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Changes in inflation compensation and oil prices: short-term and long-term dynamics

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Abstract
This paper investigates the relationship between changes in euro area short-term and long-term market-based inflation expectations from January 2005 to September 2018, also devoting special attention to the relevance of the oil market. The full sample is split into three subsets related to different economic and financial landscapes. To model the conditional mean and the variance–covariance structure, a VAR-CCC-GARCH specification with oil effects in the volatility proves to be a preferable approach compared to other multivariate GARCH models. In general, the conditional correlation between changes in short-term and long-term inflation compensation appears as constant and relatively low in each subset, though increasing since mid-2014. Furthermore, there are no signs of fundamental deviations in how changes in short-term inflation expectations affect changes in longer-term expectations and vice versa. There is evidence that changes in short-term inflation expectations tend to respond to the movements of oil prices over time, while changes in longer-term ones started responding to crude dynamics after mid-2008. On the whole, these findings are relevant for analysts, investors and especially for the policymakers who charged with ensuring price stability.

Keywords Monetary policy · Inflation expectations · Oil · Trading rule · Anchoring

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1 Introduction

Inflation expectations play a crucial role in macroeconomics and especially in the realm of monetary policy. Indeed, they are a relevant determinant of actual inflation as firms and households usually take into consideration the expected path of increase in prices when making their economic and financial decisions. All these choices impinge on the inflation outcome and hence the achievement of central bank's objective of price stability. Provided this paramount role, policymakers closely monitor the evolution of inflation expectations as one of the most relevant inputs for assessing the inflation outlook and the related risks (see e.g., Adeney et al. 2017).

This paper seeks to contribute to the literature on inflation expectations by exploring the dynamics of changes in euro area short-term and long-term inflation over time, covering not only the conditional mean, but also the conditional variance–covariance structure of these variables that is still underexplored. Additionally, by means of an innovative approach based on the typical moving average trading rule, this research brings further insight into the transmission mechanism from crude to inflation expectations in both moments, contrary to the majority of the previous works that is concentrated on the conditional mean.

The empirical research builds on the vector autoregressive (VAR) specifications for the conditional mean and on multivariate generalized autoregressive conditional heteroskedasticity (MGARCH) models. In particular, the constant conditional correlation (CCC-) model proposed by Bollerslev (1990) is applied given the evidence that the conditional correlations are constant rather than dynamic. Beyond this standard specification, the conditional variance process is also adjusted to include potential effects of oil price movements in line with Nicolau's (2007) works. As documented (see, e.g., Wang et al. 2016), the oil market is also subject to the moving average rule according to which buy and sell indications are generated by long-term and short-term averages of the price level. Hence, when the short-term average is above (below) the long-term average, i.e., when recent prices are higher (lower) than the older ones, there is a buy (sell) prescription since economic agents believe that prices are following an upward (downward) trend. The bigger the difference between the two moving averages the stronger the signal to trade, the higher the market activity and the greater the volatility. Taking into account the economic relevance of these dynamics and the documented linkages of oil movements with the economy, it is worth exploring their role in shaping market-based inflation expectations, in particular whether the outlook on energy prices fluctuations affect inflation swap market volatility as investors may be interested in entering into positions in inflation-linked instruments to protect against future inflation changes. The tracking of this eventual causal relationship is relevant due to the fear that oil price shocks trigger inflation changes if inflation expectations materialize.

As regards the sample, the empirical work developed in this research relies on oil prices and on zero-coupon inflation swap rates (ZCISR), which are the most liquid inflation derivatives that trade in the over-the-counter market. Indeed, by and large, it is possible to gain insight into future inflation by means of econometric forecasting models, surveys and information retrieved from financial markets. In particular, over recent years, market-implied measures of inflation expectations have become very popular as they may be readily collected for a large set of maturities and reflect the beliefs of agents who are willing to risk money based on their expectations. Accordingly, the simplest and most frequent inflation expectation analyses draw on spot and forward rates from ZCISR and break-even inflation rates (BEIR). Additionally, forward rates may be preferred to spot rates to avoid any direct influence from short-term developments. Therefore, the sample comprises data on forward 1-year-1-year and 5-year-5-year euro area zero-coupon inflation-linked swaps (ILS) (ZCISR 1Yx1Y and ZCISR 5Yx5Y, respectively). It is important to note that, in line with the main central banks' practices, the 5-year horizon is used to analyze longer-term inflation expectations (see, e.g., Autrup and Grothe 2014).

As regards the sample time span, this investigation covers three sub-periods from January 2005 to September 2018 that encompass dissimilar economic and financial patterns and are supported by econometric tests: (1) the pre-crises period from January 2005 to June 2008, (2) the phase of financial and economic turmoil from July 2008 to July 2014 and (3) the period after the peaks of greater economic and financial instability from August 2014 to September 2018.

Overall, the results reveal that the conditional correlation between changes in ZCISR 1Yx1Y and in ZCISR 5Yx5Y was constant and relatively low in the first two subsets, but it has increased significantly since mid-2014. Nevertheless, with the exception of the period of major turbulence, there are no signals of fundamental deviations in how changes in short-term inflation expectations affected changes in long-term ones and vice versa. Tracking the impact of crude on these two variables, different behaviors stand out, as changes in short-term inflation expectations tended to respond to movements of oil prices both in the conditional mean and in the conditional variance while changes in long-term inflation expectations started responding to oil price fluctuations with the financial turmoil, firstly in terms of the conditional variance and then in the conditional mean and variance. Focusing on the oil market dynamics, there were some changes which signal that, over the full sample, the long-term moving average of oil prices reacted differently to the latest information on oil prices.

The remainder of this paper is structured as follows. Section 2 reviews the main related literature. Section 3 introduces the methodology. Section 4 looks at the sample in more detail, and Sect. 5 presents and discusses the estimated results. The main conclusions are provided in Sect. 6.

2 Literature review

This section reviews some of the most important research related to inflation-linked securities, which generally spins around the evaluation of inflation expectations and the estimation of possible risk premia.

The dynamics of inflation expectations may evolve differently depending on the maturity under inspection. If the objective function of the monetary authority is credible, then medium to longer-term expectations are supposed to be firmly anchored to the central bank goal.[1] Accordingly, if longer-term inflation expectations are well-anchored, then they should not be affected by temporary shocks or short-lived financial or economic developments with no implications for the long-run (see e.g., Nautz and Strohsal 2015). In turn, greater changes in short-term inflation expectations do not necessarily point toward a weak credibility of the central bank's objective. In practice, there is evidence that short-term inflation expectations are likely to deviate from the inflation aim, namely in response to economic and financial conditions (Posen 2011).

The relationship between short-term and long-term inflation expectations is mainly focused on the inflation pass-through, i.e., the extent to which movements in short-term inflation expectations influence longer-term ones (see, e.g., Jochmann et al. 2010 or Gefang et al. 2012) and the literature is still scarce in what concerns the bidirectional behavior.

