What Does "Below, but Close to, 2 Percent" Mean? Assessing the ECB's Reaction Function with Real-Time Data*

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Using unique real-time quarterly macroeconomic projections of the Eurosystem/ECB staff, we estimate competing specifications of the ECB's monetary policy reaction function. We consider specifications which include inflation and output growth projections, a past inflation gap, a time-varying natural real interest rate, and different inflation targets. Our first key finding is that the de facto inflation target of the ECB lies between 1.6 percent and 1.8 percent. Our second key finding is that the ECB reacts both to short-term macroeconomic projections and to past deviations of inflation from its de facto target.

JEL Codes: E31, E52, E58.

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1. Introduction

In recent years, inflation has been persistently low in many economies. As a response, policy rates have been cut to very low levels, and new measures have been introduced to maintain an accommodative stance of monetary policy. The low inflation and interest rate environment have raised the question of whether and how the current monetary policy framework should be reformed (see, e.g., Bernanke 2017a, 2017b; Williams 2017; Bullard 2018; Honkapohja and Mitra 2018). In the case of the European Central Bank, there has also been a vivid debate on the precise numerical target for inflation and possible asymmetry of the ECB's policy responses.

The debate on the ECB's price stability objective stems from the fact that its inflation aim is not precisely defined in the Treaty on the Functioning of the European Union. 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 2%." In 2003, the Governing Council clarified that "in the pursuit of price stability it aims to maintain inflation rates below, but close to, 2% over the medium term." This clarification can be seen as an effort to reduce uncertainty about the lower bound of the inflation aim relative to the earlier definition and to provide a buffer against large negative shocks to inflation.

As discussed in Hartmann and Smets (2018), the exact formulation by the Governing Council in 2003 was a compromise that maximized that buffer while remaining consistent with the definition of price stability. With this reformulation, the inflation aim remained nevertheless ambiguous.[1] In particular, although the ECB communication stresses symmetry, the expression "below, but close to 2%" has some feel of asymmetry, and the exact numerical target is not spelled out.[2]

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[1] Apel and Claussen (2017) classify three different categories for inflation targeting. A point target refers to a single number. If certain deviations from the point target are "acceptable" for the central bank, it is complemented with a tolerance band. In the case of a target range, a targeted inflation interval is announced without any specific desirable level of inflation.

[2] According to the ECB strategy, "the Governing Council's aim to keep euro area inflation below, but close to, 2% over the medium term signifies a commitment to avoiding both inflation that is persistently too high and inflation

Not surprisingly, the ECB’s inflation aim has been interpreted in various ways. For example, Miles et al. (2017) point out that the ECB’s “target itself is perceived as asymmetric.” They also note that there “is uncertainty about what ‘close to, but below’ means.” Regarding the public, survey evidence indicates that households’ knowledge about the ECB’s inflation target is “far from perfect” (van der Cruijsen, Jansen, and de Haan 2015). Different interpretations of the inflation target and/or vague monetary policy communication may increase inefficiency in monetary policymaking, give rise to risks of deanchored inflation expectations, and, hence, jeopardize the effective transmission of monetary policy. After introducing new policy measures, the ECB has strengthened its communication and adopted a forward-guidance framework in order to reduce uncertainty concerning its reaction function and future policy actions.[3]

In this paper, we are specifically interested in assessing the ECB’s own interpretation of the price stability objective and its reaction function. Using unique real-time quarterly macroeconomic projections of the Eurosystem/ECB staff, we attempt to quantify the gist of the expression “below, but close to 2%.” First, we consider the levels toward which the ECB inflation projections converge in the medium term. Second, we estimate a large number of alternative output-growth-gap-based reaction functions in order to directly infer the ECB’s de facto inflation target. Finally, using primarily the real gross domestic product (GDP) growth as a cyclical variable, we estimate more general reaction function specifications, which allow the ECB to react (either symmetrically or asymmetrically) also to past inflation gaps, determined by the deviations of realized inflation from the de facto target. In all cases, we pay special attention to the relevant forecast horizon in monetary policymaking.

