DNB Working Paper

No. 509 / April 2016

Deflation risk in the euro area and central bank credibility

Gabriele Galati, Zion Gorgi,
Richhild Moessner and Chen Zhou

DeNederlandscheBank
EUROSYSTEEM

Deflation risk in the euro area and central bank credibility

Gabriele Galati, Zion Gorgi, Richhild Moessner and Chen Zhou *

* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

Working Paper No. 509

April 2016

De Nederlandsche Bank NV
P.O. Box 98
1000 AB AMSTERDAM
The Netherlands

Deflation risk in the euro area and central bank credibility*

Gabriele Galati[a], Zion Gorgi[a], Richhild Moessner[a,b] and Chen Zhou[a,c]

[a] *De Nederlandsche Bank, PO Box 98, 1000 AB Amsterdam, The Netherlands*
[b] *Cass Business School, London, United Kingdom*
[c] *Erasmus University, Rotterdam, The Netherlands*

March 2016

Abstract

This paper investigates how the perceived risk that the euro area will experience deflation has evolved over time, and what this risk implies for the credibility of the ECB. We use a novel dataset on market participants' perceptions of short- to long-term deflation risk implied by year-on-year options on forward inflation swaps. We investigate whether long-term inflation expectations have become de-anchored, by studying whether long-term deflation risk has been affected by changes in oil prices and by short-term deflation risk. Our analysis suggests that the anchoring properties of euro area inflation expectations have weakened, albeit in a still subtle way.

Keywords: Deflation, inflation expectations, monetary policy, financial crisis.
JEL classification: E31, E44, E52, E58.

* The views expressed in this paper are those of the authors and not necessarily the views of De Nederlandsche Bank.

1 Introduction

Since mid-2014, inflation in many economies has been only slightly positive or even negative. In early 2015, the United States and the United Kingdom joined the euro area in slipping into a slight deflation. Current or prospective deflation has prompted concerns about its recessionary consequences – particularly in the presence of high levels of debt. It has prompted central banks to either step up or delay exit from unconventional monetary policy. The ECB's decision to embark on quantitative easing is a case in point.

This paper investigates how the perceived risk that the euro area will experience deflation has evolved over time, and what this risk implies for the credibility of the ECB. We use a novel dataset on market participants' perceptions of short- to long-term deflation risk implied by year-on-year options on forward inflation swaps. A key advantage of our dataset is that it allows to extract expected probabilities of deflation from options on forward inflation rates, as opposed to zero-coupon options on spot inflation rates, which have been mainly used in the literature so far. This allows us to study long-term deflation risk, rather than merely an average over short- and long-term deflation risk as provided by options on spot inflation rates. We also present a comparison of these market-based expectations with the expectations of professional forecasters. We investigate whether long-term inflation expectations have become de-anchored, by studying whether long-term deflation risk has been affected by changes in oil prices and by short-term deflation risk. Our analysis suggests that the anchoring properties of euro area inflation expectations have weakened, albeit in a still subtle way.

Much of the literature on deflation has been written by economic historians. Their studies have documented deflation as a widespread phenomenon in the 19th century and in the interwar period of the 20th century (e.g. Bordo, Landon-Lane and Redish, 2004). In the more recent past, most attention has focused on the experience of Japan in the 1990s, the brief spells of falling prices in some Asian economies in the early 2000s, and the deflation scare in the United States in 2003 (Ahearne at al., 2002; Borio and Filardo, 2004; Bordo and Filardo, 2005). A recent paper by Borio et al. (2015) examines the historical record of deflation – defined in terms of a decline in the price of goods and services, and of asset prices – over a sample covering 140 years and 38 economies.

Very little is known about expectations of deflation. Three literature strands shed some light on this issue. The first consists of descriptive analyses based on a range of macroeconomic and financial indicators. Borio and Filardo (2004) examined historical episodes of deflation and argued tentatively that these tended to be unanticipated. They also suggested that deflation expectations might have become more accurate in the more recent past. Kumar and others (2003) develop an indicator of deflation vulnerability based on variables such as various price indices, GDP growth and the output gap, the real exchange rate, equity prices, credit growth, and monetary aggregates.

The second literature strand captures probabilities of deflation as fan charts around baseline projections of forecasting models (Decressin and Laxton, 2009). This line of research shows that the dynamics of deflationary expectations hinges on whether changes in the level of oil prices are perceived to be temporary or are extrapolated to the future.

The third strand consists of dynamic term structure models that disentangle inflation expectations and risk premia to calculate implied deflation probability forecasts at all forecast horizons, embedded in inflation-indexed bonds (Christensen et al., 2012; Grishchenko et al., 2016). Deflation probabilities estimated with these models are found to be generally consistent with those derived from macroeconomic models or surveys of professional forecasters.

The fourth literature strand encompasses papers that estimate option-implied probability density functions for future inflation. Information on the entire distribution of inflation expectations, or higher moments of that distribution, may be useful as an early warning indicator of a de-anchoring of inflation expectations, in addition to the mean inflation expectations which can be derived from inflation swaps. In this strand of literature, density functions for future inflation are estimated with data on inflation linked options – inflation caps and floors – which have become increasingly liquid in recent years. Markets for these derivatives have expanded quickly in the euro area, the United Kingdom and – albeit to a much lesser extent – the United States since 2012, as market participants became increasingly concerned about the risk of either deflation or elevated levels of inflation in the short- and medium term.