Movements in oil prices have also been associated with macroeconomic and financial changes, since, historically, large jumps have been followed by higher inflation and recessions. At this respect, it is worth mentioning the work of Badel and McGillicuddy (2015) that, by employing the correlation coefficient, identifies a tighter synchronization of 5-year BEIR and oil prices over three subsets between 2003 and 2015. In turn, other authors resort to simple mean regression models to explore the relationship between oil prices and financial market inflation compensation (see, e.g., Elliot et al. 2015 or Perez-Segura and Vigfusson 2016). Wong (2015) uses a structural vector autoregression and uncovers evidence suggesting the United States (US) inflation expectations are sensitive to crude price shocks, although their quite modest role in propagating real oil price shocks. By means of an autoregressive distributed lag model, Hammoudeh and Reboredo (2018) find that the impact of oil price changes on market-based inflation expectations in the US is more intense when crude prices are above a certain threshold. Notwithstanding the various empirical analyses on the role played by oil price changes in shaping the level of long-term inflation expectations, there is space and interest in a more comprehensive study focused on the euro area, which encompasses the effect of oil prices on the variability of both short-term and long-term inflation expectations.

Research on inflation-linked securities has also sprouted in other related dimensions. One of the fields of the literature is dedicated to breaking down ILS and BEIR into 'true' inflation expectations and risk premia (see e.g., Christensen et al. 2010; Haubrich et al. 2012; Hördahl and Tristani 2014 or Ribeiro and Curto 2018). Indeed, without any adjustment, the straightforward reading of these measures reflects the inflation compensation demanded by economic agents for taking on inflation risk, which includes 'genuine' inflation expectations as well as risk premia (namely, inflation and liquidity premia, among others). This paper does not isolate the 'true' expectations from the risk premia since they are inherently unobservable and any attempt to disentangle them is complex and model-dependent (see, e.g., Chernov and Mueller 2012 or Bauer 2015). As raw spot and forward rates are often used to measure inflation expectations, the terms inflation compensation and inflation expectations will be mentioned indifferently throughout this work.

[1] In the euro area, the objective is an inflation rate below, but close to, 2% over the medium term.

The literature on the anchoring of long-term inflation expectations to the central banks' objective is also extensive (see, e.g., Beechey et al. 2011; Nautz et al. 2017 or Fracasso and Probo 2017). Although there is not a unique definition and a single quantification approach of expectations de-anchoring, many studies center this investigation on the longer-term horizon where it is assumed that the credibility of central bank shall prevail over short-term shocks. In addition, this assessment is usually made in terms of both level and lack of responsiveness to short-term news, i.e., how close inflation expectations are in relation to the inflation objective and whether they react to short-term developments (see e.g., Łyziak and Paloviita 2017 or Garcia and Werner 2018). Despite this traditional perspective, the risks of de-anchoring can also be identified at higher moments, as recently argued by some authors (see, e.g., Natoli and Sigalotti 2018 or Dovern and Kenny 2020). The present work addresses this still underexplored avenue by examining not only the level, but also the volatility of inflation expectations for different time horizons.

Notwithstanding the relevance of anchored inflation expectations to conduct monetary policy, the knowledge about their determinants is scant. The works of Ehrmann (2015), Bauer (2015) and Glas and Hartmann (2015) aim to explore this topic by devoting particular attention to the realized inflation, the state of the economy and monetary policy measures. Finally, other authors endeavor to assess the linkage of inflation expectations across different jurisdictions (see e.g., Bayoumi and Swiston 2010 or Netšunajev and Winkelmann 2014).

In light of the above, by exploring how the relationship between changes in euro area short-term and long-term inflation compensation has evolved over time and by shedding new light on the impact of crude on inflation expectations, the contribution of this paper is threefold. First, it provides a complete analysis on the dynamics of changes in euro area market-based inflation expectations by analyzing both the evolution and linkage between short-term and long-term horizons over a significant sample characterized by different economic and financial landscapes. In general, the existing literature is mainly focused on the stability and general drivers of longer-term inflation indicators and does not cover such a long time span. Second, contrary to the majority of the authors that concentrate their research on inflation expectations on the conditional mean structure, this paper also strives to better grasp the volatility features of both short-term and long-term ILS. Third, special attention is devoted to the potential impact of oil prices on the first two moments of the short-term and long-term inflation compensation, which complements the current studies that center this investigation on the conditional mean. All in all, the conclusions inferred in this paper are relevant for central banks, investors, companies and families.

3 Econometric methodology

This section outlines the econometric methodology. As the paper is focused on the co-movements between inflation swap rates from different tenors, under the context of stationary time series, a VAR parameterization is entertained in order to assess the transmission effects in the conditional mean. Additionally, the use of MGARCH processes seem to be appropriate given that data exhibits conditional heteroskedasticity. In this specification, the CCC-GARCH is employed since the LM test of Tse (2000) points to constant conditional correlations in each subset.

Combining the VAR with the CCC-GARCH, and taking into account the series under discussion, it is possible to construct the following base equations:

VAR specification[2]

$$\begin{aligned}\Delta \mathrm{ZCISR}_t^{1Y1Y} &= c_1 + \varphi_1 \Delta \mathrm{ZCISR}_{t-1}^{1Y1Y} + \varphi_3 \Delta \mathrm{ZCISR}_{t-2}^{1Y1Y} \\ &+ \phi_1 \Delta \mathrm{ZCISR}_{t-1}^{5Y5Y} + \phi_3 \Delta \mathrm{ZCISR}_{t-2}^{5Y5Y} + \delta_1 \Delta \mathrm{OIL}_{t-1} + u_{\mathrm{ZCISR}_t^{1Y1Y}}\end{aligned} \tag{1}$$

$$\begin{aligned}\Delta \mathrm{ZCISR}_t^{5Y5Y} &= c_2 + \varphi_2 \Delta \mathrm{ZCISR}_{t-1}^{5Y5Y} + \varphi_4 \Delta \mathrm{ZCISR}_{t-2}^{5Y5Y} \\ &+ \phi_2 \Delta \mathrm{ZCISR}_{t-1}^{1Y1Y} + \phi_4 \Delta \mathrm{ZCISR}_{t-2}^{1Y1Y} + \delta_2 \Delta \mathrm{OIL}_{t-1} + u_{\mathrm{ZCISR}_t^{5Y5Y}}\end{aligned} \tag{2}$$

where $\Delta\mathrm{OIL}$, $\Delta\mathrm{ZCISR}^{1Y1Y}$ and $\Delta\mathrm{ZCISR}^{5Y5Y}$ represent oil price changes, short-term and long-term changes of inflation expectations, respectively.

