Bank of Finland Research Discussion Papers
29 • 2017

Maritta Paloviita – Markus Haavio – Pirkka Jalasjoki – Juha Kilponen

What does “below, but close to, two percent” mean? Assessing the ECB’s reaction function with real time data

Bank of Finland
Research

Bank of Finland Research Discussion Papers
Editor-in-Chief Esa Jokivuolle

Bank of Finland Research Discussion Paper 29/2017
5 October 2017

Maritta Paloviita – Markus Haavio – Pirkka Jalasjoki – Juha Kilponen
What does “below, but close to, two percent” mean? Assessing the ECB’s reaction function with real time data

ISBN 978-952-323-188-7, online
ISSN 1456-6184, online

Bank of Finland
Research Unit

PO Box 160
FIN-00101 Helsinki

Phone: +358 9 1831

Email: research@bof.fi
Website: www.bof.fi/en/research

What does "below, but close to, two percent" mean? Assessing the ECB's reaction function with real time data

Maritta Paloviita[1] – Markus Haavio – Pirkka Jalasjoki – Juha Kilponen

October 5, 2017

Abstract

We estimate the ECB's monetary policy reaction function by using real time Eurosystem/ECB staff macroeconomic projection data, which are presented to the ECB's Governing Council when it assesses the monetary policy stance in the euro area. Alternative specifications of the reaction function account for a possible credibility loss due to persistent deviations of past inflation from the ECB's inflation target. The results provide support for two alternative interpretations of the definition of price stability. First, the ECB dislikes inflation rates above two percent more than rates below two percent. Second, the ECB policy responses to past inflation gaps are symmetric with respect to a target of 1.6 - 1.7 percent. The out-of-sample predictions of the reaction function based on the second interpretation of the definition of price stability track well an estimated shadow interest rate during the zero lower bound period.

JEL Codes: E52, E58

Keywords: credibility, inflation target, monetary policy, real time projections, Taylor rule

[1] Corresponding author: email firstname.lastname[at]bof.fi. All authors are from the Bank of Finland's Monetary Policy and Research Department. We are indebted to Tuomas Välimäki and Jarmo Kontulainen for valuable comments and suggestions. The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Bank of Finland or the Eurosystem.

1 Introduction

Euro area economic developments have been very volatile after the onset of the financial crisis. In 2009 - 2011 inflation remained surprisingly high despite the deep recession. In contrast, since 2012 the HICP inflation rate remained persistently lower than expected in spite of ongoing recovery. The unusually long-lasting recession and slow recovery have contributed to large forecasting errors and an increasing difficulty of conducting monetary policy at a low inflation environment. The ECB policy rate has been cut to a negative territory, and non-standard measures have been introduced to maintain an accommodative stance of monetary policy. Prior to the financial crisis, inflation varied mostly between two and three percent. More recently, inflation has remained persistently on a low level and the euro area's recovery from the recession has been sluggish.

In 1998, the ECB's Governing Council defined price stability as "a year-on-year increase in the Harmonised Index of Consumer Prices (HICP) for the euro area of below two percent". In 2003, the Governing Council clarified that "in the pursuit of price stability it aims to maintain inflation rates below, but close to, two percent over the medium term". In this paper we shed light on this definition by estimating the ECB's monetary policy reaction function using real time information. Our analysis is based on the Eurosystem/ECB staff quarterly macroeconomic projections of inflation and real GDP growth in 1999 - 2016. These projections are key inputs presented regularly to the ECB's Governing Council. The real time projection data allow us to assess the ECB's monetary policy decisions in a realistic setting where information about the current state and the future path of the economy is surrounded by uncertainty.

Based on this real time information, we estimate a large number of competing specifications of the monetary policy reaction function in order to study possible asymmetries in the ECB's interest rate setting. We use in our key estimations a so-called monetary policy credibility loss term, which is determined by past deviations of inflation from the target.[2] The credibility loss term penalizes large deviations of inflation from the target more than small ones, hence those specifications including the credibility loss term are nonlinear. In this context, we consider two alternative interpretations of the ECB's definition of price stability. First, we attempt to quantify the gist of the expression "below, but close to" by allowing a point target to vary at 1.6 - 2.0 percent in the estimated reaction functions. Second, we also allow for asymmetric policy responses to positive and negative deviations of inflation from the targeted level.

Our sample period, 1999Q4 - 2016Q4, covers the relatively stable pre-crisis years as well as the recent turbulent years characterised by the financial crisis, sovereign debt crisis and low inflation regime. Using sub-sample analysis and recursive estimations we analyse the stability of estimated parameters of the ECB's reaction function over time. The EONIA interest rate is the dependent variable in our baseline estimations. In the analysis of the most recent period when standard interest rate policy has approached its effective lower bound, we evaluate the performance of our estimated reaction functions by comparing their out-of-sample predictions to a shadow interest rate.

[2] More specifically, the credibility loss term is defined as an average deviation of past inflation from the target times the absolute value of that deviation, following Neuenkirch and Tillmann (2014).

Earlier studies of possible asymmetries of the ECB's monetary policy include Aguiar and Martins (2008), who report that in 1995Q1 - 2005Q2 the ECB revealed a precautionary demand for price stability, weighting inflation above two percent twice as much as deviations below two percent. They point out that this type of asymmetry is consistent with the ECB's definition of price stability and with the credibility-building by a recently created monetary authority. Surico (2003) analyzes the euro area monetary policy in 1997M1 - 2002M10 and Surico (2007) in 1999M1 - 2004M12. Both studies indicate that the price stability objective is symmetric, whereas output contractions lead to larger policy responses than output expansions of the same size. Ikeda (2010) studies time-varying asymmetries in the ECB's preferences in 1999M1 - 2004M12. He finds that the time-varying asymmetry with respect to inflation is not significant, while the ECB has an aversion to output expansions. Contrary to our analysis, these studies cover only the first years of the monetary union.

The paper is organised as follows. The Eurosystem/ECB staff projections are described in section 2 and alternative specifications of the monetary policy reaction function and estimation results are presented in section 3. In section 4, we discuss in-sample and out-of-sample predictions of different reaction functions and assess whether the recent unconventional monetary policy measures can be interpreted as a continuation of conventional monetary policy. Concluding remarks are provided in section 5.

2 Data analysis

2.1 Data description

Our dataset includes the real time Eurosystem/ECB staff projections made in 1999Q4 - 2016Q4 for the euro area year-on-year HICP inflation rate and year-on-year real GDP growth rate. These projections are publicly available as annual data for full calendar years, but our analyses are based on confidential quarterly information.[3]

For both the inflation rate and real GDP growth rate our data include real time estimates of previous-quarter values, current-quarter values (nowcast estimates) and real time projections until the end of each forecast horizon. The projections in our data cover the current and next two calendar years. The "final" data, i.e. revised data, for our purposes, are the latest available vintages published by Eurostat in spring 2017. The euro area GDP data are seasonally and working day adjusted. Our data take compositional changes in the euro area into account over time. Data vintages also reflect Eurostat's methodological changes and regular benchmark revisions made since 1999.

As is typical in forecasting, the Eurosystem/ECB staff inflation projections tend to underestimate actual rates if there is an upward trend in inflation and vice versa. Projections are gradually revised to take account for the trend at hand, but they have a tendency to revert quite fast to a level below two percent.

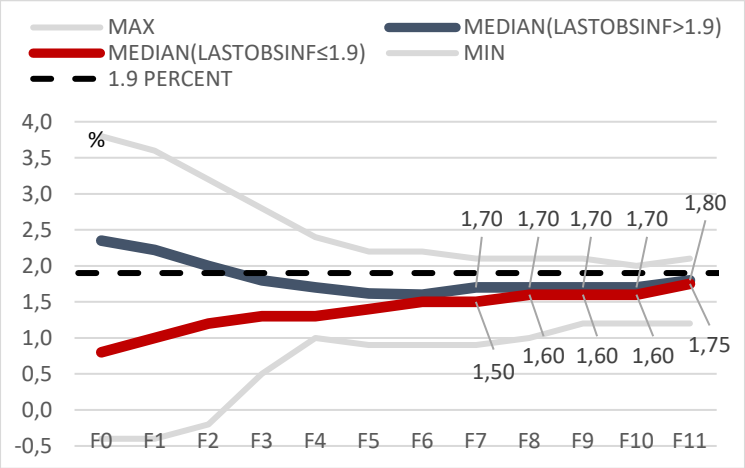
This same phenomenon of projections lagging behind actual trends can also be seen in the real GDP growth projections. The difference, however, is that the GDP growth projections do not

[3] See the ECB (2016) and Alessi et al. (2014) for a detailed description of the Eurosystem/ECB staff projections exercises.

revert towards a long-run value over the sample, but rather the projections seem to capture the slowdown of long-run growth rates over the sample period. While at the beginning of the sample the GDP growth projections converged to growth rates of around three percent, more recently the projections have converged to below two percent growth. The decline in the projected long run growth rate is also consistent with the trend-like decline in the real interest rates (see figure 3) and productivity.