A novel feature of our analysis is that our data set includes the Eurosystem/ECB staff quarterly macroeconomic projections of inflation and real GDP growth made in 1999–2016. Consequently,

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that is persistently too low.” For example, in March 2016 Mario Draghi, President of the European Central Bank, stated: “The key point is that the Governing Council is symmetric in the definition of the objective of price stability over the medium term.” (https://www.ecb.europa.eu/press/pressconf/2016/html/is160310.en.html.) See also President Draghi’s speech of June 2016, at https://www.ecb.europa.eu/press/key/data/2016/html/sp160602.en.html.

[3]See, e.g., Cœuré (2017).

we are able to estimate the reaction function with a subset of the very same information the Governing Council has available when it decides on the monetary policy stance.[4] As emphasized by Woodford (2007), an important feature of "optimal" monetary policy is that it should respond to the projected future path of the economy and not only to current conditions.

Our sample period, 1999:Q4–2016:Q4, covers the relatively stable pre-crisis years as well as the recent turbulent years characterized by the financial crisis, the sovereign debt crisis, and low inflation. Using subsample analysis and recursive estimations, we analyze the stability of estimated parameters of the ECB's reaction function over time. In addition to the targeted rate of inflation, we conduct a robustness analysis with respect to the time span of forward-looking and backward-looking variables in the reaction function and with respect to time-varying long-run natural real interest rates. We assess the performance of estimated reaction functions by comparing their in-sample predictions against the key interest rates. 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 functions by comparing their out-of-sample predictions against shadow interest rates estimated by Kortela (2016) and by Wu and Xia (2016).

Our extensive analyses based on alternative approaches and unique real-time data indicate that the de facto inflation target of the Governing Council lies between 1.6 percent and 1.8 percent. This finding is consistent with the fact that the Eurosystem/ECB staff medium-term inflation projections have had a tendency to converge rapidly on values well below 2 percent. We also find that the ECB conditions its interest rate decisions not only on short-term macroeconomic projections but also on past inflation developments. This is also consistent with the recent ECB communication, according to which the launch of asset purchase programs can be justified as a response to too-prolonged a period of low inflation. Finally, we find

[4]To our knowledge, earlier reaction function estimations using the ECB's projections have been based on annual information only, with one exception: Hartmann and Smets (2018). Fischer et al. (2009) examine euro-area monetary analysis in 1999–2006 using quarterly information.

some evidence of asymmetry in policy rules in which we fix the inflation target to 2 percent. However, the out-of-sample predictions of the symmetric reaction function with a low de facto target outperform the asymmetric reaction function during the zero lower bound period.

In earlier studies, euro-area monetary policy has also been widely examined using alternative specifications of the classical Taylor rule (Taylor 1993).[5] Monetary policy analysis has often been based on real-time information. As a proxy for real-time information, the ECB Survey of Professional Forecasters (ECB SPF) (e.g., Gerlach and Lewis 2014) and Consensus Forecast (e.g., Gorter, Jacobs, and de Haan 2008) have been used. Some authors have also used the ECB's macroeconomic projections (e.g., Belke and Klose 2011; Bletzinger and Wieland 2017). As the ECB projections were published only for full calendar years until 2017, quarterly variation in the projections has been taken into account in reaction function estimations so far only by Hartmann and Smets (2018). Close to our study also is an article by Bletzinger and Wieland (2017), who also estimate a forecast-based reaction function for the euro area in order to assess the targeted level of inflation and the ECB policy during the zero lower bound period. Their analysis is based on the ECB SPF survey and the ECB projections for full calendar years. The main difference from our approach is that they do not take into account the impact of past inflation deviations from the target, and their cyclical variable is defined as a difference between output growth and the European Commission's estimate of potential output growth.[6]

The paper is organized as follows. The Eurosystem/ECB staff projections are described and their medium-term convergence is examined in section 2. 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. Concluding remarks are provided in section 5.

[5] See, e.g., Clarida, Galí, and Gertler (1998).

[6] Earlier studies of possible asymmetries in ECB monetary policy include Surico (2003, 2007), Aguiar and Martins (2008), and Ikeda (2010).

2. The Data and Eurosystem/ECB Staff Projections

2.1 Data Description

Our data set includes the real-time Eurosystem/ECB staff projections made in 1999:Q4–2016:Q4 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.[7]

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 the spring of 2017. The euro-area GDP data are seasonally and working-day adjusted.