Variance–covariance specification

$$\begin{aligned}u_t &= D_t \eta_t \\ \mathrm{Var}\left(u_t | F_{t-1}\right) &= H_t = D_t \Gamma D_t\end{aligned} \tag{3}$$

where F_t is the sigma-algebra generated by the available information up to time t ,$\eta_t = \left(\eta_{1t}, \dots \eta_{mt}\right)'$ forms a sequence of independent and identically distributed (i.i.d.) random variables, $D_t = \mathrm{diag}\,(h_{1t}^{1/2}, \dots, h_{mt}^{1/2})$ is a diagonal matrix of time-varying standard deviations and $\Gamma = \left\{\rho_{ij}\right\}$ is the symmetric positive definite matrix of constant conditional correlations in which $\rho_{ij} = \rho_{ji}$. The main feature of this model is that the conditional correlations are assumed to be constant. So, the conditional correlation matrix is defined as $\Gamma = D_t^{-1} H_t D_t^{-1}$ and each conditional correlation coefficient is estimated from the standardized residuals.

In fact, the CCC model assumes that the conditional variance for each series, h_{it}, follows a standard univariate GARCH (*r, s*) process (Bollerslev 1986). On the grounds of a GARCH (1,1) and taking into account the series under analysis, the conditional variances can be written as follows:

$$h_{\mathrm{ZCISR}_t^{1Y1Y}} = \omega_1 + \alpha_1 u^2_{\mathrm{ZCISR}_{t-1}^{1Y1Y}} + \beta_1 h_{\mathrm{ZCISR}_{t-1}^{1Y1Y}} \tag{4}$$

$$h_{\mathrm{ZCISR}_t^{5Y5Y}} = \omega_2 + \alpha_2 u^2_{\mathrm{ZCISR}_{t-1}^{5Y5Y}} + \beta_2 h_{\mathrm{ZCISR}_{t-1}^{5Y5Y}} \tag{5}$$

This is the specification of the benchmark model of this paper (Model A). In order to bolster the knowledge about the volatility dynamics of forward inflation swap rates in relation to oil price movements, the technique proposed by Nicolau (2007) is used, which is based on the typical moving average trading rule. When recent prices are higher (lower) than older prices, i.e., when the short-term average is above (below) the long-term average, economic agents tend to believe that prices

[2] According to the information criteria, this is the maximum VAR lag length considered in the study. From subset to subset it varies between 1 and 2.

are following an upward (downward) trend so that they are prone to buy (sell) more. By increasing their activity in the market, agents end up affecting the asset volatility. As a commodity, oil is also subject to this trading scheme, as postulated by Wang et al. (2016). Therefore, one of the main contributions of this paper is the inclusion of the differential between short-term and long-term moving averages in relation to oil prices in the variance of ILS, by adding the component $(\mathrm{OIL}_{t-1} - m_{t-1})^2$ to Eqs. 4 and 5. Through this approach, it is possible to analyze whether expectations regarding higher (lower) energy prices lead to greater inflation swap market activity and higher volatility as investors may be interested in entering into positions in inflation-linked instruments to protect against fears of higher (lower) inflation.

In this process, OIL_{t-1} represents the latest oil market price, while m_{t-1} is the long-term moving average and results from an exponentially weighted moving average (EWMA), such that:

$$m_t = \lambda \times m_{t-1} + (1-\lambda) \times \mathrm{OIL}_{t-1},\ 0 \leq \lambda < 1 \tag{6}$$

By admitting that volatility is a function of the magnitude $\mathrm{OIL}_{t-1} - m_{t-1}$, the variance equations are adjusted as below:

$$\begin{aligned} h_{\mathrm{ZCISR}_t^{1Y1Y}} &= \omega_1 + \alpha_1 u^2_{\mathrm{ZCISR}_{t-1}^{1Y1Y}} + \beta_1 h_{\mathrm{ZCISR}_{t-1}^{1Y1Y}} \\ &+ \gamma_1 (\mathrm{OIL}_{t-1} - m_{t-1})^2 + \gamma_1^- (\mathrm{OIL}_{t-1} - m_{t-1})^2 I_{(\mathrm{OIL}_{t-1} - m_{t-1} < 0)} \end{aligned} \tag{7}$$

$$\begin{aligned} h_{\mathrm{ZCISR}_t^{5Y5Y}} &= \omega_2 + \alpha_2 u^2_{\mathrm{ZCISR}_{t-1}^{5Y5Y}} + \beta_2 h_{\mathrm{ZCISR}_{t-1}^{5Y5Y}} \\ &+ \gamma_2 (\mathrm{OIL}_{t-1} - m_{t-1})^2 + \gamma_2^- (\mathrm{OIL}_{t-1} - m_{t-1})^2 I_{(\mathrm{OIL}_{t-1} - m_{t-1} < 0)} \end{aligned} \tag{8}$$

where γ_i measures the impact of oil price on ILS and γ_i^- catches eventual asymmetric effects on this relationship.

Together with mean Eqs. 1 and 2, these two last variance specifications constitute Model B that is also estimated in this investigation.

From Eq. 6, it is possible to infer that:

$$\begin{aligned} &\mathrm{OIL}_t - m_t \\ &\quad = \mathrm{OIL}_t - \lambda m_{t-1} - (1-\lambda) \times \mathrm{OIL}_{t-1} \\ &\quad = \lambda \times \left(\mathrm{OIL}_{t-1} - m_{t-1}\right) + \mathrm{OIL}_t - \mathrm{OIL}_{t-1} \\ &\quad = \lambda \times \left(\mathrm{OIL}_{t-1} - m_{t-1}\right) + u_t z_t \end{aligned} \tag{9}$$

If $z_t = \mathrm{OIL}_t - m_t$, then $z_t = \lambda z_{t-1} + u_t$.

Accordingly, Eqs. 7 and 8 can also be simplified as follows.

$$h_{\mathrm{ZCISR}_t^{1Y1Y}} = \omega_1 + \alpha_1 u^2_{\mathrm{ZCISR}_{t-1}^{1Y1Y}} + \beta_1 h_{\mathrm{ZCISR}_{t-1}^{1Y1Y}} + \gamma_1 z^2_{t-1} + \gamma_1^- z^2_{t-1} I_{(\mathrm{OIL}_{t-1} - m_{t-1} < 0)} \tag{10}$$

$$h_{\mathrm{ZCISR}_t^{5Y5Y}} = \omega_2 + \alpha_2 u^2_{\mathrm{ZCISR}_{t-1}^{5Y5Y}} + \beta_2 h_{\mathrm{ZCISR}_{t-1}^{5Y5Y}} + \gamma_2 z^2_{t-1} + \gamma_2^- z^2_{t-1} I_{(\mathrm{OIL}_{t-1} - m_{t-1} < 0)} \tag{11}$$