In order to illustrate more clearly the strong convergence of the inflation projections to a certain level, we compute two separate medians of the inflation projections based on whether the latest observed inflation rate during each projection exercise has been above or below 1.9 percent. More precisely, we have organized the projection data in figure 1 in the following way: the label "F0" on the horizontal axis refers to the median value of nowcast estimates from all the projection vintages and the labels "F1" - "F11" refer to the median values of the corresponding inflation projections for 1 - 11 quarters ahead. In addition to the medians, figure 1 also presents the highest and lowest inflation projections for different forecast horizons.

Figure 1. Median inflation projections conditioned on the latest observed inflation rate during each projection exercise



Note: *On the horizontal axis, the label "F0" refers to real time current quarter nowcasts and the label "F1" to one-quarter-ahead projections, etc. The curves "MAX" and "MIN" refer to the highest and lowest inflation projections made in 1999Q4 - 2016Q4.*

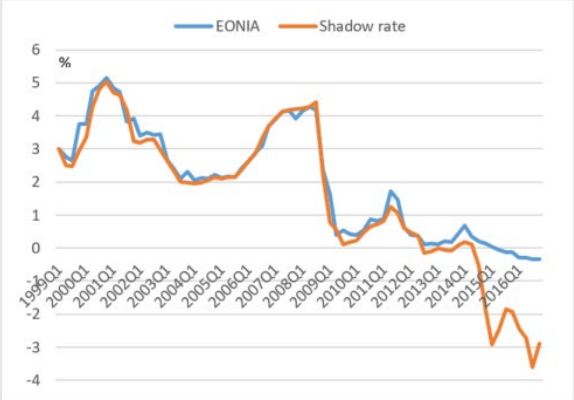
Sources: *ECB and authors' own calculations.*

Figure 1 shows that the medians of projections made at times when the recent observed inflation rate is high (i.e. higher than 1.9 percent) converge to 1.70 - 1.80 percent after six quarters. At the same time, however, the medians of projections starting from lower inflation conditions (i.e. 1.9 percent or lower) converge to slightly lower rates around 1.60 - 1.75 percent. Lower medians converge to their eventual rates in a rather linear fashion, while the evolution of the higher medians has a somewhat different shape: the median projections for five and six-quarters-ahead are slightly below the medians at the end of the forecast horizon, i.e. inflation is projected to temporarily undershoot when inflation has been initially above 1.9 percent.

It is also notable in figure 1 that regardless of the current level of inflation, after about six quarters the median inflation projections are already in the proximity of their levels at the end of the forecast horizon. When compared to the actual realized inflation, the projected inflation exhibits stronger and faster mean reversion, and the same applies to the GDP growth.

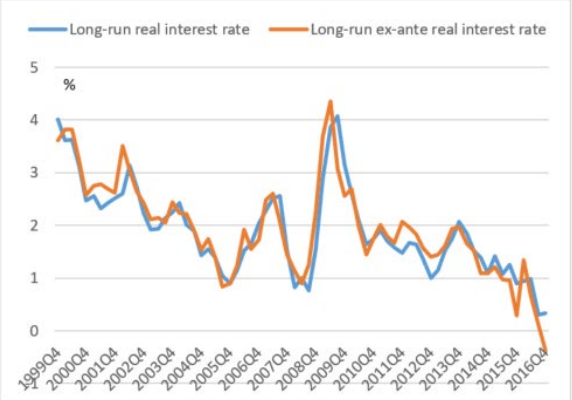
Our dataset also includes the EONIA interest rate measured at the end of each quarter, a shadow rate (a summary measure of policy stance, which tries to capture unconventional as well as conventional policy measures) estimated by Kortela (2016) and two proxies of the long-run natural real interest rate. An ex-post proxy for the natural real interest rate is constructed as the difference between a composite nominal yield of ten year euro area government bonds and real time nowcast estimates of current inflation, while an ex-ante proxy is calculated as the composite nominal bond yield minus the real time projection of the one-period-ahead inflation rate. The composite nominal yield is constructed by the ECB by aggregation using GDP weights.

Figure 2. EONIA and the shadow rate at the end of each quarter



Sources: *Thomson Reuters (EONIA) and Kortela (2016) (the shadow rate).*

Figure 3. Proxies of the long-run natural real interest rate



Notes: *Long-run real interest rate equals to the difference of a euro area composite nominal yield of ten year government bonds and the real time nowcast of inflation rate. The ex-ante real interest rate equals to the difference of the composite yield and the real time one-period-ahead expected inflation rate.*

Sources: *ECB and authors' own calculations.*

Figures 2 and 3 present the EONIA rate, shadow rate and proxies for the natural real interest rate. The shadow rate follows closely the EONIA rate until about mid-2014. Thereafter, the shadow rate starts falling strongly into a negative territory reflecting the quantitative easing of the ECB.

2.2 Relation between projections and actual realized data

Economic projections are always subject to errors, which stem from data revisions, real time uncertainty and errors in underlying assumptions such as oil prices, world economic growth and exchange rates. Another source of uncertainty originates from forecasting models and

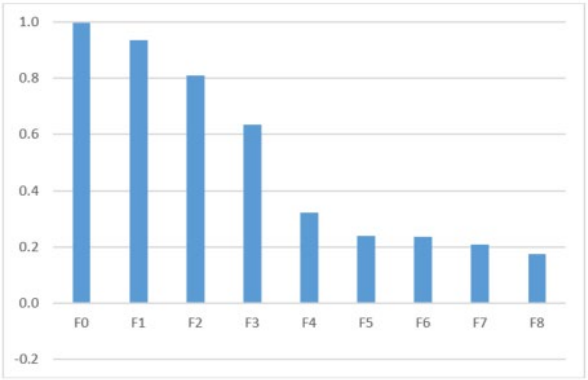
economists' own off-model judgement that is always incorporated into forecasts. We focus on inflation and GDP growth since they are, also according to the ECB's mandate, central pieces of information guiding policy decisions.

The Eurosystem/ECB staff projections were at first based on a constant interest rate assumption, but in order to further improve the quality and internal consistency of macroeconomic projections, both short and long term interest rate assumptions have been based on market expectations since the June 2006 projection exercise. According to the ECB (2006), "this change is of a purely technical nature", which "does not imply any change in the ECB's monetary policy strategy or in the role of projections within it". We therefore interpret this change as if the internal forecasting procedure of the ECB had changed, but do not expect a change in the reaction function itself.

Figure 4 shows how the actual realized inflation and projected inflation are correlated in our data set: the "F0" bar refers to the correlation coefficient between the actual inflation and nowcast estimates, and the bars "F1" - "F8" indicate how the actual inflation is correlated with the projections made 1 - 8 quarters earlier. The corresponding correlation coefficients between the projected and actual real GDP growth rates are summarized in figure 5.

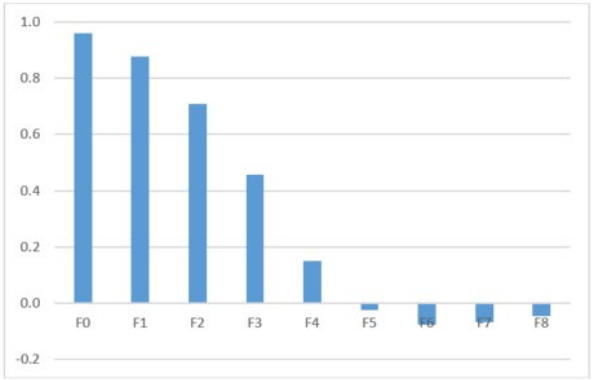
Figures 4 and 5 clearly show that inflation projections are highly correlated with the actual inflation up to a three-quarter forecast horizon, while the corresponding correlations of real GDP growth projections are relatively high only for the current and next two quarters.