Projection errors increase substantially with the length of the forecast horizon, reflecting real-time challenges in actual monetary policymaking.[8] The mean errors (ME) for the one- to four-quarters-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 root mean squared errors (RMSE) 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. A limited forecast accuracy in the medium to long term is not specific to the ECB and the Eurosystem. Charemza and Ladley (2016) have analyzed inflation forecasts made in 2000–11 in 10 inflation-targeting central banks (the ECB is not included in the study). They show that compared with the CESifo World Economic Survey forecasts, the central banks' one-year-ahead inflation forecasts are biased toward the inflation target. According to their analysis, the bias is even stronger in two-years-ahead inflation forecasts.[9]

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

[8]We define projection errors as the difference between projections and realizations.

[9]Charemza and Ladley's (2016) analysis includes 10 inflation-targeting central banks: Australia, Canada, Chile, Czech Republic, Korea, Mexico, New Zealand,

Our data set also includes the EONIA (euro overnight index average) interest rate, the MRO (main refinancing operations) rate, and shadow interest rates estimated by Kortela (2016) and Wu and Xia (2016).[10] The shadow rates follow closely the EONIA rate until about mid-2014, but thereafter they start to fall strongly into a negative territory, reflecting the quantitative easing of the ECB (see figure A.1 in appendix A).

We also calculate several time-varying ex ante and ex post proxies of the long-run natural real interest rate, which are constructed using yields on German government bonds of different maturities or a composite nominal yield of 10-year euro-area government bonds. The composite nominal yield is constructed by the ECB by aggregation using GDP weights. We use these different proxies of the natural rate because of measurement issues. Differences in long-term bond yields of different euro-area economies were small until around the inception of global financial crisis in our sample, so it does not make a great difference whether the German government bonds or composite yield is used for that period. Since about 2007, however, the difference becomes significant, and the German government bond yields are likely to be a better proxy for the euro-area risk-free nominal rate, as it corresponds to the lowest of the 10-year government bond yields. However, this is not necessarily the best proxy for the euro-area long-run natural rate, i.e., for the rate which would stabilize the euro-area economy as a whole, in the long run. The literature in general uses either short-term bond yields or long-term bond yields to approximate the natural rate.

Norway, Poland, and Sweden. See Sveriges Riksbank (2017) for the accuracy of Riksbank's inflation forecasts.

[10] A shadow rate is a summary measure of monetary policy stance, capturing unconventional as well as conventional policy measures. It indicates how much the central bank would have lowered the interest rates had the zero lower bound not been binding, i.e., it reflects monetary policy stance in very low or negative interest rate environments. Differences between alternative shadow rates for the euro area based on different methods are typically quite large. However, they all indicate that the ECB's monetary policy stance has recently been very accommodative. In Kortela (2016), the shadow rate is based on a multifactor shadow rate term structure model (SRTSM) with a time-varying lower bound.

2.2 Medium-Term Convergence of Inflation and Output Growth Projections

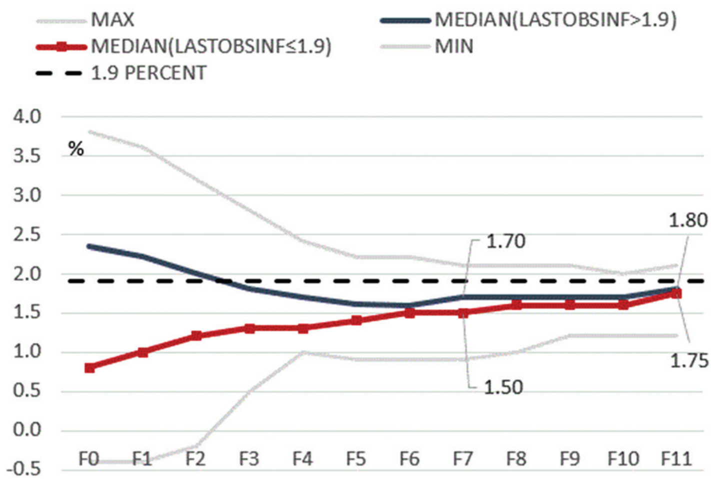
The Eurosystem/ECB staff inflation projections provide suggestive evidence of the ECB's de facto inflation target. Projected values of the economic variables, including inflation, at the end of the forecast horizon are largely determined by the models' long-run equilibriums, i.e., values to which they are expected to converge in the absence of new shocks hitting the economy. This is important for the determination of inflation itself, since empirical literature largely agrees that the central bank forecasts have an impact on the private sector's inflation forecasts and expectations.[11] It is important to note that the ECB inflation projections are conditioned on market expectations of the interest rate (since June 2006) and not on some "optimal state contingent path of the interest rates." Therefore, the projected inflation does not reflect the ECB's desired path of inflation per se. However, one can plausibly argue that the projected inflation rates at the end of the forecast horizon give the public a good guideline for inflation which the ECB considers consistent with its mandate. This is supported by the fact that inflation forecasts have typically converged to the promixity of "close but below two" already after about six quarters. There is rather little movement in inflation forecasts thereafter, as we show below.