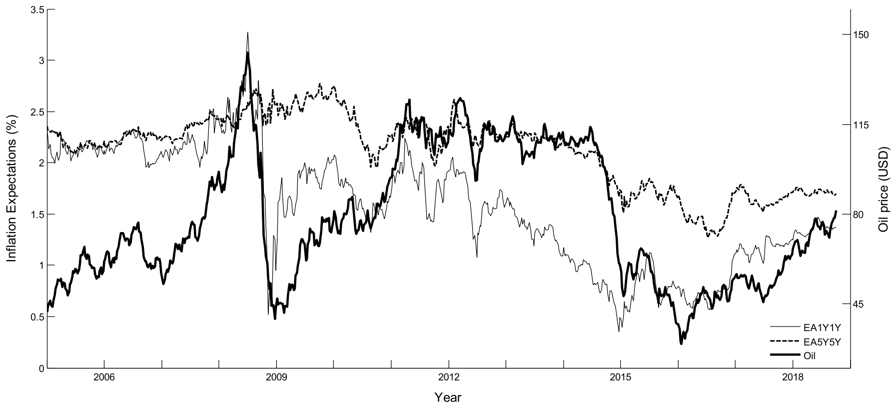

Fig. 1 Evolution of market-based inflation expectations and oil prices over the full sample period

4 Sample

Our data set comprises weekly data on euro area 1-year, 2-year, 5-year and 10-year ZCISR and on oil prices (expressed in USD)[3] retrieved from Bloomberg. Once the spot ZCISR for those maturities is extracted, the 1Yx1Y and 5Yx5Y years forward inflation swap rates are computed in accordance with the following formula:

$$\mathrm{Fwd}_{aYbY} = \left[\frac{(1+\mathrm{ZCISR}_b)^b}{(1+\mathrm{ZCISR}_a)^a}\right]^{1/(b-a)} - 1 \tag{12}$$

where a and b denote the shortest and the longest tenors of ZCISR contracts, respectively.

Figure 1 displays the evolution of ZCISR 1Yx1Y, ZCISR 5Yx5Y and oil prices from January 2005 to September 2018. This chart gives rise to some comments: short-term inflation expectations tended to exhibit frequent and large movements over the entire sample, thereby unveiling a stronger volatility compared to longer-term ones, which is in consonance with the idea that short-term inflation compensation is more likely to respond to economic and financial shocks. In turn, long-term inflation expectations have been relatively stable around the 2% reference level until mid-2014, thus supporting the anchoring of medium to longer-term inflation expectations to the European Central Bank (ECB)'s objective of price stability.

Moreover, it is noticeable that while until the summer of 2008 short-term and long-term market-based inflation expectations moved close to the 2% reference rate, in the wake of the global financial crisis, ZCISR 1Yx1Y dropped below that rate, while ZCISR 5Yx5Y remained close to the 2%. Yet, from mid-2014 onwards another pattern can be identified in relation to longer-term inflation expectations that

[3] In line with common practice, oil prices are not expressed in EUR to discard any effect of the EUR/USD exchange rate in this analysis.

started a slow but downward path, crossing the 2% barrier and reaching historical lows.[4] Finally, over the entire sample period, oil prices and ZCISR 1Yx1Y tended to exhibit a closer relationship.

In light of the different dynamics of ZCISR 1Yx1Y and ZCISR 5Yx5Y over this period, the full sample period is split into three subsets that reflect distinct economic and financial conditions: (1) the pre-crises period which spans from January 2005 to June 2008, (2) the phase of greater turmoil which runs from July 2008 to July 2014 and (3) the period which goes from August 2014 to September 2018.

Table 1 unveils the descriptive statistics related to the full sample and to each sub-period. Likewise, it displays the results from the unit root tests. At the conventional levels of significance, the outcomes of the Augmented Dickey–Fuller (ADF) test (Dickey and Fuller 1981) reveal that the three time series are non-stationary[5] and that at least one of the time series is non-stationary in each subset. These results are also corroborated by the Phillips–Perron (PP) test (Phillips and Perron 1988) and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test (Kwiatkowski et al. 1992). On account of this preliminary analysis, the three time series are transformed into first differences, thus allowing the use of a VAR model in the conditional mean. The descriptive statistics associated with the new time series are shown in Table 2. Based on the results from Engle's ARCH LM test (Engle 1982), there is evidence of conditional heteroskedasticity and therefore it is appropriate to model the conditional volatility as well.

5 Empirical results

As shown by the preliminary tests in Sect. 4, time series are transformed into first differences, and a VAR model is then applied for the conditional mean in order to study the relationship between short-term and long-term euro area inflation compensation as well as the dynamics of oil prices. Additionally, given that these variables exhibit conditional heteroskedasticity in the three sub-periods, a GARCH specification is employed to model the variance–covariance structure.

With a view to understand whether the inclusion of oil information on volatility improves the usual GARCH process, the benchmark model (Model A) is compared to the proposed model (Model B).[6] As mentioned in the previous section dedicated

[4] Understanding the reasons behind this trajectory and whether long-term inflation expectations remain consistent with the ECB's price stability objective is crucial. This decline of inflation expectations comes along with a low inflation environment since 2013, potentially reflecting several factors, such as: (1) some economic slack following the financial and sovereign debt crises, (2) some long-running structural forces, namely the effects of demographics, globalization and an acceleration of digitalization, (3) less well-anchored inflation expectations and (4) monetary factors, in consequence of the low level of interest rates coupled with a real interest rate that is not affected by monetary policy in the long-run.

[5] The breakpoint unit root test was also applied, which allows for a structural break in the trend process, to ZCISR 1Yx1Y and ZCISR 5Yx5Y. The outcomes show that the non-stationarity detected by the conventional unit root tests is not due to the existence of structural breaks. Additionally, the structural breaks identified by this test support the breakdown of the full sample into these three subsets.

[6] The codes were developed by the authors in RATS.

Table 1 Descriptive statistics and preliminary tests for the original series

	Full sample: From January 2005 to September 2018			Panel A: From January 2005 to June 2008			Panel B: From July 2008 to July 2014			Panel C: From August 2014 to September 2018		
	1Yx1Y	5Yx5Y	OIL	1Yx1Y	5Yx5Y	OIL	1Yx1Y	5Yx5Y	OIL	1Yx1Y	5Yx5Y	OIL
Mean	1.57	2.12	78.10	2.21	2.28	71.40	1.61	2.35	95.43	0.96	1.65	58.44
Median	1.56	2.21	72.92	2.17	2.27	65.38	1.61	2.32	106.53	0.91	1.68	55.50
Maximum	3.27	2.77	143.05	3.27	2.59	143.05	3.18	2.77	140.28	1.47	2.08	105.01
Minimum	0.35	1.27	29.32	1.95	2.09	41.89	0.52	1.96	39.20	0.35	1.27	29.32
SD	0.57	0.35	25.43	0.19	0.11	20.16	0.39	0.19	22.08	0.29	0.15	14.86
Skewness	− 0.04	− 0.50	0.32	2.02	0.37	1.50	0.28	0.26	− 0.81	0.06	− 0.36	0.92
Kurtosis	2.17	2.28	1.87	9.36	2.35	5.05	4.16	2.11	2.64	1.66	3.34	3.92
Jarque–Bera LM test	20.82***	45.91***	50.81***	433.85***	7.35**	100.50***	21.94***	14.19***	36.39***	16.40***	5.78**	38.35***
Engle LM ARCH test	937.90***	684.68***	676.79***	140.00***	146.60***	178.18***	249.55***	249.54***	300.58***	182.68***	197.14***	210.50***
ADF test	− 2.85	− 1.19	− 2.05	− 1.08	− 3.13	2.86	− 3.27**	− 2.14	− 4.23***	− 2.71	− 2.89**	− 2.85
PP test	− 2.13	− 1.39	− 2.38	− 0.75	− 3.03	1.30	− 4.53***	− 2.29	− 4.38***	− 2.85	− 2.79	− 2.86
KPSS test	2.46***	2.15***	0.47**	0.27***	0.18**	0.29***	0.16**	1.27***	0.20**	0.22***	0.30***	0.38***
Observations	717			183			317			217		