Figure 4. Correlations between the actual and projected inflation rates



Sources: *ECB and authors' own calculations.*

Figure 5. Correlations between the actual and projected real GDP growth rates



Sources: *ECB and authors' own calculations.*

Simple correlations reveal that it is very challenging for the Eurosystem/ECB staff to assess future price and output growth developments when considering four quarters or longer projection horizons. The correlation coefficients fall from close to one to about 0.2 in the case of inflation and even to negative values in the case of GDP growth projections. Comparison of forecast performances based on mean errors (ME) and root mean squared errors (RMSE)

indicate that short term inflation projections are more accurate than short term real GDP projections.[4]

Given the rather limited accuracy of inflation and GDP growth projections in the medium term, it is worth asking whether this is specific to the ECB staff and the Eurosystem. Charemza and Ladley (2016) have analyzed inflation forecasts made in 2000 – 2011 in ten inflation targeting central banks (unfortunately, the ECB is not included in their study).[5] They compare distributions of inflation forecasts with corresponding distributions of actual inflation by scaling the data based on inflation target bands (-1/+1 percent band around the target is assumed). Charemza and Ladley report that the central banks' one-year ahead inflation forecasts have been within the bands clearly too often compared with the distribution of the actual inflation. Two-year-ahead inflation forecasts of the central banks are even more strongly biased towards the inflation target: only in one out of 99 cases forecasts indicate that future inflation will be outside the bands even though a substantial share of actual outcomes are outside the bands. Compared to CESifo World Economic Survey forecasts, the central banks' one year ahead inflation forecasts tend to be within the target bands more often.

Sveriges Riksbank (2017) compares inflation forecast accuracy of the Riksbank in 2007 - 2016 to that of other institutions in Sweden. The Riksbanks' forecasts of the consumer price index with a fixed interest rate (CPIF) for the current calendar year have been relatively accurate compared to other analysts. As for the following calendar year, the Riksbank made the most accurate forecasts for 2010, but since then the Riksbank's annual ranking for the following year inflation forecasts has gradually declined. The Riksbank's analysis considers also the average CPIF inflation forecast errors for 1 - 24 months ahead. In 2007 - 2011, the Riksbank's forecasts have no clear bias up to one year, but for longer horizons the Riksbank has overestimated inflation to some extent. In 2012 - 2016, the Riksbank's forecasts have clearly overestimated inflation for all horizons as the horizon becomes longer.

Overall, the forecast performance of the Eurosystem/ECB staff seems to be in line with other central banks. The ECB's projections for inflation and real GDP growth are relatively good for zero to three quarters ahead, but forecasting becomes clearly more challenging thereafter.

3 Estimation of the ECB reaction function

In this section we estimate a number of different specifications of the ECB's policy reaction function. In all cases we assume that the ECB potentially reacts to real time macroeconomic conditions, as well as to its own projections of future macroeconomic variables. The main goal of this exercise is to examine and interpret the ECB's definition of price stability whereby it aims to maintain inflation rates below, but close to, two percent over the medium term.

As a baseline, we estimate simple linear reaction functions with interest rate smoothing. Then we augment the linear function with a nonlinear credibility loss term, which accounts for past deviations of inflation from the target. In this context, we consider two alternative

[4] We have defined errors as the difference between projections and realisations. The MEs for one to four quarter ahead inflation projections (real GDP growth projections) are -0.02, -0.06. -0.11 and -0.13 (-0.11, 0.07, 0.29 and 0.51). The corresponding RMSE values for inflation are 0.37, 0.59, 0.78 and 0.95 and for real GDP growth 0.96, 1.33, 1.68 and 1.96.

[5] Australia, Canada, Chile, Czech Republic, Korea, New Zealand, Mexico, Norway, Poland and Sweden.

interpretations of the definition of price stability. First, we allow for the possibility that the *de facto* inflation target of the ECB is well below two percent. Second, we also allow asymmetric reactions of the ECB to the credibility loss term.[6] Finally, we consider in-sample and out-of-sample dynamic predictions of the estimated reaction functions. We also assess whether the recent unconventional monetary policy measures can be interpreted as a continuation of conventional monetary policy.

Projected real GDP growth is a proxy for the euro area's cyclical stance in our estimations. Also Neuenkirch and Tillmann (2014), Gerlach and Lewis (2014), Gorter et al. (2008) and Sturm and de Haan (2011) have estimated reaction functions based on forecast real GDP growth instead of the output gap. This choice can be motivated by the fact that the ECB's communication is largely based on the projected real GDP growth rather than on the output gap. Furthermore, it is very challenging to measure the output gap, especially in real time (see Orphanides and van Norden 2002).

Apart from choosing inflation and real GDP growth as explanatory variables in the reaction function, an important choice to be made is related to the projection horizon of these variables. In the literature of monetary policy reaction functions, forecast horizons of forward looking variables are typically relatively short. This seems to be well motivated also in the case of the ECB due to relatively good short term forecasting performance of the Eurosystem/ECB staff. For example, estimations in Neuenkirch and Tillmann (2014) are based on expected inflation and expected real GDP growth 12 months ahead. A-year-ahead forecasts of inflation and output growth are also used in estimations by Gerlach and Lewis (2014). As explained below, we have nevertheless experimented with a reasonably large number of different leads and lags of GDP growth and inflation projections and used statistical criteria to choose the preferred forecast horizon of inflation and output growth in the reaction function.

In order to address the potential endogeneity of the explanatory variables, we estimate the models with the general method of moments (GMM), with lags of regressors used as instruments. As our baseline case, we estimate reaction functions using a sample spanning from 1999Q4 to 2014Q2. The end point of the sample is chosen so as to match the date when the zero lower bound was reached. As robustness checks, we use both shorter and longer samples.

When comparing and eventually choosing between alternative specifications of the reaction function, we have applied the following criteria: the signs and relative sizes of estimated coefficients for inflation and output growth must be consistent with the classical Taylor (1993) principle, and the coefficients must be statistically significantly different from zero. In regard to the first mentioned criterion, we require that the estimated coefficients of projected inflation rates are larger than the coefficients of real GDP growth, consistent with the classical Taylor rule and also with the ECB's mandate for maintaining price stability. In addition, we have checked for stability of the estimated coefficients of the linear models and nonlinear

[6] We have also considered a number of purely forward-looking nonlinear reaction functions allowing the monetary policy to react differently when expected inflation and/or output growth is high or low. We also allowed the reaction function to be nonlinear with respect to current or expected GDP growth, see e.g. Surico (2003). However, we found only limited evidence in favour of these alternative nonlinear specifications.

symmetric models by using an initially shorter sample (pre-crisis period) which is recursively extended forward a quarter by quarter.[7]

3.1 Linear reaction functions

We start out by estimating simple linear reaction functions with interest rate smoothing. The purpose of this exercise is to identify the most relevant projection horizons for inflation and output growth.

$$i_t = c_1 * i_{t-1} + (1 - c_1) * \left(c_2 + c_3 * \left(\pi^f_{t+j|t} - \pi^*\right) + c_4 * \Delta y^f_{t+k|t} + D * r^n_t\right) \qquad (1)$$

In equation (1), the measure of monetary policy stance i_t is the EONIA rate. Current monetary policy is allowed to depend on the one period lagged EONIA rate i_{t-1}; this captures interest rate smoothing. The explanatory variables used in different linear specifications are the ECB's real time projection of j-quarters-ahead HICP inflation $\pi^f_{t+j|t}$ and real time projection of k-quarters-ahead real GDP growth $\Delta y^f_{t+k|t}$ with possible values *of j* and *k* spanning from zero (i.e. nowcasts) to four. The HICP inflation and GDP growth are both measured in year-on-year terms. In addition, the two different proxies of natural real interest rate (r^n_t) described in section 2.1 are considered as regressors; if the natural real rate enters into a reaction function, the dummy variable *D* takes the value of one, and if the natural rate is not in the estimated reaction function, then *D* = 0. In these benchmark linear specifications, we have set the target rate of inflation equal to a number close to 2 percent, more specifically $\pi^* = 1.9$.[8]

Table A1 in the appendix reports a number of different specifications for the central bank reaction function, where we vary projection horizons and use different proxies for the natural real rate of interest. In what follows, we report the key findings from estimations of this basic reaction function specification, and then discuss model selection issues.

The results lend support to monetary policy reaction functions with i) very short run (one quarter ahead) GDP growth projections; ii) somewhat longer term (one year ahead) inflation projections; and iii) reaction functions including a proxy for the natural rate of interest. To be more specific:

a) Coefficients of inflation projections in specifications with the inflation nowcast and one-quarter-ahead and four-quarters-ahead inflation projections are statistically significant when the real GDP growth variable is assumed to contain only very short term projections, i.e. the nowcast or one-quarter-ahead projection.

b) When accounting for the effect of the natural real interest rate in the monetary policy reaction functions, a specification with the four-quarters-ahead inflation projection and one-quarter-ahead real GDP growth projection (i.e. $\pi^f_{t+4|t}$ and $\Delta y^f_{t+1|t}$) produces satisfactory coefficient estimates with either of the two proxies of the natural real interest rate, as well as without a natural rate proxy.