Three contributions to this literature are closely related to our paper. The first, by Kitsul and Wright (2012), examines the tails of those distributions for US inflation, using daily data on indicative quotes of zero coupon inflation caps with maturity ranging from one to 30 years. Their data source is BGC Partners, one of the main brokers in the market for inflation-linked options. The authors estimate option-implied probability densities under the assumption of risk neutrality. They find that these densities assign considerably more mass to extreme inflation outcomes (either deflation or high inflation) than do those obtained by time series methods. They also report that their estimates of option-implied densities assign much higher probabilities to both tails than do respondents of the Federal Reserve Bank of New York's survey of primary dealers. The second, by Scharnagl and Stapf (2015), uses the same type of data to estimate option-implied probabilities for euro area HICP over the sample period from 2009 to 2013. They find that option traders have been pricing in an increasing, albeit still contained, likelihood of deflation in the euro area. The third contribution, by Cechetti et al. (2015), extracts probability distributions of inflation expectations in the euro area from quotes of European options (caps and floors) on inflation. They use daily closing quotes of zero-coupon inflation options with maturities of 1, 2, 3, 5, 7 and 10 years, from 5 October 2009 to 18 February 2015. Their data source is Bloomberg. Cecchetti et al. (2015) test for the anchoring of inflation expectations using both linear correlations and measures of tail comovement based on the theory of copulas and on the non-parametric TailCor indexes. They find that for both the mean and the variance of expectations, the tail comovement of short- and long-term expectations has tended to increase between mid-2014 and early 2015. They find evidence of a significant asymmetry: the co-movement between short- and long-term expectations is positive when short-term expectations decline, while long-term expectations are inelastic when short-term expectations rise.

One problem with this approach is that the measure of long-term inflation expectation derived from zero coupon inflation-linked options may be less useful in assessing the perceived credibility of the ECB. When considering zero coupon inflation-linked options, they are contracts written on the average inflation rate over their lifetime, for example, between the start of the contract and five years thereafter. From such a derivative, one can directly obtain probabilities regarding the spot inflation rate from the start until five years. Hence, as Kitsul and Wright (2013) discuss, densities for forward inflation over specific future dates cannot be extracted without making further assumptions.

In contrast, a year-on-year inflation cap or floor option is a series of independent caplet/floorlet options. Theoretically, by employing two options with different maturities, one can strip out the single price of each caplet/floorlet in the series, and derive the implied probabilities regarding such a forward rate. In this paper, we adopt this theoretical idea and use year-on-year cap or floor options as opposed to options on spot inflation rates.

A number of papers have studied the effects of oil prices on private agents' mean inflation expectations. The effects of oil prices on the term structure of inflation expectations in the euro area, the United Kingdom and the United States have been studied in Gerlach-Kristen and Moessner (2014). Trehan (2006) studied the effects of oil prices in the years up to 2006 on expected inflation in the United States, the United Kingdom and Canada. Leduc, Sill and Stark (2007) find that higher oil prices in the period after 1979 oil shocks did not trigger an increase in US short-term inflation expectations. Mehra and Herrington (2008) study the effect of commodity prices on short-term US inflation expectations from 1953 to 2007. Beechey, Johannsen and Levin (2011) find that oil futures prices have affected long-term inflation swap rates and break-even inflation rates in the United States, but not in the euro area. They interpret their results in terms of the anchoring properties of inflation expectations. Sussman and Zohar (2015) study the effect of oil prices on five-year breakeven inflation rates in the United States, the United Kingdom, the euro area and Israel. They find that oil prices have a strong correlation with medium-term inflation expectations, as measured by five-year breakeven inflation rates. They conclude that the public's belief in the ability of monetary authorities to stabilize inflation in the medium term has deteriorated. In this paper we build on this strand of the literature by studying the effect of oil prices on deflation risk at short to long-term horizons, rather than on mean inflation expectations, and also interpret the results in terms of the anchoring properties of inflation expectations.

The remainder of the paper is organized as follows. Section 2 describes the market for inflation caps and floors, and how data on these derivatives are used to derive measures of market-based deflation probabilities. Section 3 describes the data sources for market participants' deflation probabilities, and section 4 shows comparisons with deflation expectations measured by surveys. Section 5 presents the empirical method and results, and in section 6 we draw conclusions.

2 Using inflation options to derive measures of forward inflation expectations

Research on market measures of inflation expectations typically focuses on inflation swaps and inflation-indexed bonds (e.g. Gürkaynak, Sack and Swanson, 2005; Gürkaynak, Levin and Swanson, 2010). One limitation of these instruments is that they do not clearly reflect the level of uncertainty that is inherent in market prices. The recent growth in inflation options markets now offers a way to move beyond swap-price developments for gauging inflation expectations by exploring the probability density functions of expected future inflation, and also higher moments such as the skewness and kurtosis of inflation.

Although a relatively new market, the inflation options market has been evolving rapidly since the onset of the financial crisis, undoubtedly stimulated by central banks' unconventional monetary policies and new regulatory initiatives which have increased investors' needs to hedge against inflation risks. And although still considered a relatively non-transparent over-the-counter market, there is currently sufficient evidence to suggest that the inflation options market has matured to an extent that justifies greater consideration, with an increased availability of quoting agents and brokers that report larger transaction volumes and better price developments, particularly in the European options market.

The demand for inflation caps and floors is largely driven by investors with future cash flows that are exposed to inflation risk. In more recent years demand was also driven by investors' diversification purposes, perhaps due to the low correlation of inflation options with conventional investments. The main participants in the market are hence pension funds, insurance companies, infrastructure funds, hedge funds, banks, asset managers and mutual funds.

Inflation caps and floors are options that are based on the annual or cumulative inflation rate and, in a way, are analogous in their structure to interest rate options. An inflation cap could be regarded as a call option; the buyer of the cap would usually aim to limit the risk of inflation rising above a specific level (represented by the option's strike price). An inflation floor could be regarded as a put option; the buyer of a floor would aim to limit the risk of inflation dropping below a certain level.