***Statistically significant at 1%

**Statistically significant at 5%

*Statistically significant at 10%

Table 2 Descriptive statistics for the time series in first differences

	Full sample: From January 2005 to September 2018			Panel A: From January 2005 to June 2008			Panel B: From July 2008 to July 2014			Panel C: From August 2014 to September 2018		
	1Yx1Y	5Yx5Y	OIL	1Yx1Y	5Yx5Y	OIL	1Yx1Y	5Yx5Y	OIL	1Yx1Y	5Yx5Y	OIL
Mean	0.00	0.00	0.06	0.01	0.00	0.56	− 0.01	0.00	− 0.11	0.00	0.00	− 0.11
Median	0.00	0.00	0.06	0.00	0.00	0.55	− 0.01	0.00	0.03	0.00	0.00	− 0.02
Maximum	0.38	0.16	9.69	0.31	0.08	8.45	0.38	0.16	9.69	0.21	0.16	6.57
Minimum	− 0.49	− 0.20	− 11.77	− 0.29	− 0.07	− 4.82	− 0.49	− 0.20	− 11.77	− 0.15	− 0.14	− 6.09
Std. Dev	0.08	0.04	2.60	0.08	0.03	2.27	0.10	0.05	3.03	0.05	0.04	2.09
Skewness	− 0.14	0.04	− 0.36	0.50	0.02	0.27	− 0.24	0.06	− 0.51	0.55	0.08	− 0.08
Kurtosis	9.40	5.79	4.62	6.18	3.27	3.24	7.75	4.65	4.37	5.28	5.61	3.31
Jarque–Bera LM test	1 224.8***	232.38***	93.69***	84.49***	0.56**	2.65	300.21***	36.11***	38.64***	57.82***	61.64***	1.11
Engle LM ARCH test	694.65***	703.48***	706.35***	151.05***	170.49***	178.93***	293.92***	294.82***	308.72***	211.60***	204.02***	212.51***
Observations	716			182			316			216		

***Statistically significant at 1%

**Statistically significant at 5%

*Statistically significant at 10%

Table 3 VAR-CCC-GARCH model estimates for the period from January 2005 to June 2008

	Model A	Model B
λ		0.30*
Mean equation		
1Yx1Y		
$\varphi 1$	− 0.1553**	− 0.1732**
$\phi 1$	0.3032***	0.3121*
$c1$	0.0013	0.0016
$\delta 1$	0.0058***	0.0062***
5Yx5Y		
$\varphi 2$	0.0435	0.0313
$\phi 2$	− 0.0893	− 0.0809
$c2$	0.0008	0.0011
$\delta 2$	0.0010	0.0007
Volatility equation		
1Yx1Y		
$\omega 1$	3.0448E−05	− 2.6367E−04*
$\alpha 1$	0.1436*	0.0057
$\beta 1$	0.8479***	0.9521***
$\gamma 1$	–	9.8709E−05***
$\gamma 1^{-}$	–	− 4.8899E−05
5Yx5Y		
$\omega 2$	0.0004***	2.3081E−04***
$\alpha 2$	0.1922**	0.2379**
$\beta 2$	0.2437***	0.2465***
$\gamma 2$	–	1.3491E− 05
$\gamma 2^{-}$	–	1.3900E− 05
ρ1Yx1Y,5Yx5Y	0.1897***	0.1506**
LM TSE test	1.9462	1.1055
Information criteria		
AIC	− 7.177	− 7.230
SBC	− 6.912	− 6.995
HQ	− 7.070	− 7.094
(log) FPE	− 7.177	− 7.230

***Statistically significant at 1%

**Statistically significant at 5%

*Statistically significant at 10%

to the econometric methodology, the latter includes the term $(\text{OIL}_{t-1} - m_{t-1})^2$ in the conditional variance, where $m_t = \lambda \times m_{t-1} + (1 - \lambda) \times \text{OIL}_{t-1}$, $0 \le \lambda < 1$, and λ is optimized for each sub-period.[7]

[7] For $0 \le \lambda < 1$, the value of λ that minimizes the information criteria is selected.

Table 4 VAR-CCC-GARCH model estimates for the period from July 2008 to July 2014

	Model A	Model B
λ		0.03
Mean equation		
1Yx1Y		
$\varphi 1$	0.0773	0.0877
$\varphi 3$	− 0.0226	− 0.0487
$\phi 1$	0.0845	0.0679
$\phi 3$	− 0.0463	− 0.0192
$c1$	− 0.0034	− 6.127E−03**
$\delta 1$	0.0053***	5.280E−03***
5Yx5Y		
$\varphi 2$	− 0.0875**	− 0.0936***
$\varphi 4$	0.1096***	0.1089***
$\phi 2$	0.2238***	0.2275***
$\phi 4$	− 0.2230***	− 0.1865***
$c2$	− 0.0013	− 1.175E−03
$\delta 2$	0.0004	1.2278E−04
Volatility equation		
1Yx1Y		
$\omega 1$	0.0002	1.4837E− 05
$\alpha 1$	0.1776	0.084
$\beta 1$	0.8022***	0.7911***
$\gamma 1$	–	4.9154E−05*
$\gamma 1^{-}$	–	7.0480E−05***
5Yx5Y		
ω2	1.6861E− 05	5.4588E− 06
$\alpha 2$	0.0800**	0.034
$\beta 2$	0.9092***	0.896***
$\gamma 2$	–	1.2935E−05***
$\gamma 2^{-}$	–	4.1086E− 06
ρ1Yx1Y,5Yx5Y	0.2461***	0.2341***
LM TSE test	1.1798	0.7184
Information criteria		
AIC	− 5.885	− 5.980
SBC	− 5.658	− 5.705
HQ	− 5.794	− 5.870
(log) FPE	− 5.884	− 5.979

***Statistically significant at 1%

**Statistically significant at 5%

*Statistically significant at 10%

Table 5 VAR-CCC-GARCH model estimates for the period from August 2014 to September 2018