Figure 1 illustrates the inflation projections. It shows 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 shows that the medians of projections made at times when the recent observed inflation rate is high (i.e., higher than

[11] See, e.g., Fujiwara (2005), Hubert (2015), and Lyziak and Paloviita (2018).

Figure 1. Median Inflation Projections Conditioned on Latest Observed Inflation Rate during Each Projection Exercise

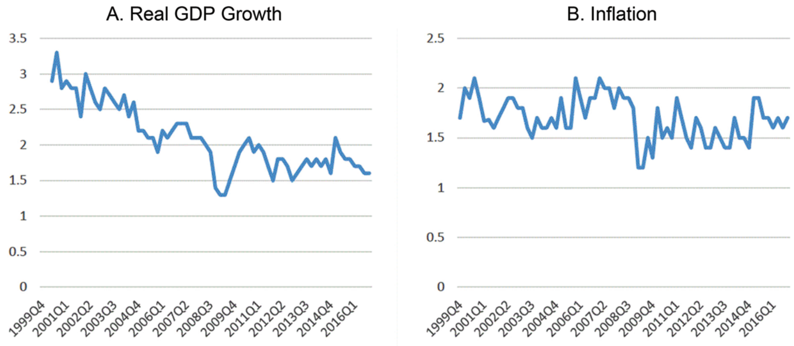


Sources: ECB and authors’ own calculations.
Notes: On the horizontal axis, the label “F0” refers to the real-time current-quarter nowcasts and the label “F1” to the one-quarter-ahead projections, etc. The curves “MAX” and “MIN” refer to the highest and lowest inflation projections made in 1999:Q4–2016:Q4.

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 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 with the actual realized inflation, the

Figure 2. Medium-Term Projections



Sources: ECB and authors' own calculations.
Note: The graphs present the real GDP growth and inflation projections for the last quarter of the projection horizon for each projection exercise (the horizontal axis).

projected inflation exhibits stronger and faster mean reversion. Similarly to the inflation forecasts, the GDP growth forecasts also have a tendency to revert very quickly back to the perceived long-run growth rate. As a result, in both cases of inflation and GDP growth, the sample standard errors are much higher than the standard errors computed from different forecast vintages, especially at the end of the forecast horizon (see table A.1 in appendix A).

The medium-term real GDP growth and inflation projections are summarized in figure 2. The GDP growth projections do not revert toward a single 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 2.5 percent, more recently the projections have converged to below 2 percent growth. This decline in the projected medium-term growth rate is consistent with the trendlike decline in the real interest rates (see figure A.2 in appendix A), and also with the more recent Eurosystem's view that the potential growth of the euro-area economy is in the proximity of 1.5 percent. In contrast to the medium-term GDP growth forecasts, the inflation forecasts do not show a similar downward trend.

3. Estimation of the ECB Reaction Function

In what follows, we estimate alternative specifications of the Eurosystem/ECB's reaction functions for the period 1999:Q4–2014:Q2 (i.e., until the zero lower bound was reached) and assess the ECB's de facto inflation target both directly and indirectly. In our extensive analysis, we pay special attention to real-time data challenges and we also focus on possible backward-looking features of the monetary policy decisions.