The two most common structures are zero coupon (zc) and year-on-year (yoy) inflation options. Both structures offer caps and floors with similar maturity and strike arrays, yet there are several differences between the two. A zero coupon inflation option is a single option with a single maturity date. The payoff on a zero coupon cap/floor is based on the cumulative inflation rate between the settlement and maturity of the option. The option could have a maximum of one cash flow at maturity. A year-on-year cap/floor option is a basket of multiple, so-called caplet/floorlet options with an identical strike price but with different maturities. For instance, a 5-year year-on-year cap with a 2% strike price is a series of five independent options (caplets) maturing at annual intervals. The payoff on an individual caplet, if in-the-money, is based on the difference between the annual (year-on-year) realized inflation rate and the option's strike price multiplied by a notional amount. A year-on-year inflation cap/floor could potentially yield more than a single cash flow to its holder.

There are several advantages in preferring the less straightforward year-on-year structure to extract information about deflation probabilities. First, the year-on-year option allows for extracting the implied probability regarding a forward inflation rate. In contrast, the zero coupon option is based on the spot inflation rate until the maturity, which does not allow to extract the probabilities regarding the expectations of a forward inflation without making further assumptions on the dynamics of inflation expectations.

In addition, major market makers report that the year-on-year inflation options markets has a better price development across different strikes compared to the zero coupon market. The year-on-year options market is generally more liquid, it is easier to price, less problematic concerning the seasonality of inflation, and is more suitable for a large investor base that seeks to hedge against annual exposure of cash-flows to inflation.

Moreover, a leading brokers has recently mentioned that there is a steady increase in the year-on-year options market activity, specifically at the far out-of-the-money (OTM) strikes. This demand at the tails, according to our source, is driven mainly by real-money investors interested in limiting tail risks, rather than by fast money investors such as pension funds and insurance companies who are usually more active around the at-the-money (ATM) range of the market. Zero coupon options, on the other hand, are reportedly less liquid at the far OTM strikes, suggesting they might be less accurate in assessing the more extreme market scenarios.

3 Data on deflation probabilities

The empirical analysis is based on option-implied probabilities that were provided to us by the Royal Bank of Scotland (RBS). Based on the prices of year-on-year euro HICP (ex-tobacco) inflation caps and floors, with the bank's own calculation, RBS has provided us with option-implied inflation probabilities regarding one year forward inflation rates ending to 2, 3, 5, 7 and 10-years ahead. The probabilities were calculated for the corresponding forward rates being in one of the seven probability-buckets as follows: [≦-1%], [-1%,0%], [0%,1%], [1%,3%], [3%,4%], [4%,5%] and [≧5%]. The dataset runs from January 2010 to December 2015. The daily data is shown in Figure A in the appendix.[1] Monthly averages of the daily data on deflation risk from

[1] On trading days with missing values, we carried over the previous days' values. We removed the values on five dates where they were very likely outliers due to inputting errors, namely on 30.8.2013, 28.10.2013, 30.12.2013, 24.3.2014 and 28.3.2014.

year-on-year options are shown in Figure 1.

Note that these measures of deflation risk must be considered with caution, as the prices of inflation caps and floors can be affected by other factors such as liquidity or risk premia or technical factors. Market-based measures of deflation risk may be affected by technical factors, such as liquidity premia unrelated to expectations of future price changes. We deal with this important issue in three ways. First, we also look at survey data from the ECB's Survey of Professional Forecasters (SPF). These capture the expected euro area inflation probability distributions of each individual forecaster. They provide direct information on their perceived likelihood of deflation. Individual responses are averaged to give the survey-based probability distributions of expected inflation for survey respondents as a whole. This measure reflects both the uncertainty of each individual respondent and the dispersion in views between different respondents. Second, we convert daily data on deflation risk from year-on-year options and oil prices to monthly data by taking monthly averages of the daily data (Figure 1). Although lack of liquidity in the market for year-on-year inflation options makes day-to-day changes in implied deflation probabilities noisy, these contracts are useful in providing information about lower frequency movements (Smith, 2012). Third, in our econometric tests we use different control variables to capture technical factors unrelated to expectations.

4 Comparison with survey-based measures

We find that in the course of 2014 and 2015, market participants and professional forecasters attached an increasing probability to a deflationary scenario. Professional forecasters still considered this a very unlikely event over the next two years at end-2014, with only a 2% probability (Figure 2). Market participants instead appeared more pessimistic. Inflation-linked year-on-year options in December 2015 priced in a 25% chance that HICP inflation will be negative 2 years ahead (Figure 1). As discussed above, however, this is not a precise measure of expectations, as it could partly also reflect credit and liquidity risk premia. We therefore verify that broader changes in the two measures of deflation probabilities are consistent. All in all, there is a clear ongoing trend in the distribution of inflation expectations by professional forecasters and market participants, which has become increasingly skewed towards a scenario of low and possibly negative inflation over the medium-term (see Figures 2 to 4).

5 Econometric method and results

Looking at graphs of deflation risk measures may be misleading, as these are notoriously imperfect measures of expectations. We therefore perform econometric tests using market data to verify more formally whether the anchoring properties of inflation expectations have changed.

We first examine whether deflation probabilities at short-, medium- and long-term horizons embedded in inflation options react to oil prices. If inflation expectations are anchored at the central bank's inflation target, deflation probabilities at the short- and medium-term horizon may react to changes in oil prices, but at the long-term horizon they should not.

We regress monthly changes in deflation risk at horizons of m=2, 3, 5, 7 and 10 years ahead, f_t^m, on a constant and month-on-month percentage changes in oil prices,

$$\Delta f_t^m = \alpha + \Delta oil_t + \varepsilon_t, \tag{1}$$

where $\Delta f_t^m = f_t^m - f_{t-1}^m$ is the monthly change in deflation risk m years ahead in percentage points, Δoil_t is the month-on-month percentage change in oil prices (West Texas Intermediate in US dollars per barrel). The sample period is January 2010 to December 2015. Newey-West adjusted standard errors are used to correct for serial correlation and heteroskedasticity. Using this regression we test whether long-term inflation expectations have reacted to changes in oil prices, which would provide evidence for a de-anchoring of long-term inflation expectations, reflecting a loss in the central bank's credibility of achieving its price stability definition of an inflation rate of "below, but close to two percent". By contrast, a reaction of short-term inflation expectations to changes in oil prices is to be expected, and not a sign of a loss in central bank credibility.