[7] Due to the relatively short length of our dataset, these recursive sample estimations have not been done in the case of asymmetric nonlinear models.
[8] Note that the specific choice of the target does not have an impact on the results in these linear specifications.

c) As for examining the stability of the estimated monetary policy reaction functions, we estimate reaction functions with the four-quarters-ahead inflation projection ($\pi^f_{t+4|t}$) and one-quarter-ahead GDP projection ($\Delta y^f_{t+1|t}$) for the (pre-Lehman) period of 1999Q4 - 2008Q2, and then expand the sample forward one quarter at a time, until we reach the baseline sample 1999Q4 - 2014Q2. We find that monetary policy reaction functions including a proxy for the natural real interest rate lead to considerably more stable coefficients for inflation and output growth than functions without a natural interest rate. Moreover, the specification using the ex-ante long real interest rate ($\tilde{r}_t^{10yr}$) seems to work even better than the natural real interest rate calculated with current inflation (r_t^{10yr}).

With these observations, our preferred benchmark linear reaction function is summarized in table 3.1. The linear monetary policy reaction function suggests the ECB reacts to the projected four-quarters-ahead deviation of inflation from the target much stronger (about 3 times stronger) than to the projected one-quarter-ahead output growth. The interest rate smoothing term is also rather high, as is typically found in the literature. Furthermore, the relatively large coefficient of inflation gap implies that the Taylor principle holds.

Table 3.1 Baseline linear reaction function

$$i_t = c_1 * i_{t-1} + (1 - c_1) * \left(c_2 + c_3 * \left(\pi^f_{t+4|t} - 1.9\right) + c_4 * \Delta y^f_{t+1|t} + \tilde{r}_t^{10yr}\right)$$

	Coefficient	Std. Error	t-Statistic	Prob.
c_1	0.84	0.044	19.23	0.0000
c_2	-0.95	0.737	-1.29	0.2049
c_3	4.45	0.832	5.34	0.0000
c_4	1.48	0.507	2.92	0.0057
J-statistic	6.07			
Prob(J-statistic)	0.73			

Note: *This table shows the GMM estimation results of our preferred linear reaction functions of the ECB. The estimation sample is 1999Q4 - 2014Q2. See the main text for the definition of the variables and table A1 in the appendix for alternative competing linear specifications. The reported J-statistic is obtained from the Sargent-Hansen test for validity of the instruments.*

3.2 Responses to a credibility loss

Monetary policy credibility refers to the degree of confidence that economic agents have in the central bank's determination and ability to meet its objectives. Credibility of monetary policy in the case of the ECB can be related to the deviation of current, and past, rates of inflation from the target rate of inflation. When current inflation is close to the target, the degree of credibility is high and the central bank just needs to keep the inflation rate stable in order to maintain credibility. A substantial deviation of inflation from the target is more challenging for the conduct of monetary policy. In this case, the central bank has to convince the public that in spite of this deviation it is committed to the inflation target and it is able to gear inflation to the target with the policy instruments at its disposal. Otherwise, a persistent deviation can lead to increasing risks of de-anchoring inflation expectations (see for example Lyziak and Paloviita 2017).

In order to capture this potential credibility channel, we use the specification of Neuenkirch and Tillmann (2014)[9], and augment the linear monetary policy reaction function (1) with a credibility loss term *CL:*

$$i_t = c_1 * i_{t-1} + (1 - c_1) * \left(c_2 + c_3 * \left(\pi^f_{t+4|t} - \pi^*\right) + c_4 * \Delta y^f_{t+1|t} + c_5 * CL_t + r^n_t\right) \quad (2)$$

In this specification, the central bank responds both to the expected economic outlook for inflation and output growth and to past deviations of inflation from the target.

Based on the findings reported above in section 3.1 we choose to focus on the reaction functions with the four-quarters-ahead inflation projection $\pi^f_{t+4|t}$, one-quarter-ahead GDP growth projection $\Delta y^f_{t+1|t}$, and a natural rate proxy (either r_t^{10yr} or $\tilde{r}_t^{10yr}$). As robustness checks, we have also considered a number of alternative specifications including other projection horizons for inflation and GDP growth.

The idea of the specification of the reaction function in equation (2) is that the central bank conditions its policy decision both on the future outlook of inflation and growth, and on the past misses of its inflation target. In other words, it may set higher (lower) interest rate today if the inflation gap has been positive (negative) in the past even if inflation was expected to be at the target in the future. Following Neuenkirch and Tillmann (2014), the credibility term CL_t is specified such that a large deviation of inflation from the target weighs more than small ones:

$$CL_t = (\overline{\pi}_{t-1,t-q} - \pi^*) \, |\overline{\pi}_{t-1,t-q} - \pi^*|$$

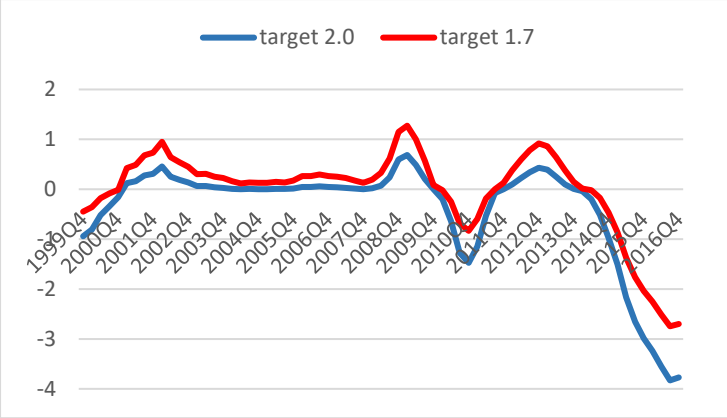
Essentially, the credibility loss term CL_t depends on the deviation of the average past inflation rate ($\overline{\pi}_{t-1,t-q}$) from its target π*, where q corresponds to the number of lags. In addition to this symmetric specification, we consider asymmetric responses in section 3.3.

The length of the time span, i.e. the maximum number of lags (q) over which the average past inflation is measured, can be varied. We also consider a number of different inflation targets π*, at or below 2.0 percent; the lowest inflation target rate examined is chosen to be 1.6 percent in light of figure 1. This exercise allows us to draw some inference concerning the *de facto* inflation target of the ECB.

Figure 6 presents the values of the credibility loss term for the inflation targets of 1.7 and 2.0 using seven lags ($\overline{\pi}_{t-1,t-7}$) over which the average past inflation is measured. It shows that inflation has deviated from the target periodically. The past deviations of inflation from the target have been pronounced around 2002, 2009, 2011 and 2013, and then again after 2014 when the nominal interest rate hit the lower bound and inflation slowed down persistently. Especially the relatively large (and persistent) inflation gaps in the post-2009 period may have had a significant impact on the monetary policy of the ECB. Augmenting the reaction function with the credibility loss term allows us to test whether this is the case.

[9] Neuenkirch and Tillmann (2014) analyze monetary policy in five inflation targeting economies: Australia, Canada, New Zealand, Sweden and the United Kingdom.

Figure 6. Values of the credibility loss term



Note: *Horizon over which the average inflation is measured is seven quarters ($\overline{\pi}_{t-1,t-7}$). See the main text above for the definition of the credibility term.*

Sources: *ECB and authors' own calculations.*

Estimating the augmented Taylor rule (2) allows us to study whether past deviations from the inflation target have impacted on the ECB's interest rate setting. In particular, for the CL term to capture concerns about a credibility loss in a meaningful way, its coefficient should be positive and statistically significant. In addition, also the coefficients of inflation and GDP growth projections should be meaningful, along the lines explained in section 3.1.

The estimation results for our preferred nonlinear reaction function are reported in table 3.2. Table A2 in the appendix summarizes estimation results from a number of different specifications of the nonlinear reaction function. Using the above mentioned model evaluation criteria, we find that longer credibility loss time spans, ranging up to 6 - 8 lags, and lower inflation target rates (perhaps even as low as 1.6 or 1.7 percent) produce satisfactory and relatively robust coefficient estimates. The coefficient estimates of these nonlinear specifications also seem to be relatively stable when the sample rolls recursively over the financial crisis towards 2014Q2.

In comparison to the linear reaction function summarized in table 3.1, we observe that the inflation smoothing term is typically smaller and the Taylor coefficient for projected inflation deviation is somewhat smaller. According to this estimated reaction function the ECB reacts to expected inflation less strongly than in the case of the linear reaction function while weighting relatively strongly the past misses from its inflation target, since the coefficient of the credibility loss term is positive and significantly different from zero (see table 3.2). The Taylor coefficient for output growth is roughly unchanged relative to the linear Taylor rule.