	Model A	Model B
λ		0.66***
Mean equation		
1Yx1Y		
$\varphi 1$	0.2522***	0.2699***
$\phi 1$	− 0.1582	− 0.0937
$c1$	0.0047	0.0015
$\delta 1$	0.0012	0.0015
5Yx5Y		
$\varphi 2$	0.0928*	0.0731
$\phi 2$	0.0022	0.0442
$c2$	0.0007	0.0001
$\delta 2$	0.0008	0.0018**
Volatility equation		
1Yx1Y		
$\omega 1$	1.7820E−05	− 2.6519E−05
$\alpha 1$	0.1315	0.1409**
$\beta 1$	0.8696***	0.6496***
$\gamma 1$	–	2.3086E−05***
$\gamma 1^{-}$	–	4.4619E−05**
5Yx5Y		
$\omega 2$	6.1159E−06	− 3.0885E−05**
$\alpha 2$	0.0903	0.1069**
$\beta 2$	0.8985***	0.8084***
$\gamma 2$	–	8.7970E−06***
$\gamma 2^{-}$	–	4.7369E−06
ρ1Yx1Y,5Yx5Y	0.5258***	0.5155***
LM TSE test	0.1408	0.7308
Information criteria		
AIC	− 7.963	− 8.126
SBC	− 7.728	− 7.828
HQ	− 7.868	− 8.006
(log) FPE	− 7.963	− 8.126

***Statistically significant at 1%

**Statistically significant at 5%

*Statistically significant at 10%

Tables 3, 4 and 5 display the results for the two VAR-MGARCH models that are run for each subset. To begin with, it should be noted that in the three periods under investigation, the values of the information criteria are lower when oil data is included in the conditional variance equation, which means that Model B is preferable to Model A. Likewise, the parameter γ is positive and statistically significant in each period for at least one of the variables under investigation, thus confirming that oil price movements also impinge on the volatility of changes in ZCISR.

As regards the analysis for the period before the financial crisis, whose results are displayed in Table 3, and focusing on Model B, changes in ZCISR 1Yx1Y seemed to respond negatively to their own values[8] and positively to both changes in ZCISR 5Yx5Y and changes in oil prices. Indeed, monetary policy tends to fuel inflation dynamics with a lag so that unforeseen shocks, namely in the oil market, are prone to influence short-term inflation expectations.

The behavior of longer-term inflation expectations gives clues about the success of inflation targeting as a monetary policy strategy. Until June 2008, one can infer that none of the variables considered in the conditional mean determined changes in long-run inflation expectations, provided that the estimates for the respective parameters are not statistically significant at the conventional levels. These results back up the view that if the monetary authority is perceived as being fully committed to control inflation around levels consistent with the price stability goal, then shocks that drive inflation dynamics should be viewed as transitory and should not influence long-term inflation expectations.

Moving on to the conditional variance–covariance process, results of the LM test of Tse (2000) suggest that the CCC is a suitable parameterization as the conditional correlation seems to be constant rather than time-varying. The conditional correlation between changes in ZCISR 1Yx1Y and changes in ZCISR 5Yx5Y is statistically significant, standing at 0.15. This quite low figure is in line with the argumentation that, in the backdrop of successful monetary policy, short-term and long-term inflation expectations may not be strongly correlated.

Furthermore, throughout January 2005–June 2008, the optimal value for the parameter λ is 0.30, and it is statistically significant at the 10% level. Rearranging Eq. 9, it results in $z_t = \frac{u_t}{1-\lambda\times L}$, where L denotes de lagged value of z_t. So, λ reflects the dependence of z_t on past shocks during the time span under review, which seems to be limited in this case.

As for the conditional volatility of changes in short-term inflation expectations, the GARCH process is statistically significant as well as the parameter γ_1. Looking at the upward trend in the oil market over the first period, agents increase their activity both in the spot and derivative markets. At the same time, *ceteris paribus*, an expectation surrounding higher energy prices feeds into an expectation of higher inflation in the short-run. As a result, investors are more likely to be interested in entering into positions in inflation-linked instruments, which in the euro area can be accomplished by trading inflation swaps that are recognized as the most liquid inflation-linked securities. By amplifying the activity in the inflation swap market, the respective volatility also becomes greater, which ultimately explains the significance of the parameter γ_1. Lastly, the parameter γ_1^- does not point to the presence of asymmetric effects.

[8] The eigenvalues associated with the coefficient matrix have modulus less than 1, indicating that the VAR (1) is stable (see Lütkepohl, 2005).

As regards the conditional variance of changes in ZCISR 5Yx5Y, it is worthwhile remarking on the presence of ARCH and GARCH effects. Overall, in the pre-crises, oil price movements, which are captured by γ_2, did not drive the volatility of changes in long-term inflation compensation. As explained above, this outcome mirrors the notion that, if agents are confident that the ECB will achieve the price stability objective, long-term expectations should be insensitive to temporary economic and financial shocks.

Table 4 unveils the empirical results for the period from July 2008 to July 2014. According to the output from Model B, which consists of a VAR(2)-CCC-GARCH, and starting the analysis with changes in the short-term inflation compensation, they were only affected by oil price variations. In turn, movements in ZCISR 5Yx5Y were explained by their own lagged values and by adjustments in short-term inflation expectations. Nevertheless, the oscillatory signal, as well as the magnitude of the estimated parameters, point toward a mean reversion process.[9]

As regards the conditional variance–covariance structure, the result of the LM test of Tse (2000) supports the application of the CCC specification, and there is evidence that the conditional correlation between changes in ZCISR 1Yx1Y and changes in ZCISR 5Yx5Y ticked up to 0.23.

On the contrary, the optimal value for the parameter λ is no longer statistically significant at the conventional levels, hinting a total dependence of long-term moving average of oil prices on the latest oil price information. This new estimate for λ testifies that the global crisis led to sizeable changes in the financial landscape, namely in the oil market.

Concerning the conditional variance of changes in ZCISR 1Yx1Y, estimates for both the GARCH process and the parameter γ_1 remain statistically significant. The economic slowdown from mid-2008 to mid-2014 was accompanied by a reduction in the demand for energy, with oil prices falling and putting downward pressure on inflation expectations. Worried about the scenario of low inflation, agents would have incentives to enter into the inflation swap market, thereby increasing the respective activity and volatility. In addition, the positive estimate for the parameter γ_1^- bears out that, during the turmoil period, negative oil price shocks increased the volatility of changes in short-term inflation expectations more than the positive ones.

An analogous pattern is found for the volatility of changes in ZCISR 5Yx5Y, with previous long-run shocks and general oil effects being statistically significant. The estimate for the parameter γ_2 is especially relevant because risks of de-anchoring may arise in higher moments before becoming visible in the first moment. It seems to be the case, i.e., despite the statistical insignificance of δ_2, which gives the idea that changes in the level of ZCISR 5Yx5Y were not affected by crude, the sensitivity of changes in long-term inflation expectations to oil price dynamics detected in the volatility process may raise some relevant economic questions. As documented in the literature, if the monetary policy is credible, oil prices shocks should only have a short-lived effect on inflation (see, e.g., Conflitti and Cristadoro 2018).