We find that short-term deflation risk (2 years ahead) reacts significantly and most strongly to oil prices. Medium-term deflation risk (3, 5, and 7 years ahead) also reacts significantly to oil prices, but less strongly than at shorter horizons, while long-term deflation risk (10-years ahead) does not react to oil prices (Table 1). This suggests that inflation expectations have remained relatively well-anchored, since the longest-term deflation risk does not react to oil price changes. However, some reaction of deflation risk at the 7-year horizons may give an indication that inflation expectations have not remained strongly anchored.

We also perform Granger causality tests between monthly changes in deflation risk at the different horizons and month-on-month percentage changes in oil prices. Results are shown in Table 2. We can see that oil prices Granger causes deflation risk at the 2, 3, and 5-year horizons at the 1%, 5% and 5% significance levels, respectively, but not at the 7- and 10-year horizons. These results are consistent with the results shown in Table 1, in that long-term deflation risk is not Granger caused by oil prices, while short-term deflation risk is, suggesting that long-term inflation expectations have remained well-anchored.

Second, we test whether short- and medium-term deflation probabilities influence long-term expectations. If the central bank is fully credible, they should not. We find that 2-year ahead deflation risk Granger causes deflation risk 3, 5 and 7 years ahead, but does not Granger cause long-term deflation risk 10 years ahead; 3-year ahead deflation risk Granger causes deflation risk 2 and 5 years ahead, but does not Granger cause longer-term deflation risk 7 and 10 years ahead.

Moreover, 5-year ahead deflation risk Granger causes none of the deflation risk at other horizons. Finally, 7- and 10-year ahead deflation risk Granger cause each other. These results are also consistent with long-term inflation expectations remaining relatively well anchored, since short-term deflation risk does not Granger cause long-term deflation risk 10 years ahead. However, the finding that short-term (2 year-ahead) deflation risk Granger causes deflation risk 7-years ahead may also give some indication that long-term inflation expectations have not remained strongly anchored.

Next we study whether the anchoring of inflation expectations has changed over time, by estimating the reactions of deflation risk to oil price changes separately for the first half of the sample period (January 2010 to December 2012) and the second half (2013 to December 2015). The results are shown in Table 3. We can see that in the first half of the sample, only short-term deflation risk (2 and 3 years ahead) reacted significantly to oil prices, while medium and long-term deflation risk (5, 7 and 10 years ahead) was not significantly affected. By contrast, in the second half of the sample, deflation risk 5 and 7 years ahead reacted significantly to oil prices. But long-term deflation risk 10 years ahead remained unaffected by oil prices in the second half of the sample. Short-term deflation risk (2 and 3 years ahead) continued to be significantly affected by oil prices in the second half of the sample, although with a lower magnitude of the reaction. These results suggest that long-term inflation expectations may have become somewhat less well anchored in the second half of the sample.

Finally, we consider the robustness of the results above to including a proxy for local financial market uncertainty, in the form of the VSTOXX financial volatility indicator for the euro area, which is commonly used for this purpose. The VSTOXX is a measure of implied volatility for options on the Eurostoxx equity index, taken from Bloomberg. We include this financial volatility index since it may be related to risk and liquidity premia contained in the market measures of euro area deflation risk, and thereby control for changes in such risk and liquidity premia. We estimate the following regression,

$$\Delta f_t^m = \alpha + \Delta oil_t + \Delta VSTOXX_t + \varepsilon_t, \qquad (2)$$

where $\Delta VSTOXX_t$ is the month-on-month percentage change in the VSTOXX index.

Moreover, we consider the robustness of the results above to including a proxy for global financial market uncertainty, in the form of the VIX financial volatility indicator, which is commonly used for this purpose. The VIX is a measure of implied volatility for options on the US S&P 500 equity index, taken from Bloomberg. We include this financial volatility index since it may be also related to risk and liquidity premia contained in the market measures of euro area deflation risk, and thereby control for changes in such risk and liquidity premia. We estimate the following regression,

$$\Delta f_t^m = \alpha + \Delta oil_t + \Delta VIX_t + \varepsilon_t, \qquad (3)$$

where ΔVIX_t is the month-on-month percentage change in the VIX index.

The results are shown in Tables 4 and 5. We can see that both the VSTOXX and VIX volatility indices are significant for deflation risk only at the 3 and 5-year horizons, with higher volatility leading to an increase in deflation risk. We find that long-term deflation risk continues not to react to oil prices in the first half of the sample. But in the second half of the sample, deflation risk 7 and 10 years ahead when controlling for $\Delta VSTOXX_t$, and 7 years ahead when controlling for ΔVIX_t, does react significantly to oil prices. These results therefore also suggest that long-term inflation expectations may have become somewhat less well anchored in the second half of the sample. This conclusion is consistent with the evidence presented by Scharnagl and Stapf (2015) and Cecchetti et al. (2015).

6 Conclusions

This paper investigated how the perceived risk that the euro area will experience deflation has evolved over time, and what this risk implies for the credibility of the ECB. We used a novel dataset on market participants' perceptions of short- to long-term deflation risk implied by year-on-year options on forward inflation swaps. A key advantage of our dataset is that it allows to extract expected probabilities of deflation from options on forward inflation rates, as opposed to zero-coupon options on spot inflation rates, which have been mainly used in the literature so far. This allows us to study long-term deflation risk, rather than merely an average over short- and long-term deflation risk as provided by options on spot inflation rates.

We investigated whether long-term inflation expectations have become de-anchored, by studying whether long-term deflation risk has been affected by changes in oil prices and by short-term deflation risk. Our analysis suggests that the anchoring properties of euro area inflation expectations have weakened, albeit in a still subtle way.

Acknowledgements

We would like to thank RBS for providing us with inflation options data.