Table 3.2 Baseline reaction function with symmetric responses to a credibility loss

$$i_t = c_1 * i_{t-1} + (1 - c_1) * \left(c_2 + c_3 * \left(\pi^f_{t+4|t} - 1.7\right) + c_4 * \Delta y^f_{t+1|t} + c_5 * CL_t + \tilde{r}_t^{10yr}\right)$$

where $CL_t = (\overline{\pi}_{t-1,t-7} - 1.7)\ |\overline{\pi}_{t-1,t-7} - 1.7|$

	Coefficient	Std. Error	t-Statistic	Prob.
c_1	0.77	0.051	15.30	0.0000
c_2	-1.51	0.396	-3.83	0.0004
c_3	3.61	0.798	4.53	0.0001
c_4	1.25	0.317	3.94	0.0013
c_5	1.07	0.417	2.56	0.0145
J-statistic	6.58			
Prob(J-statistic)	0.68			

Note: *This table shows the GMM estimation results of our preferred reaction function of the ECB including symmetric reactions to a credibility loss. The estimation sample is 1999Q4 - 2014Q2. See the main text for the definition of the variables and table A2 in the appendix for alternative specifications. The reported J-statistic is obtained from the Sargent-Hansen test for validity of the instruments.*

In sum, our results indicate that concerns for a credibility loss may have played a role in the ECB's policy decisions. Quite intuitively, however, these considerations seem to affect monetary policy only if deviations from the inflation target have been rather persistent as indicated by the long lags of the credibility loss term. Our results also suggest that the *de facto* inflation target might have been considerably below two percent, perhaps even as low as 1.6 - 1.7 percent.

3.3 Asymmetric responses to a credibility loss

In the previous section we assumed that the ECB reacts symmetrically to past deviations from the inflation target irrespective of whether inflation has been above or below the target. We tested for different *de facto* target rates of inflation and concluded that the *de facto* inflation target might have been as low as 1.6 - 1.7 percent. An alternative interpretation of the definition of price stability is that the ECB reacts to positive and negative inflation gaps differently.

To allow for the possibility of asymmetric reactions, we estimate yet another reaction function of the form

$$i_t = c_1 * i_{t-1} + (1 - c_1) * \left(c_2 + c_3 * \left(\pi^f_{t+4|t} - \pi^*\right) + c_4 * \Delta y^f_{t+1|t} + c_5 * CL_t^+ + c_6 * CL_t^- + r_t^n\right) \quad (3)$$

where

$$CL_t^+ = D_t^{CL} * CL_t$$

$$CL_t^- = (1 - D_t^{CL}) * CL_t$$

and the dummy variable $D_t^{CL} = 1$ if CL_t>0, while $D_t^{CL} = 0$ if CL_t<0. In equation (3), the coefficient c_5 captures monetary policy reactions to past positive deviations from the inflation target, while the coefficient c_6 captures reactions to negative deviations. For our measures to describe concerns about a credibility loss in a meaningful way, the coefficients c_5 and c_6 must both be positive; however they may be different in size.

Similarly to the previous section, we consider a number of credibility loss measures CL, varying both with respect to the time span of the average past inflation, and with respect to the *de facto* inflation target (see tables 3.3 and A3). Consistent with our earlier results, we find that the time span of the past inflation deviation should be rather long, ranging from 6 to 8 quarters; the ECB only reacts to rather persistent past deviations from the target. However, now the *de facto* inflation target closer to two percent seems more reasonable, with the ECB reacting more aggressively when past inflation has exceeded the target than when inflation has fallen short of the target (i.e. c_5 is significantly larger than c_6). [10]

Table 3.3 Baseline reaction function with asymmetric responses to a credibility loss

$$i_t = c_1 * i_{t-1} + (1 - c_1) * \left(c_2 + c_3 * \left(\pi^f_{t+4|t} - 2.0\right) + c_4 * \Delta y^f_{t+1|t} + c_5 * CL_t^+ + c_6 * CL_t^- + r_t^{10yr}\right)$$

where $CL_t = (\overline{\pi}_{t-1,t-7} - 2.0)\ |\overline{\pi}_{t-1,t-7} - 2.0|$

	Coefficient	Std. Error	t-Statistic	Prob.
c_1	0.79	0.046	16.94	0.0000
c_2	-1.92	0.755	-2.54	0.0153
c_3	1.23	0.585	2.10	0.0424
c_4	1.69	0.379	4.47	0.0001
c_5	8.00	2.606	3.07	0.0039
c_6	0.63	0.312	2.01	0.0518
J-statistic	6.66	F-statistic ($H0$: $c_5 = c_6$)		6.84
Prob(J-statistic)	0.67	Prob(F-statistic)		0.013

Note: *This table shows the GMM estimation results of our preferred asymmetric reaction function of the ECB. The estimation sample is 1999Q4 - 2014Q2. See the main text for the definition of the variables and table A3 in the appendix for alternative competing specifications. The reported J-statistic is obtained from the Sargent-Hansen test for validity of the instruments. The F-statistic is obtained from the test for asymmetry of the reaction function, by testing equality of the positive and negative credibility loss term coefficient estimates.*

The finding that monetary policy reactions to past high inflation are stronger than reactions

[10] Note that a time invariant potential output can be calculated as $\Delta y^* = (\pi^* - c_2)/c_4$. According to the symmetric reaction function (asymmetric reaction function), the average projected potential output growth is 2.5 percent (2.3 percent). These numbers naturally deviate somewhat from the ex-post data, reflecting both real time uncertainty of future real GDP growth and end-point-problems. At the same time, the implied projected potential growth rates are in line with the Eurosystem/ECB staff real GDP growth projections. The projected growth rates at the end of each projection horizon are good proxies for the real time estimates of projected potential output growth. As already discussed in section 2, the ECB's projections of real GDP growth converge to values between slightly below two and three percent.

to past low inflation may be influenced by the zero lower bound of interest rates. As a robustness check, we have re-estimated the reaction function (3) using the shadow rate instead of EONIA, and with a longer sample ranging from 1999Q1 to 2016Q4. The results were qualitatively unchanged.[11]

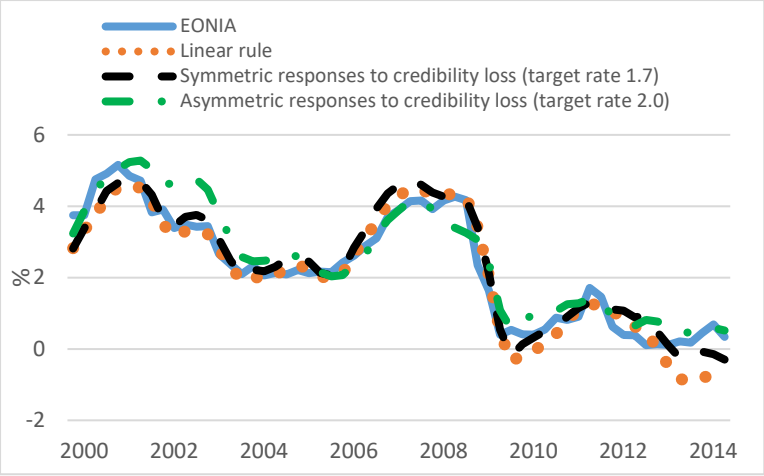
In summary, the ECB's definition of price stability manifests itself in the estimations in two ways. Either the *de facto* target of the ECB is significantly below two percent, or the ECB reacts more strongly to past positive inflation gaps than to negative ones. As for now, there is no clear statistical criteria by which we could give preference to either of the two reaction function specifications.

4 **Predictive performance of different reaction functions**

4.1 In-sample predictions

The performance of estimated reaction functions from tables 3.1 - 3.3 can be assessed by comparing their in-sample predictions to the EONIA interest rate. The in-sample predictions of the three reaction functions are shown in figure 7. It can be observed that the asymmetric reaction function deviates at times significantly from the EONIA rate and predictions of the two other functions. This is especially the case at the beginning of the sample, when the euro area inflation was quite often above two percent. During 2005 - 2007, the asymmetric reaction function tracks relatively well the EONIA rate. In mid-2008 it misses the increase in the EONIA rate, and from there on it stays most of the time above the EONIA and also above the predictions of the two other reaction functions. At the same time, both the symmetric and linear reaction function would have implied a stronger interest rate hike prior to the financial crisis, but in general more lax policy after 2009.