[9] Again, the eigenvalues associated with the coefficient matrices have modulus less than 1, signalling that the VAR (2) process is considered stable.

Table 5 contains the estimates of the VAR(1)-CCC-GARCH for the period from August 2014 to September 2018. With respect to the conditional mean, the outcomes of Model B associated with changes in short-term inflation expectations sustains the relevance of their own lagged values but, in contrast to the prior subsets, oil price variations lost their relevance in explaining this variable. Moving on to the changes in ZCISR 5Yx5Y, the estimate for the parameter δ_2 is statistically significant, signaling that variations in the level of long-term inflation expectations became dependent on fluctuations in crude prices. On the back of a credible monetary policy, these results are somewhat controversial because if a central bank is trustworthy in the pursuit of its mandate, then long-term inflation expectations must be anchored at the central bank's objective and should not respond to short-run developments.

Looking at the conditional correlation between short-term and long-term inflation compensation, the LM test of Tse (2000) indicates that it is not dynamic, favoring the application of the CCC specification. While the conditional correlation between changes in ZCISR 1Yx1Y and changes in ZCISR 5Yx5Y was relatively weak until July 2014, it has become higher since then, standing at 0.52 in the third period. This closer relationship is clearly identified in Fig. 1 and suggests a stronger co-movement between shorter-term and longer-term inflation compensation. Knowing that the anchoring of longer-term inflation expectations plays a crucial role in the conduct of monetary policy, these results may deserve the attention of the central bank. A second remark is that this higher correlation between changes in short-term and long-term inflation expectations occurs in an environment where conventional monetary policy has increasingly been constrained by the effective lower bound (ELB). Indeed, the combination of a low inflation environment and low inflation expectations with a low natural real interest rate[10] put additional challenges for the central banks given that, in these circumstances, the space for conventional monetary policy easing (further monetary policy rate cuts) is clearly reduced, which led to the deployment of non-standard monetary policy measures.

As regards the estimate for λ, it is statistically significant at the 1% level, ascending to 0.66. Focusing on z_t as $z_t = \frac{u_t}{1-\lambda \times L}$, and comparing the estimates of λ across the three subsets, it is possible to conclude that it is in the last period that the dependence of $OIL_t - m_t$ on past values was higher.

Concentrating on the conditional variance, the ARCH and GARCH processes are statistically significant in the two cases. Notwithstanding the fact of remaining statistically significant, the estimations for γ_1 and γ_1^- diminished slightly, showing a lower impact of oil price movements on the volatility of changes in short-term

10 The natural interest rate is commonly defined as the real interest rate prevailing under conditions deemed as desirable on grounds of macroeconomic stabilization, in the absence of transitory shocks or nominal adjustment frictions. Available evidence suggests that, over the past few years, the euro area natural interest rate followed a downward trend, and currently it is and may stand at historically lows (close to zero or even in negative territory), which poses significant challenges to the conduct of monetary policy: On the one hand, the room for increases in policy interest rate may be more limited than that estimated in the past. On the other hand, it becomes more likely that the monetary policy interest rate will hit the ELB, thereby using more frequently non-standard monetary policy measures. For a detailed analysis on the euro area natural interest rate, see, e.g., Brand et al. (2018).

inflation expectations. The lower but still statistically significant estimate for the parameter γ_2 implies that the volatility of changes in long-term inflation expectations remained reactive to oil price fluctuations, albeit less intensely.

Overall, the downward trajectory of long-term inflation expectations in parallel with both the burgeoning synchronization of changes in short-term and long-term market-based inflation expectations and the impact of oil prices on the level and on the volatility of ZCISR 5Yx5Y over the third period merit particular attention as they may signal a softer anchoring of long-term inflation expectations in the period from August 2014 to September 2018. Indeed, according to the traditional premise, if medium to longer-term inflation expectations are well-anchored, they must stand at levels compatible with the central bank's objective and agents are not expected to revise them in result of short-term developments (see, e.g., Natoli and Sigalotti 2018).

The dynamics of euro area long-term inflation expectations may be related to the persistence of a low inflation (and core inflation,[11] which is likely to act as an attractor for long-term inflation expectations) over recent years that may have raised concerns regarding the central bank's ability to ensure that, in the medium to long term, inflation follows a sustained path toward levels that are consistent with the objective of price stability (see e.g., Erceg and Levin 2003). In order to tackle the challenges of subdued inflation (namely to discard a possible deflation risk) and indications of declining longer-term inflation expectations accompanied with a higher responsiveness of long-term inflation expectations to short-term shocks, once exhausted the space of conventional monetary policy, the Eurosystem launched an unconventional monetary policy package comprised by four instruments: negative policy interest rates, an asset purchase program, forward guidance on interest rates and on the size and duration of asset purchase programmes and targeted longer-term refinancing operations (TLTROs). There is evidence pointing out that, when approaching the ELB on nominal interest rates, these measures contributed to alleviate the lack of conventional policy space, thus improving lending conditions and providing support to the economy (see e.g., Rostagno et al. 2019; Eser et al. 2019 or BIS 2019). Yet, the magnitude of these effects is surrounded by high uncertainty.

Despite the measures adopted over the third period, inflation remained low and in the end of the sample 5Yx5Y inflation expectations stood at 1.7%, exhibiting a higher responsiveness to short-term news. In spite of the Eurosystem's actions, investors' outlook on far forward inflation may have been affected by inflation outcomes persistently below the inflation aim, thus creating the view that inflation will remain below the ECB's objective for a protracted period and casting doubts on the efficiency of the monetary policy framework to increase inflation in a sustainable manner. This may be justified by both the expectations that the ELB on interest rates may be binding more frequently than in the past and the high uncertainty regarding the effectiveness of non-standard instruments to increase inflation.

Moreover, this greater instability of long-term inflation expectations may come from a misunderstood perception of the price stability objective pursued by the

[11] Inflation excluding energy, food, alcohol and tobacco.

Eurosystem since 2003, as hinted by Lagarde (2020). In fact, the current definition of price stability used by the Eurosystem can be seen as asymmetric because, while there is a clear upper bound for inflation, the identification of the lower bound is not explicit stated. This formulation might have created the perception that the ECB would be more tolerant toward low inflation than high inflation, leading to a perceived absence or insufficient policy response that resulted in a slow drop of long-term inflation expectations. In order to clarify the symmetric nature of ECB's reaction, the ECB's Introductory Statement includes an explicit reference to symmetry function since July 2019. Furthermore, the measures triggered by the Eurosystem over the last years denote an outstanding effort to ensure that inflation moves toward its aim in a sustained manner, which does not lend support to the view of an asymmetric policy reaction function. Therefore, empirical evidence is inconclusive as to the symmetry of the reaction function of the ECB's interest rate (see e.g., Rostagno et al. 2019; Paloviita et al. 2017).