References

[1] Ahearne, A, J Gagnon, J Haltimaier, S Kamin et al. (2002) "Preventing deflation: lessons from Japan's experience in the 1990s". Federal Reserve Board International Finance Discussion Papers No. 729, June.

[2] Andrade, P., Ghysels, E., and Idier, J. (2012) "Tails of inflation forecasts and tales of monetary policy". Working Paper 407, Banque de France.

[3] Beechey, M., Johannsen, B. and A. Levin (2011) "Are long-run inflation expectations anchored more firmly in the euro area than in the United States?". American Economic Journal: Macroeconomics, 3, 104-129.

[4] Bordo, M. and A. Filardo (2005) “Deflation and monetary policy in a historical perspective: remembering the past or being condemned to repeat it?”. Economic Policy.

[5] Bordo, M and A Redish (2004) "Is deflation depressing: evidence from the classical gold standard", in R Burdekin and P Siklos (eds), Deflation: Current and Historical Perspectives, Cambridge University Press.

[6] Borio, C., Erdem, M., Filardo, A. and B. Hofmann (2015) “The costs of deflations: a historical perspective”. BIS Quarterly Review, January (http://www.bis.org/publ/qtrpdf/r_qt1503e.pdf).

[7] Borio, C. and A. Filardo (2004) “Back to the future? Assessing the deflation record”, BIS Working Papers No. 152, March.

[8] Cecchetti, S., Natoli, F. and L. Sigalotti (2015) “Tail comovement in option-implied inflation expectations as an indicator of anchoring.” Banca d’Italia Temi di discussion No. 1025, July.

[9] Christensen, J., Lopez, J., and G. Rudebusch (2012) "Extracting deflation probabilities from treasury yields". International Journal of Central Banking, 8, 21-60.

[10] Fleckenstein, M., Longstaff, F., and Lustig, H. (2013) "Deflation Risk". NBER Working Paper No. 19238.

[11] Galati, G., Poelhekke, S. and Zhou, C. (2011) "Did the crisis affect inflation expectations?". International Journal of Central Banking, 7(1), 167-207.

[12] Gerlach-Kristen, P. and R. Moessner (2014) "Inflation expectations, central bank credibility and the global financial crisis". Swiss Journal of Economics and Statistics, 150(2), 55-87.

[13] Grishchenko, O. V., J. Vanden, and J. Zhang (2016) "The informational content of the embedded deflation option in TIPS". Journal of Banking & Finance, 65, April, 1-26.

[14] Gürkaynak, R., Sack, B. and E. Swanson (2005) "The Sensitivity of Long-Term Interest Rates to Economic News: Evidence and Implications for Macroeconomic Models". American Economic Review, 95(1), 425–436.

[15] Gürkaynak, R., Levin, A. and E. Swanson (2010) "Does Inflation Targeting Anchor Long-Run Inflation Expectations? Evidence from Long-Term Bond Yields in the U.S., U.K. and Sweden". Journal of the European Economic Association, 8(6), December, pp. 1208-1242.

[16] Hagan, P., Kumar, D., Lesniewski, A. and D. Woodward (2002) "Managing smile risk". Wilmott magazine, September, 84-108.

[17] Kitsul, Y. and J. Wright (2013) "The Economics of Options-Implied Inflation Probability Density Functions". Journal of Financial Economics, 110 (December), 696-711.

[18] Kumar, M., T. Baig, J. Decressin, C. Faulkner-MacDonagh, and T.Feyzioglu (2003) "Deflation: Determinants, Risks, and Policy Options". IMF Occasional Paper No. 221.

[19] Leduc, S., Sill, K. and T. Stark (2007) "Self-fulfilling expectations and the inflation of the 1970s: Evidence from the Livingston Survey". Journal of Monetary Economics, 54, 433-459.

[20] Levin, A., Natalucci, F. and J. Piger (2004) "The Macroeconomic Effects of Inflation Targeting". Federal Reserve Bank of St. Louis Review, 86 (July), 51-80.

[21] Scharnagl, M. and J. Stapf (2015) “Inflation, deflation, and uncertainty: What drives euro area option-implied inflation expectations and are they still anchored in the sovereign debt crisis?” Economic Modelling, 48, 248–269.

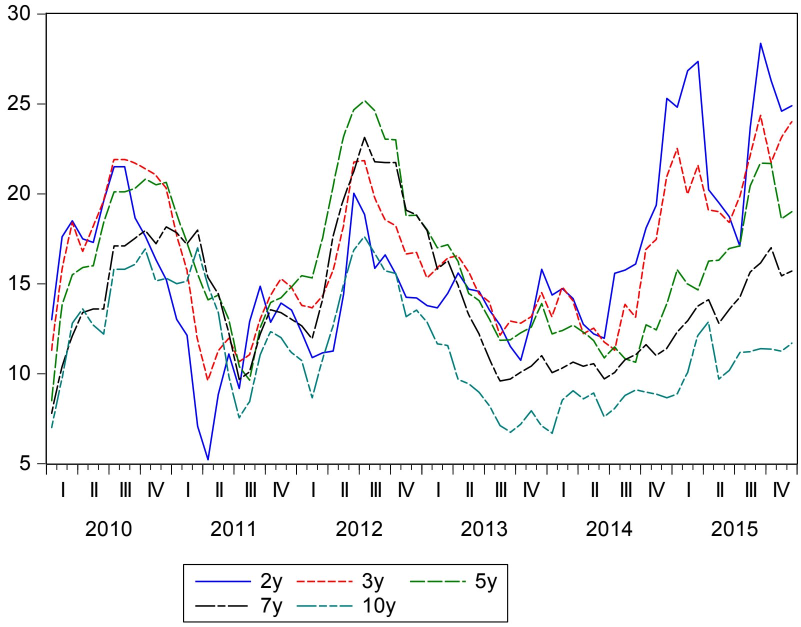
[22] Smith, T. (2012) “Option-implied probability distributions for future inflation.” Bank of England Quarterly Bulletin Q3.