Figure 7. Dynamic in-sample predictions of different reaction functions



Note: *The dynamic in-sample predictions are based on our preferred specifications of the ECB's reaction function reported in sections 3.1 - 3.3.*

Sources: *ECB, Thomson Reuters and authors' own calculations.*

[11] Estimation results are available upon request.

The linear reaction function, which only responds to projected inflation and real GDP growth and not at all to past inflation gaps, generates the lowest interest rate path at the end of the sample. The symmetric reaction function with a low *de facto* target inflation generates a similar path, but on a higher level, because the reaction function puts weight on a past positive inflation gap (see figure 6) and less weight on a projected slowdown of inflation. Excluding the end of the sample, the symmetric and linear reaction functions give rather similar predictions for the interest rate path until about 2012. Furthermore, according to the symmetric and linear reaction functions, the zero lower bound would have been reached much earlier, already in 2009, while according to the asymmetric reaction function it would not have been reached at all.

4.2 Out-of-sample predictions and comparison to a shadow rate

How do the estimated reaction functions describe the monetary policy stance under unconventional monetary policy measures when the interest rate has hit the zero lower bound? In other words, are unconventional and conventional measures determined by the same basic principles, so that unconventional measures can be thought of as a continuation of conventional monetary policy when the zero lower bound is reached?

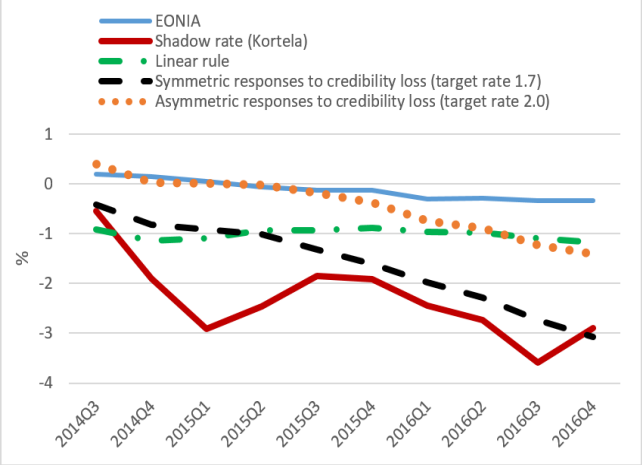
To analyze this question, we use our estimated ECB reaction functions (estimated for the time period 1999Q4 - 2014Q2) to produce out-of-sample forecasts for the time period 2014Q3 - 2016Q4. In this exercise, we predict the interest rate path using the estimated reaction functions given the projected real time inflation and GDP growth and the proxy for the natural real rate of interest. Then we compare the interest rates implied by our model specifications to the euro area shadow rate estimates obtained from Kortela (2016).

The results from this exercise are shown in figure 8a. The interest rate implied by the baseline linear rule (green line with dashes and dots) remains negative and stable around minus one percent throughout the whole period; it is roughly one percentage point below the EONIA rate (blue line), but considerably higher than the shadow rate (red line) for most of the period.

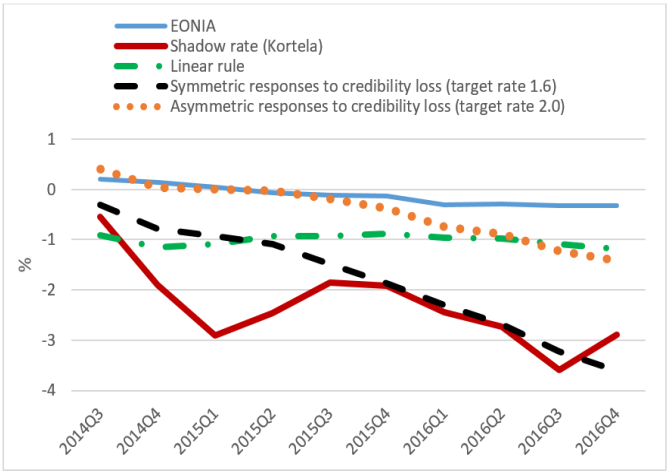
The reaction functions taking account of a credibility loss imply falling interest rates over the period 2014Q3 - 2016Q4. We find that the symmetric reaction function with a low *de facto* inflation target of 1.7 percent (black dashed line) tracks the shadow rate considerably better than the asymmetric reaction function with an inflation target of two percent (orange dotted line). This suggests, tentatively, that the ECB's definition of price stability is best characterized by an inflation target that is markedly below two percent, but the ECB is symmetric in its reactions to past inflation gaps. If we consider the symmetric reaction function based on a lower inflation target of 1.6 percent, which is also a plausible target rate according to our estimation results shown in table A.2, the implied predictions are even more close to the shadow rate. The symmetric responses with this lower target rate of 1.6 percent are presented in figure 8b.

Figure 8. Shadow rate and predictions based on different reaction functions

8a. Our preferred specification of the symmetric reaction function



8b. Alternative specification of the symmetric reaction function with a lower inflation target



Note: *The symmetric responses to a credibility loss refer to a reaction function with a low de facto inflation target (1.6 or 1.7 percent). The asymmetric responses to a credibility loss refer to a reaction function with an inflation target of 2.0 percent.*

Sources: *ECB, authors' own calculations and Kortela (2016) for the shadow rate.*

5 Conclusions

In this paper, we have estimated the ECB's reaction function using real time projection information from the Eurosystem/ECB staff macroeconomic projection exercises. These projections are key inputs presented to the ECB's Governing Council and they are routinely referred to by the ECB's President when motivating monetary policy decisions for the euro area. Given the large revisions of GDP data and uncertainty over the future course of the economy, using real time projection data provides the best way to "simulate" the ECB's monetary policy decisions and gain understanding of its reaction function.

Our results are in line with two alternative interpretations of the ECB's definition of price stability. First, the ECB dislikes inflation rates above two percent more than rates below two percent. Second, the *de facto* inflation target of the ECB is well below two percent, perhaps even as low as 1.6 - 1.7 percent. This finding is also consistent with the fact that the Eurosystem/ECB staff medium term inflation projections have had a tendency to converge to values which are well below two percent. The out-of-sample predictions of the reaction function based on the second interpretation of price stability track well an estimated shadow rate during the zero lower bound period.

Overall, our findings have the following policy implications. The ECB's asymmetric response to inflation and/or low *de facto* inflation target may hamper its ability to achieve price stability. First, when approaching the inflation target from below, the central bank may need to tolerate inflation rates above the target. Overshooting the target for a limited time may facilitate the central bank to achieve its price stability objective faster and more efficiently,

when the interest rates are at the zero lower bound. Under credible monetary policy, overshooting the target raises inflation expectations and lowers the ex-ante real interest rate. This boosts consumption and investment and therefore reduces economic slack. Second, for a given equilibrium real interest rate, anchoring of inflation expectations to a relatively low level also leads to low nominal rates over the business cycle. This reduces the scope to absorb shocks in economic downturns and increases the likelihood of hitting the zero lower bound.

References

Aguiar, A. and Martins, M. M. F. (2008), Testing for asymmetries in the preferences of the euro-area policymaker, Applied Economics, 40(13), 1651-1667.

Alessi, L., Ghysels, E., Onorante, L., Peach, R. and Potter, S. (2014), Central Bank Macroeconomic Forecasting During the Global Financial Crisis: The European Central Bank and Federal Reserve Bank of New York Experiences. Journal of Business & Economic Statistics, 32(4), 483-500.

Charemza, W. and Ladley, D. (2016), Central banks' forecasts and their bias: Evidence, effects and explanation, International Journal of Forecasting, 32, 804-817.

European Central Bank (2006), Monthly Bulletin, March.

European Central Bank (2016), A guide to the Eurosystem/ECB staff macroeconomic projection exercises, July.

Gerlach, S. and Lewis, J. (2014), ECB Reaction Functions and the Crisis of 2008, International Journal of Central Banking, March, 137-157.

Gorter, J., Jacobs, J. and de Haan, J. (2008), Taylor rules for the ECB using expectations data, Scandinavian Journal of Economics, 110, 473-488.

Ikeda, T. (2010), Time-varying asymmetries in central bank preferences, Journal of Macroeconomics, 32, 1954-1066.

Kortela, T. (2016), A shadow rate model with time-varying lower bound of interest rates, Bank of Finland Research Discussion Paper No. 19.

Łyziak, T., and Paloviita, M. 2017. Anchoring of inflation expectations in the euro area: Recent evidence based on survey data. European Journal Political economy, 46, 52-73.

Neuenkirch, M. and Tillmann, P. (2014), Inflation targeting, credibility, and non-linear Taylor rules, Journal of International Money and Finance, 41, 30-45.