Finally, given that inflation remained subdued despite the multitude of unconventional measures introduced since mid-2014, it is possible to conjecture if it occurred due to insufficient monetary policy stimulus or due to the policy accommodation adopted, i.e., in which extent the policy response triggered by the Eurosystem to increase inflation contributed itself to fuel the low inflation environment. In fact, if the real interest rate is independent of nominal interest rates and of the level of inflation in the long-run—standard long-run monetary neutrality propositions—then the Fisher relation implies that nominal interest rate and inflation move one-for-one over the long-run. Accordingly, the current low levels of inflation would be expected because (nominal) interest rates have been low for a prolonged period of time and they are expected to persistently remain in such territory in light of the forward guidance used to signal the likely future path of the monetary policy interest rate (see e.g., Uribe 2020).

On the grounds of this discussion, it is worth noting that in January 2020 the Governing Council of the ECB launched a review of its monetary policy strategy with the purpose of ensuring that the strategy is the most suited to deliver the primary objective of maintaining price stability. This strategy review will explore both the quantitative formulation of price stability and how it should be achieved and will certainly shed new light on the reasons behind the drop and higher responsiveness of 5Yx5Y inflation expectations from mid-2014 onwards.

6 Conclusion

Inflation expectations are a cornerstone of monetary policy, being one of the most relevant metrics used for assessing the inflation outlook and the central banks' credibility in safeguarding price stability.

This paper strives to contribute to the literature by investigating the dynamics of euro area market-based inflation expectations for different tenors throughout three sub-periods from January 2005 to September 2018, covering not only the conditional mean, but also the conditional variance–covariance structure of these variables. In addition, this research sheds further light on the transmission mechanism between oil price movements and changes in euro area inflation expectations for various time horizons by means of an innovative approach which is based on the typical moving average trading rule.

Given the presence of conditional heteroskedasticity and constant conditional correlations, the empirical exercise draws on a VAR-CCC-GARCH model, which is then adjusted to include information about oil prices in the conditional variance. With the view to bolster the knowledge of the volatility dynamics of forward inflation swap rates in relation to crude, this research builds on the parameterization proposed by Nicolau (2007), which was firstly set out in the case of univariate models and resorts to a typical moving average trading rule. According to this trading scheme, when recent prices are higher (lower) than older prices, i.e., when the short-term average is above (below) the long-term average, economic agents tend to believe that prices are following an upward (downward) trend so that they are prone to buy (sell) more. By increasing their activity in the market, agents end up affecting its volatility. In this investigation, it is originally explored the extent to which oil price movements in relation to the long-term average are able to influence the volatility of changes in inflation expectations. This novel specification is relevant in a context where it is widely documented that the dynamics of crude prices are key drivers of inflation compensation (see e.g., Badel and McGillicuddy 2015; Elliot et al. 2015 or Wong 2015).

Taken together, the evidence found in this paper reveals that:

1. The conditional correlation between changes in ZCISR 1Yx1Y and in ZCISR 5Yx5Y was constant and relatively low in the first two subsets, but it has increased significantly since mid-2014. This fact deserves special attention because if long-term expectations are well-anchored, then the 5-year inflation expectations 5-years ahead are not supposed to be highly correlated with revisions to 1-year inflation expectations 1-year ahead. In light of the effect that the higher synchronization of short-term and long-term inflation expectation dynamics may have on the central bank's credibility, the ECB should closely monitor the evolution of these variables in the near future.
2. With the exception of the period of major turmoil, there are no signals of fundamental deviations in how changes in short-term inflation expectations affected changes in longer-term compensation and vice versa. In particular, the insensitivity of changes in ZCISR 5Yx5Y to changes in ZCISR 1Yx1Y is a remarkable finding since, despite the higher conditional correlation especially noted since mid-2014, there is no evidence of fundamental deviations in their relationship.
3. Changes in short-term inflation expectations tended to respond to movements of oil prices both in the conditional mean and in the conditional variance and are in consonance with the literature that claims that short-term inflation compensation tends to react to economic and financial conditions (Posen 2011).
4. Changes in long-term inflation expectations started responding to oil price fluctuations with the onset of financial and economic turmoil, firstly in terms of the conditional variance and then both in the conditional mean and in the conditional

variance. Although the estimates associated with the impact of oil on both the conditional mean and the conditional variance are relatively low, they are statistically significant, which is likely to cast suspicions if long-term inflation expectations remain well-anchored.

5. During the last sub-period, changes in long-term inflation expectations became more correlated with changes in short-term inflation expectations and the dependence of ZCISR 5Yx5Y on crude prices was also extended to the conditional mean. These facts occurred in a period in which, notwithstanding the accommodative monetary policy stance where the ECB adopted a host of non-standard measures, realized inflation stood below the central bank's goal. As such, it is legitimate to conjecture that the behavior of long-term inflation expectations may result from investors' concerns about the central bank's ability to ensure that inflation moves toward the inflation aim in a sustained manner or due to a possible misunderstood perception of the ECB's price stability objective and its reaction function. Additionally, one can interpret the evidence found in the third period in two different ways, i.e., the greater instability of long-term inflation expectations can be viewed as both a cause and a consequence of an accommodative monetary policy stance. On the one hand, the drop and lower stability of long-term inflation expectations can result from a prolonged period of low inflation due to insufficient monetary policy accommodation, especially in the context of the ELB where the space to further accommodation is lower. On the other hand, given the massive response adopted by the Eurosystem, it is also possible to put into question if the drop and lower stability of long-term inflation expectations may derive from the adopted accommodation policy, namely the low level of nominal interest rates and the forward guidance promising that they will persistently remain so.
6. There were some changes in the oil market dynamics, reflected in different values for the parameter λ, signaling that, over the full sample, the long-term moving average of oil prices reacted differently to the latest information on oil prices.

In all, this study points out to the importance of modeling higher moments of inflation expectations since some de-anchoring risks may be anticipated. Additionally, the reaction of inflation compensation to oil price shocks in the level and variance structure should be considered when tracking the monetary policy during the last years. These conclusions were based on a novel approach that may be useful in future to monitor such dynamics. Moreover, by offering a comprehensive analysis of how euro area short-term and long-term market-based inflation expectations have interacted and evolved over a long time horizon that covers diverse economic and financial contexts, this paper may support the Eurosystem's monetary policy strategy review launched in January 2020. In this process, issues such as the inflation objective and the horizon over which price stability should be achieved will be particularly addressed.

Taken together, beyond their importance to central banks, these findings are relevant for analysts, investors, firms and households that take the path of future inflation into consideration in their consumption and investment decisions.

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Declarations

Conflict of interest The views expressed are those of the authors and do not necessarily represent those of the Banco de Portugal or the Eurosystem.

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