[23] Sussman, N. and O. Zohar (2015) "Oil prices, inflation expectations and monetary policy". Central Bank of Israel Discussion Paper, available at http://www.boi.org.il/en/Research/DiscussionPapers1/dp092015e.pdf .

[24] Trehan, B. (2006) "Inflation targets and inflation expectations: Some evidence from the recent oil shocks". FRBSF Economic Letter No. 2006-22, September 1.

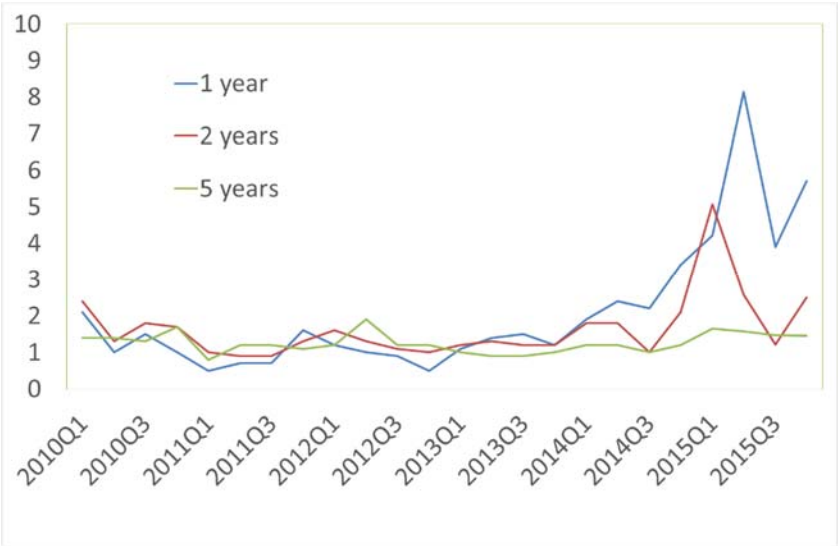
[25] Whittal, C. (2012) "Derivatives: Inflation options markets booms". International Financing Review, available at: www.ifre.com/derivatives-inflation-options-market-booms/210004568.article, .

Figure 1: Deflation risk from year-on-year inflation options n years ahead, in percent



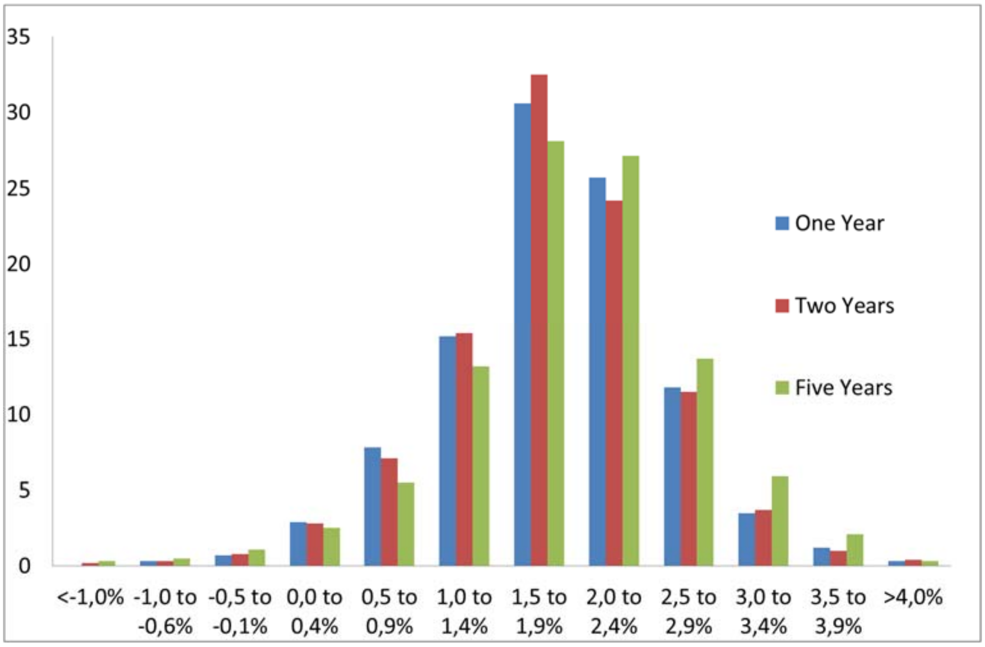
Source: Royal Bank of Scotland, authors' calculations.

Figure 2: Professional forecasters' expectations of deflation risk one, two and five years ahead (in percent)



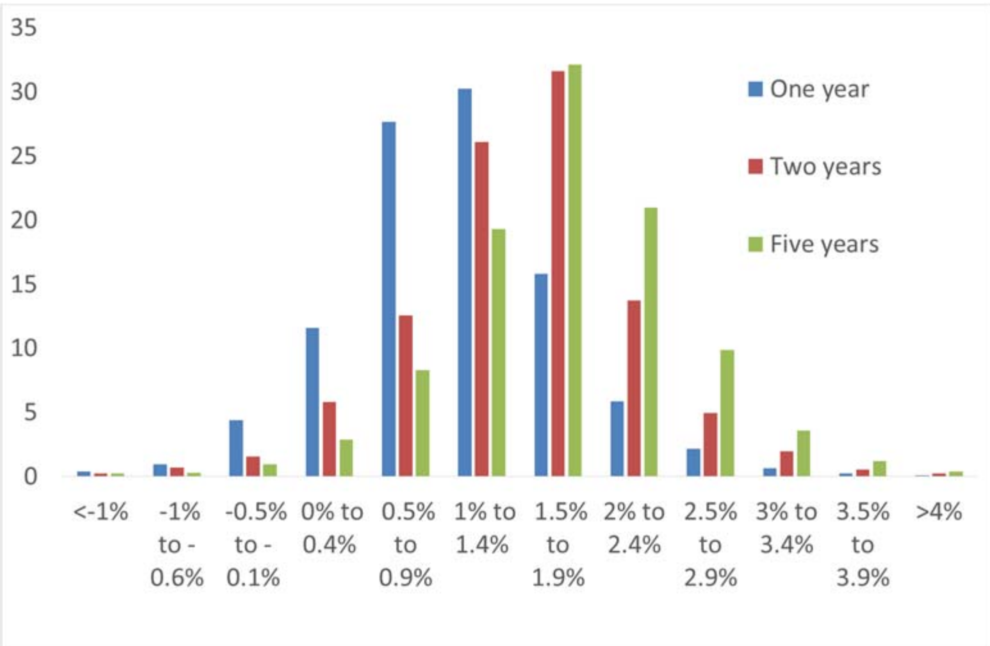
Source: ECB Survey of Professional Forecasters.