Orphanides, A. and van Norden, S. (2002), The unreliability of output-gap estimates in real time, The Review of Economics and Statistics, Vol. 84, 569-583.

Sturm, J.-E. and de Haan, J. (2011), Does central bank communication really lead to better forecasts of policy decisions? New evidence based on a Taylor rule model for the ECB, Review of World Economics, 147, 41-58.

Surico, P. (2003), Asymmetry Reaction Functions for the Euro Area, Oxford Review of Economic Policy, 19(1), 44-57.

Surico, P. (2007), The Monetary Policy of the European Central Bank, Scandinavian Journal of Economics, 109(1, 115-135.

Sveriges Riksbank (2017), Evaluation of the Riksbank's forecasts, Rikbank Studies, May.

Taylor, J. B. (1993), Discretion versus policy rules in practice, Carnegie-Rochester Conference Series in Public Policy, 39, 195-214.

Appendix: Summary of estimations

Table A1. Coefficients of inflation and GDP growth in reaction function (1), with different projection horizons for inflation (rows) and output growth (columns)

a) Linear policy reaction function without a natural rate of interest

	$\Delta y^f_{t\|t}$		$\Delta y^f_{t+1\|t}$		$\Delta y^f_{t+2\|t}$		$\Delta y^f_{t+3\|t}$		$\Delta y^f_{t+4\|t}$	
$\pi^f_{t\|t}$	-0.50	1.30*	0.88*	1.46*	0.02	3.76*	0.00	2.89*	0.06	3.08*
$\pi^f_{t+1\|t}$	0.87*	1.06*	1.05*	1.21*	0.37	3.36*	0.11	2.84*	0.63	2.98*
$\pi^f_{t+2\|t}$	0.86	1.14*	0.76	3.19*	0.28	3.55*	0.08	2.86*	0.33	3.07*
$\pi^f_{t+3\|t}$	0.36	1.28*	0.00	3.94*	-0.47	4.07*	-0.11	2.94*	0.05	3.07*
$\pi^f_{t+4\|t}$	**2.34***	**0.94***	**2.97***	**1.84***	1.85	2.69*	0.75	2.59*	1.26	2.75*

b) Linear reaction function with r_t^{10yr} as a proxy for the natural rate of interest

	$\Delta y^f_{t\|t}$		$\Delta y^f_{t+1\|t}$		$\Delta y^f_{t+2\|t}$		$\Delta y^f_{t+3\|t}$		$\Delta y^f_{t+4\|t}$	
$\pi^f_{t\|t}$	-12.99	8.01	1.78*	5.39	0.04	4.95*	0.65	3.05*	0.50	2.79*
$\pi^f_{t+1\|t}$	**2.22***	**0.76***	2.31	6.23	0.20	4.82*	0.77	3.34*	0.66	2.63*
$\pi^f_{t+2\|t}$	**3.72***	**0.85***	2.76	5.60	0.78	4.37*	1.22	3.15*	1.00	2.63*
$\pi^f_{t+3\|t}$	2.26	0.62	3.69	5.47	0.25	4.82*	1.31	2.89*	1.40	2.55*
$\pi^f_{t+4\|t}$	**4.51***	**0.73***	**4.82***	**1.19***	**4.51***	**1.48***	**4.46***	**1.20***	**4.48***	**1.09***

c) Linear reaction function with $\tilde{r}_t^{10yr}$ as a proxy for the natural rate of interest

	$\Delta y^f_{t\|t}$		$\Delta y^f_{t+1\|t}$		$\Delta y^f_{t+2\|t}$		$\Delta y^f_{t+3\|t}$		$\Delta y^f_{t+4\|t}$	
$\pi^f_{t\|t}$	-4.32	3.35	1.16	7.49	0.13	4.41*	0.28	2.98*	1.72*	3.56*
$\pi^f_{t+1\|t}$	0.21	1.26	1.61	7.72	0.36	4.29*	0.52*	2.72*	1.05*	2.97*
$\pi^f_{t+2\|t}$	0.49	1.51	1.41	7.88	0.35	4.26	0.62	2.71	3.14*	5.12
$\pi^f_{t+3\|t}$	-4.34	2.91	-5.92	27.86	-0.59	4.96	0.40	2.91	3.68	6.67
$\pi^f_{t+4\|t}$	3.84*	0.84	**4.45***	**1.48***	**3.19***	**2.32***	**3.21***	**1.72***	3.12*	1.95

Note:

1) In each cell the first entry is the coefficient of inflation c_3, while the second entry is the coefficient of real GDP growth c_4.

2) Coefficient estimates which are statistically significant, at least at the 5 percent level, are marked by *.

3) **Bolded** numbers mark model variants, where i) both coefficients c_3 and c_4 are statistically significant, ii) the coefficient of inflation is greater than one, and iii) the coefficient of inflation is greater than the coefficient of real GDP growth.

4) We have added a grey background color to the combinations of inflation and output projection horizons ($\pi^f_{t+4|t}$, $\Delta y^f_{t+1|t}$), which satisfy the criteria i) - iii) in all the reaction functions (a, b and c), with and without a natural rate proxy.

Table A2. Symmetric monetary policy responses to a credibility loss in reaction function (2)

a) Reaction functions that include the long real interest rate r_t^{10yr} as a proxy for the natural rate

	target 1.6	target 1.7	target 1.8	target 1.9	target 2.0
$\overline{\pi}_{t-1,t-1}$	-0.61	-0.65	-0.68	-0.70	-0.61
$\overline{\pi}_{t-1,t-2}$	-0.49	-0.40	-0.20	-0.14	-0.13
$\overline{\pi}_{t-1,t-3}$	-0.11	-0.10	-0.11	-0.13	-0.17
$\overline{\pi}_{t-1,t-4}$	0.11	0.11	0.10	0.08	0.02
$\overline{\pi}_{t-1,t-5}$	0.94*	0.70*	0.58*	0.50*	0.44*
$\overline{\pi}_{t-1,t-6}$	1.21*	1.02*	0.82*	0.64*	0.09
$\overline{\pi}_{t-1,t-7}$	**1.50***	**0.94***	0.24	0.19	0.53
$\overline{\pi}_{t-1,t-8}$	**2.90***	0.77	0.42	0.39	0.53

b) Reaction functions that include the ex-ante long real interest rate $\tilde{r}_t^{10yr}$ as a proxy for the natural rate

	target 1.6	target 1.7	target 1.8	target 1.9	target 2.0
$\overline{\pi}_{t-1,t-1}$	-0.53	-0.44	-0.07	-0.02	0.01
$\overline{\pi}_{t-1,t-2}$	0.20	0.16	0.13	0.11	0.09
$\overline{\pi}_{t-1,t-3}$	0.06	0.06	0.06	0.06	0.05
$\overline{\pi}_{t-1,t-4}$	-0.43	-0.10	0.02	0.05	0.06
$\overline{\pi}_{t-1,t-5}$	-0.44	-0.44	-0.24	-0.01	0.08
$\overline{\pi}_{t-1,t-6}$	0.29	0.29	0.31	0.31	0.29
$\overline{\pi}_{t-1,t-7}$	**1.42***	**1.07***	0.76	0.62	0.58
$\overline{\pi}_{t-1,t-8}$	3.20*	1.30	1.19	1.16	0.96

Note:

1) The table reports estimates of the coefficient c_5 for the credibility loss term CL, for different spans of past inflation (rows) and inflation targets (columns).

2) Coefficient estimates c_5 which are of the correct sign (positive) and statistically significant, at least at the 5 percent level, are marked by *.

3) We have **bolded** the model specifications where also the coefficients of inflation and GDP growth projections (c_3 and c_4, not shown in the table) are positive and statistically significant, and in addition $c_3 > c_4$.

4) We have added a grey background color to the combinations of past inflation spans and inflation targets which meet the conditions 2) and 3) in both types of reaction functions considered here (i.e. these combinations are bolded in both tables, a and b).

