010)	(0.024)	(0.012)	(0.012)	(0.018)	(0.013)	(0.015)
MPA dummy	0.029***		0.024***	0.006	0.081***	-0.002	0.051***
	(0.005)		(0.006)	(0.010)	(0.014)	(0.008)	(0.007)
ELB dummy	-0.004		-0.016	0.006	-0.025	0.001	-0.013
	(0.007)		(0.009)	(0.009)	(0.021)	(0.011)	(0.012)
Constant	-0.005	0.011	-0.011	-0.003	-0.008	-0.001	-0.008
	(0.005)	(0.006)	(0.010)	(0.006)	(0.010)	(0.008)	(0.007)
Observations	985	481	504	719	266	449	536
R-squared	0.361	0.447	0.340	0.385	0.358	0.410	0.362

Notes: Dependent variable is the change in long-term inflation uncertainty. All models include fixed effects for each individual forecaster. The constant is identified by restricting the average of the fixed effects to equal 0. Standard errors are computed using the method by Driscoll and Kraay (1998) and are robust against general forms of spatial and temporal dependence. See Section 4.2 for a description of the variable labels.

Table A.1: Co-movement of long-term expectations with other variables as function of inflation persistence

Dep. Var.: dE[π(5y)]		Dep. Var.: dV[π(5y)]	
rhs variables	(1)	rhs variables	(2)
dE[π(1y)]	-0.011	dV[π(1y)]	0.019
	(0.022)		(0.055)
dE[π(1y)]*InflPer(t)	0.107	dV[π(1y)]*InflPer(t)	0.280
	(0.095)		(0.238)
dE[π(2y)]	0.095**	dV[π(2y)]	0.262***
	(0.041)		(0.069)
dE[π(2y)]*InflPer(t)	0.343**	dV[π(2y)]*InflPer(t)	-0.129
	(0.139)		(0.236)
π-E[π(1y)](t-4)	0.026	abs(π-E[π(1y)](t-4))	-0.010
	(0.020)		(0.011)
π-E[π(1y)](t-4)*InflPer(t)	-0.127	abs(π-E[π(1y)](t-4))*InflPer(t)	0.048
	(0.079)		(0.042)
π-E[π(2y)](t-8)	0.005	abs(π-E[π(2y)](t-8))	0.005
	(0.015)		(0.007)
π-E[π(2y)](t-8)*InflPer(t)	0.101**	abs(π-E[π(2y)](t-8))*InflPer(t)	-0.043**
	(0.045)		(0.021)
dE[GDP(1y)]	0.018	dV[GDP(1y)]	0.067**
	(0.015)		(0.026)
dE[GDP(1y)]*InflPer(t)	-0.039	dV[GDP(1y)]*InflPer(t)	-0.387***
	(0.062)		(0.091)
dE[U(1y)]	0.059	dV[U(1y)]	0.032
	(0.037)		(0.061)
dE[U(1y)]*InflPer(t)	-0.220*	dV[U(1y)]*InflPer(t)	-0.190
	(0.124)		(0.282)
Dπ(t-1)	0.008	abs(Dπ(t-1))	0.020**
	(0.017)		(0.008)
Dπ(t-1)*InflPer(t)	0.059	abs(Dπ(t-1))*InflPer(t)	0.035
	(0.070)		(0.038)
dOil(t-1)	-0.106	abs(dOil(t-1))	0.039
	(0.077)		(0.044)
dOil(t-1)*InflPer(t)	0.173	abs(dOil(t-1))*InflPer(t)	-0.067
	(0.292)		(0.137)
dV[π(1y)]	0.014		
	(0.075)		
dV[π(1y)]*InflPer(t)	-0.366		
	(0.332)		
dV[GDP(1y)]	0.003		
	(0.050)		
dV[GDP(1y)]*InflPer(t)	0.134		
	(0.194)		
dV[U(1y)]	0.034		
	(0.066)		
dV[U(1y)]*InflPer(t)	-0.041		
	(0.262)		
dE[GDP(5y)]	0.015	dV[GDP(5y)]	0.280***
	(0.038)		(0.042)
dE[GDP(5y)]*InflPer(t)	-0.058	dV[GDP(5y)]*InflPer(t)	-0.212
	(0.237)		(0.185)
dE[U(5y)]	-0.021	dV[U(5y)]	0.094***
	(0.017)		(0.023)
dE[U(5y)]*InflPer(t)	0.052	dV[U(5y)]*InflPer(t)	0.045
	(0.099)		(0.123)
MA(π)-E[π(5y)](t-1)	0.202***	abs(MA(π)- E[π(5y)](t-1))	0.031*
	(0.039)		(0.017)
MA(π)-E[π(5y)](t-1)*InflPer(t)	0.015	abs(MA(π)- E[π(5y)](t-1))*InflPer(t)	-0.066
	(0.233)		(0.062)
dCBBS(t-1)	-0.358**	abs(dCBBS(t-1))	0.055
	(0.147)		(0.046)
dCBBS(t-1)*InflPer(t)	0.469	abs(dCBBS(t-1))*InflPer(t)	-0.675**
	(0.660)		(0.291)
Taylor deviation(t-1)	-0.013	abs(Taylor deviation(t-1))	-0.091***
	(0.085)		(0.024)
Taylor deviation(t-1)*InflPer(t)	0.014	abs(Taylor deviation(t-1))*InflPer(t)	0.220**
	(0.343)		(0.084)
MPA dummy	-0.000	MPA dummy	0.030***
	(0.012)		(0.006)
ELB dummy	-0.042	ELB dummy	0.001
	(0.031)		(0.009)
Constant	-0.028***	Constant	-0.006
	(0.010)		(0.007)
Observations	884	Observations	884
R-squared	0.254	R-squared	0.390

Note: Dependent variables are the change in long-term inflation expectations and the change in long-term inflation uncertainty. Estimates are obtained using the full sample. All models include fixed effects for each individual forecaster. The constant is identified by restricting the average of the fixed effects to equal 0. Standard errors are computed using the method by Driscoll and Kraay (1998) and are robust against general forms of spatial and temporal dependence. Inflation persistence is measured by the autoregressive coefficient in an AR(1) model for the monthly change of the (log) CPI, estimated over rolling-windows of three years. See Section 4.1 for a description of the variable labels.

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Jonas Dovern
Alfred-Weber-Institute for Economics, Heidelberg University, Heidelberg, Germany; email: jonas.dovern@awi.uni-heidelberg.de

Geoff Kenny
Directorate General Research, European Central Bank, Frankfurt am Main, Germany; email: geoff.kenny@ecb.europa.eu

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

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