Figure 3: Distribution of inflation expected by professional forecasters in 2012Q2 one, two and five years ahead (in percent)



Source: ECB Survey of Professional Forecasters.

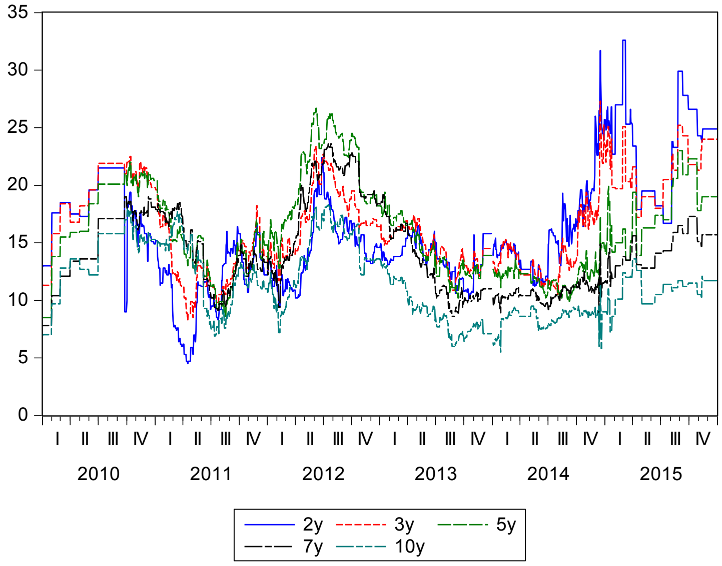
Figure 4: Distribution of inflation expected by professional forecasters (SPF) in 2015Q4 one, two and five years ahead (in percent)



Source: ECB Survey of Professional Forecasters.

Appendix Figures

Figure A: Deflation risk from year-on-year inflation options n years ahead; daily data (in percent)



Source: Royal Bank of Scotland.

Table 1: Reactions of deflation risk from year-on-year inflation options to oil prices

Dependent variable: Monthly changes in deflation risk m years ahead					
Variable	2 year	3 years	5 years	7 years	10 years
c	0.05	0.09	0.12	0.09	0.06
Δoil	-0.15***	-0.12***	-0.04*	-0.02*	-0.01
Adj. R^2	0.23	0.28	0.02	0.003	-0.01
No. of observations	71	71	71	71	71

***, ** and * represent significance at the 1%, 5% and 10% levels, respectively. Newey-West adjusted standard errors. Sample period: January 2010–December 2015.

Table 2: Granger causality tests between monthly changes in deflation risk m years ahead from year-on-year inflation options and month-on-month percentage changes in oil prices

Null Hypothesis:	Obs	F-Statistic	Prob.
Δf^3 does not Granger Cause Δf^2	69	6.34052	0.0031
Δf^2 does not Granger Cause Δf^3		7.91638	0.0008
Δf^5 does not Granger Cause Δf^2	69	1.34644	0.2674
Δf^2 does not Granger Cause Δf^5		4.14680	0.0203
Δf^7 does not Granger Cause Δf^2	69	0.69778	0.5014
Δf^2 does not Granger Cause Δf^7		4.30347	0.0176
Δf^{10} does not Granger Cause Δf^2	69	0.03756	0.9632
Δf^2 does not Granger Cause Δf^{10}		1.75619	0.1809
Δoil does not Granger Cause Δf^2	69	7.89268	0.0009
Δf^2 does not Granger Cause Δoil		0.49862	0.6097
Δf^5 does not Granger Cause Δf^3	69	0.86543	0.4257
Δf^3 does not Granger Cause Δf^5		2.79766	0.0684
Δf^7 does not Granger Cause Δf^3	69	0.13033	0.8780
Δf^3 does not Granger Cause Δf^7		2.32563	0.1059
Δf^{10} does not Granger Cause Δf^3	69	0.03316	0.9674
Δf^3 does not Granger Cause Δf^{10}		1.14150	0.3258
Δoil does not Granger Cause Δf^3	69	4.59019	0.0137
Δf^3 does not Granger Cause Δoil		0.71408	0.4935
Δf^7 does not Granger Cause Δf^5	69	0.38491	0.6821
Δf^5 does not Granger Cause Δf^7		1.43834	0.2449
Δf^{10} does not Granger Cause Δf^5	69	0.64413	0.5285
Δf^5 does not Granger Cause Δf^{10}		2.17985	0.1214
Δoil does not Granger Cause Δf^5	69	3.16824	0.0488
Δf^5 does not Granger Cause Δoil		0.40185	0.6708
Δf^{10} does not Granger Cause Δf^7	69	2.84283	0.0656
Δf^7 does not Granger Cause Δf^{10}		5.47745	0.0064
Δoil does not Granger Cause Δf^7	69	1.88945	0.1595
Δf^7 does not Granger Cause Δoil		0.02515	0.9752
Δoil does not Granger Cause Δf^{10}	69	1.97201	0.1475
Δf^{10} does not Granger Cause Δoil		0.40714	0.6673

Notes: Sample January 2010-December 2015; Pairwise Granger causality tests with 2 lags.