Table A3. Asymmetric monetary policy responses to a credibility loss in reaction function (3)

a) Reaction functions that include the long real interest rate r_t^{10yr} as a proxy for the natural rate

	target 1.6		target 1.7		target 1.8		target 1.9		target 2.0	
$\overline{\pi}_{t-1,t-1}$	0.60	0.36*	0.61	0.26	0.62	0.15	0.63	0.03	-1.55	-0.35
$\overline{\pi}_{t-1,t-2}$	0.68	0.45	0.68	0.31	0.60	0.14	-1.24	-0.08	-1.42	-0.10
$\overline{\pi}_{t-1,t-3}$	-0.91	0.25	-1.00	0.15	-1.03	0.07	-0.47	-0.04	-0.29	-0.15
$\overline{\pi}_{t-1,t-4}$	-2.31	0.61*	-2.17	0.44*	-2.19	0.34	0.49	-0.01	0.02	0.00
$\overline{\pi}_{t-1,t-5}$	-3.17	1.09*	-3.83	0.82*	-4.37	0.62*	-4.80	0.48*	-5.32	0.39*
$\overline{\pi}_{t-1,t-6}$	2.61*	0.95	2.96*	0.97*	-0.51	0.83*	-1.06	0.68*	-1.97	0.57*
$\overline{\pi}_{t-1,t-7}$	2.89*	1.00	3.67*	0.77	**4.73***	**0.64**	**6.14***	**0.61**	**8.00***	**0.63***
$\overline{\pi}_{t-1,t-8}$	3.30*	-1.02	4.18*	-1.08	5.66*	-1.21	8.39*	-1.19	12.77*	-0.71

b) Reaction functions that include the ex-ante long real interest rate $\tilde{r}_t^{10yr}$ as a proxy for the natural rate

	target 1.6		target 1.7		target 1.8		target 1.9		target 2.0	
$\overline{\pi}_{t-1,t-1}$	0.43	0.51*	0.42	0.44*	0.41	0.37*	0.38	0.31*	0.34	0.24*
$\overline{\pi}_{t-1,t-2}$	0.65	0.54*	0.68	0.48*	0.71	0.41*	0.71	0.34	0.68	0.27
$\overline{\pi}_{t-1,t-3}$	-1.66	0.72*	-1.74	0.57*	-1.81	0.45*	2.75	0.24	-0.59	0.09
$\overline{\pi}_{t-1,t-4}$	-1.24	0.53*	-1.31	0.43*	-1.43	0.36*	-1.62	0.30*	-1.91	0.25*
$\overline{\pi}_{t-1,t-5}$	-1.86	0.96*	-2.08	0.76*	-2.35	0.61*	-2.74	0.50*	-3.34	0.42*
$\overline{\pi}_{t-1,t-6}$	0.74	0.26	0.37	0.40	-2.62	1.15*	-2.98	0.91*	-3.55	*0.74
$\overline{\pi}_{t-1,t-7}$	2.4*	0.64	3.06*	0.43	3.88*	0.31	4.92*	0.28	**6.21***	**0.31**
$\overline{\pi}_{t-1,t-8}$	3.65*	-8.67	4.57*	-4.26	5.83*	-1.85	7.46*	-0.77	9.69*	-0.14

Note:

1) The table reports estimates of monetary policy reactions to *a positive past inflation gap* (coefficient c_5, left entry in each cell) and *a negative past inflation gap* (coefficient c_6, right entry in each cell), for different spans of past inflation (rows) and different *de facto* inflation targets (columns).

2) Coefficient estimates which are of the correct sign (positive) and statistically significant, at least at the 5 percent level, are marked by *.

3) **Bolded** numbers mark model variants where i) both coefficients are of the correct sign (positive), ii) at least the reaction to a past positive inflation gap (c_5) is significantly different from zero, and iii) the policy reaction to past positive deviations from the inflation target is significantly stronger than the reaction to past negative deviations from the target (i.e. c_5 is significantly larger than c_6, at least at the 5 percent level).

4) We have added a grey background color to the combinations of past inflation span and inflation target ($\overline{\pi}_{t-1,t-7}$ and target 2.0), which satisfy the criteria i), ii) and iii) in both types of reaction functions considered here (i.e. in tables a and b).

Bank of Finland Research Discussion Papers 2017

ISSN 1456-6184, online

1/2017 Gonçalo Faria – Fabio Verona
Forecasting the equity risk premium with frequency-decomposed predictors
ISBN 978-952-323-144-3, online

2/2017 Sari Pekkala Kerr – William Kerr – Çağlar Özden – Christopher Parsons
Global talent flows
ISBN 978-952-323-145-0, online

3/2017 Sari Pekkala Kerr – William R. Kerr
Global collaborative patents
ISBN 978-952-323-146-7, online

4/2017 Aino Silvo
House prices, lending standards, and the macroeconomy
ISBN 978-952-323-148-1, online

5/2017 Paavo Miettinen
Information acquisition during a descending price auction with asymmetrically informed players
ISBN 978-952-323-149-8, online

6/2017 Giovanni Caggiano – Efrem Castelnuovo – Giovanni Pellegrino
Estimating the real effects of uncertainty shocks at the zero lower bound
ISBN 978-952-323-150-4, online

7/2017 Sari Pekkala Kerr – William Kerr – Çağlar Özden – Christopher Parsons
High-skilled migration and agglomeration
ISBN 978-952-323-152-8, online

8/2017 Giovanni Caggiano – Efrem Castelnuovo – Gabriela Nodari
Uncertainty and monetary policy in good and bad times
ISBN 978-952-323-158-0, online

9/2017 Guido Ascari – Anna Florio – Alessandro Gobbi
Controlling inflation with switching monetary and fiscal policies: expectations, fiscal guidance and timid regime changes
ISBN 978-952-323-159-7, online

10/2017 Gene Ambrocio – Esa Jokivuolle
Should bank capital requirements be less risk-sensitive because of credit constraints?
ISBN 978-952-323-162-7, online

11/2017 Ville Voutilainen
Wavelet decomposition of the financial cycle: An early warning system for financial tsunamis
ISBN 978-952-323-165-8, online

12/2017 Mathias Drehmann – Mikael Juselius – Anton Korinek
Accounting for debt service: The painful legacy of credit booms
ISBN 978-952-323-169-6, online

13/2017 Tomasz Łyziak – Maritta Paloviita
Formation of inflation expectations in turbulent times. Can ECB manage inflation expectations of professional forecasters?
ISBN 978-952-323-170-2, online

14/2017 Suvi Vasama
Contracting with long-term consequences
ISBN 978-952-323-171-9, online

15/2017 Suvi Vasama
On moral hazard and persistent private information
ISBN 978-952-323-172-6, online

16/2017 Bill B. Francis – Iftekhar Hasan – Delroy M. Hunter – Yun Zhu
Do managerial risk-taking incentives influence firms' exchange rate exposure?
ISBN 978-952-323-173-3, online

17/2017 Iftekhar Hasan – Fahad Khali l – Xian Sun
The Impacts of intellectual property rights protection on cross-border M&As
ISBN 978-952-323-174-0, online

18/2017 Manthos D. Delis – Iftekhar Hasan – Nikolaos Mylonidis
The risk-taking channel of monetary policy in the US: Evidence from corporate loan data
ISBN 978-952-323-175-7, online

19/2017 Mohamad Mazboudi – Iftekhar Hasan
Secrecy, information shocks, and corporate investment: Evidence from European Union countries
ISBN 978-952-323-176-4, online

20/2017 Juha Itkonen
Efficiency and dependency in a network of linked permit markets
ISBN 978-952-323-179-5, online

21/2017 Iftekhar Hasan–Chun-Keung (Stan) Hoi– Qiang Wu–Hao Zhang
Does social capital matter in corporate decisions? Evidence from corporate tax avoidance
ISBN 978-952-323-178-8, online

22/2017 Manthos D. Delis – Iftekhar Hasan – Maria Iosifidi
On the effect of business and economic university education on political ideology: An empirical note
ISBN 978-952-323-177-1, online

23/2017 Yota D. Deli – Iftekhar Hasan
Real effects of bank capital regulations: Global evidence
ISBN 978-952-323-180-1, online

24/2017 Smriti Anand – Iftekhar Hasan – Priyanka Sharma –Haizhi Wang
Enforceability of non-complete agreements: When does state stifle productivity?
ISBN 978-952-323-181-8, online

25/2017 Samuli Knüpfer – Elias Rantapuska – Matti Sarvimäki
Why does portfolio choice correlate across generations?
ISBN 978-952-323-184-9, online

26/2017 Fabio Verona
Q, investment, and the financial cycle
ISBN 978-952-323-185-6, online

27/2017 Gur Huberman – Jacob D. Leshno – Ciamac Moallemi
Monopoly without a monopolist: An Economic analysis of the bitcoin payment system
ISBN 978-952-323-186-3, online

28/2017 Nauro F. Campos – Jarko Fidrmuc – Iikka Korhonen
Business cycle synchronisation in a currency union: Taking stock of the evidence
ISBN 978-952-323-187-0, online

29/2017 Maritta Paloviita – Markus Haavio – Pirkka Jalasjoki – Juha Kilponen
What does "below, but close to, two percent" mean? Assessing the ECB's reaction function with real time data
ISBN 978-952-323-188-7, online