Table 3: Reactions of deflation risk from year-on-year inflation options to oil prices, subsamples

Dependent variable: Monthly changes in deflation risk m years ahead					
Variable	2 year	3 years	5 years	7 years	10 years
January 2010-December 2012					
c	0.15	0.23	0.31	0.32	0.18
Δoil	-0.21***	-0.13***	-0.03	-0.01	0.01
Adj. R^2	0.34	0.20	-0.01	-0.03	-0.03
No. of observations	35	35	35	35	35
January 2013-December 2015					
c	0.05	-0.04	-0.09	-0.16	-0.10
Δoil	-0.12***	-0.12***	-0.05*	-0.04**	-0.03
Adj. R^2	0.15	0.37	0.07	0.10	0.02
No. of observations	36	36	36	36	36

***, ** and * represent significance at the 1%, 5% and 10% levels, respectively. Newey-West adjusted standard errors.

Table 4: Reactions of deflation risk from year-on-year inflation options to oil prices, controlling for local financial uncertainty

Dependent variable: Monthly changes in deflation risk m years ahead					
Variable	2 year	3 years	5 years	7 years	10 years
January 2010-December 2012					
c	0.16	0.24	0.32	0.31	0.17
Δoil	-0.23***	-0.15***	0.05	0.01	0.02
$\Delta VSTOXX$	-0.01	-0.01	-0.01	0.01	0.01
Adj. R^2	0.32	0.19	-0.04	-0.05	-0.06
No. of observations	35	35	35	35	35
January 2013-December 2015					
c	0.01	-0.10	-0.13	-0.16	-0.09
Δoil	-0.11**	-0.11***	-0.04	-0.04**	-0.03*
$\Delta VSTOXX$	0.04	0.05**	0.04***	0.0005	-0.01
Adj. R^2	0.16	0.50	0.21	0.07	0.02
No. of observations	36	36	36	36	36

***, ** and * represent significance at the 1%, 5% and 10% levels, respectively. Newey-West adjusted standard errors.

Table 5: Reactions of deflation risk from year-on-year inflation options to oil prices, controlling for global financial uncertainty

Dependent variable: Monthly changes in deflation risk m years ahead					
Variable	2 year	3 years	5 years	7 years	10 years
January 2010-December 2012					
c	0.17	0.26	0.35	0.32	0.17
Δoil	-0.23***	-0.16***	-0.07*	-0.01	0.02
ΔVIX	-0.01	-0.01*	-0.02***	0.0007	0.003
Adj. R^2	0.32	0.20	-0.02	-0.06	-0.06
No. of observations	35	35	35	35	35
January 2013-December 2015					
c	0.07	-0.03	-0.08	-0.16	-0.11
Δoil	-0.08	-0.09***	-0.02	-0.04*	-0.03
ΔVIX	0.06	0.05***	0.04***	0.01	-0.01
Adj. R^2	0.24	0.52	0.25	0.08	0.01
No. of observations	36	36	36	36	36

***, ** and * represent significance at the 1%, 5% and 10% levels, respectively. Newey-West adjusted standard errors.

Previous DNB Working Papers in 2016

No. 493 **Jacob Bikker, Dirk Gerritsen and Steffie Schwillens,** Competing for savings: how important is creditworthiness during the crisis?
No. 494 **Jon Danielsson and Chen Zhou**, Why risk is so hard to measure
No. 495 **Gabriele Galati, Irma Hindrayanto, Siem Jan Koopman and Marente Vlekke**, Measuring financial cycles with a model-based filter: Empirical evidence for the United States and the euro area
No. 496 **Dimitris Christelis, Dimitris Georgarakos, Tullio Jappelli and Maarten van Rooij**, Consumption uncertainty and precautionary saving
No. 497 **Marco Hoeberichts and Ad Stokman**, Price level convergence within the euro area: How Europe caught up with the US and lost terrain again
No. 498 **Janko Cizel, Jon Frost, Aerdt Houben and Peter Wierts**, Effective macroprudential policy: Cross-sector substitution from price and quantity measures
No. 499 **Frank van der Horst, Martina Eschelbach, Susann Sieber and Jelle Miedema**, Does banknote quality affect counterfeit detection? Experimental evidence from Germany and the Netherlands
No. 500 **Jochen Mierau and Mark Mink**, A descriptive model of banking and aggregate demand
No. 501 **Clemens Bonner, Daniel Streitz and Michael Wedow**, On the differential impact of securitization on bank lending during the financial crisis
No. 502 **Mijntje Lückerath-Rovers and Margriet Stavast-Groothuis**, The changing composition of the supervisory boards of the eight largest banks and insurers during 2008-2014 and the impact of the "4+4 suitability screenings"
No. 503 **Dirk Broeders, Damiaan Chen, Peter Minderhoud and Willem Schudel**, Pension funds' herding
No. 504 **Ronald Heijmans, Richard Heuver and Zion Gorgi**, How to monitor the exit from the Eurosystem's unconventional monetary policy: Is EONIA dead and gone?
No. 505 **Steven Ongena, Alexander Popov and Neeltje Van Horen**, The invisible hand of the government: "Moral suasion" during the European sovereign debt crisis
No. 506 **Wändi Bruine de Bruin, Wilbert van der Klaauw, Maarten van Rooij, Federica Teppa and Klaas de Vos**, Measuring expectations of inflation: Effects of survey mode, wording, and opportunities to revise
No. 507 **Jos Jansen and Jasper de Winter**, Improving model-based near-term GDP forecasts by subjective forecasts: A real-time exercise for the G7 countries
No. 508 **Malka de Castro Campos and Federica Teppa**, Individual inflation expectations in a declining-inflation environment: Evidence from survey data

DeNederlandscheBank

EUROSYSTEEM

De Nederlandsche Bank N.V.
Postbus 98, 1000 AB Amsterdam
020 524 91 11
dnb.nl