We proceed in two steps. We first consider simple output-growth-gap-based (Taylor-type) reaction functions, which allow us to calculate the ECB's implied inflation target based on the estimated parameters. Then, in section 3.2, we consider less standard specifications where we use output growth as a cyclical variable due to the difficulty of estimating the output gap in real time and the fact that the ECB's communication is based more on the current and future output growth than on the output gap (see, e.g., Orphanides and van Norden 2002, Gerlach 2007, Orphanides 2008).[12] Using these specifications, we are able to assess the value of the ECB's de facto inflation target indirectly.[13]

When estimating nonstandard specifications of the reaction function in section 3.2, we consider possible backward-looking features in the ECB monetary policymaking by following Neuenkirch and Tillmann (2014)[14]: we augment our forward-looking specifications with a backward-looking inflation gap term, which measures how strongly actual inflation has deviated on average from the presumed inflation target in recent quarters. This past inflation gap—i.e., a "credibility loss term"—is specified as

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

[12]For the euro area, the problem of reliable real-time output gap estimates is especially severe, due to a relatively short sample and methodological issues that arise from calculating the real-time output gap based on country aggregations (Marcellino and Musso 2011).

[13]Output-growth-based reaction functions have been analyzed by several authors. See, for example, Gorter, Jacobs, and de Haan (2008), Sturm and de Haan (2011), Gerlach and Lewis (2014), and Neuenkirch and Tillmann (2014).

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

$\bar{\pi}_{t-1,t-q}$ refers to an average past inflation rate and q to the number of lags. The CL term is specified such that it penalizes both negative and positive deviations of average past inflation from the target symmetrically. For instance, if average past inflation is 1 percentage point below or above the target, in both cases the CL term gets the same absolute value but the sign is different. The absolute value term in equation (1) weights large deviations of inflation from the target more than small ones, hence the term is nonlinear. This nonlinear feature is needed to make indirect inference on the de facto inflation target.

This CL term, if found significant, introduces history dependence in the ECB policymaking. Past inflation developments may play a role in monetary policy setting because of various reasons. First, if the actual inflation rate has been below (above) the inflation target over a long period of time, the central bank may need to aim for a slightly faster (slower) rise in prices in the near future in order to achieve the inflation target in the medium term. This implies more accommodative (tighter) policy than what the current economic outlook would otherwise imply (see, e.g., Woodford 2007). Second, if inflation has persistently deviated from the target, the central bank may react more aggressively than would be required by information based on purely macroeconomic forecasts to maintain its credibility and commitment to the target. In this case, monetary policy aims to ensure that general (longer-term) inflation expectations remain anchored to the central bank's inflation target (see, e.g., Ehrmann 2015, Lyziak and Paloviita 2017). The third possible interpretation relates to unconventional monetary policy and, above all, to forward guidance: in the context of persistently low inflation, the central bank may promise to keep monetary policy accommodative even after monetary policy should be tightened according to the current economic outlook. This kind of forward guidance may appear in the reaction function as a link between the current policy rate and past inflation.[15]

[15] Cœuré (2017) argues that the ECB's forward guidance is based on a structural component that corresponds to the ECB reaction function and a variable component which consists of evolving economic outlook. According to him, the reaction function "includes the mapping of any desired monetary policy stance into instruments, such as policy rates and asset purchases."

Figure A.3 in appendix A presents the evolution of the ECB's CL term for the inflation targets of 1.7 percent and 2.0 percent, using seven lags over which the average past inflation $\bar{\pi}_{t-1,t-7}$ is measured. Both measures indicate that in the mid-2000s, past inflation gaps were minor, while more pronounced past inflation gaps are measured around 2002, 2009, 2011, and 2013, and again after 2014 when the nominal interest rate hit the lower bound and inflation slowed down persistently. The relatively large inflation gaps especially in the post-crisis period may have had a significant impact on the ECB's monetary policy.

Finally, at the end of this section, we evaluate the performance of estimated reaction functions by comparing their in-sample predictions against the key interest rates and their out-of-sample predictions against shadow interest rates estimated by Kortela (2016) and by Wu and Xia (2016).

All estimations are based on the generalized method of moments (GMM) with lags of regressors as instruments. We use the heteroskedasticity and autocorrelation corrected (HAC) (Newey and West 1987) GMM weighting matrix, which accounts for heteroskedasticity and serial autocorrelation in the estimated reaction function residuals. Use of the GMM in this context is motivated by the potential simultaneity of the right-hand-side variables of the reaction function. It is conceivable that the forecasts for inflation and the cyclical variable are affected by current monetary policy. In addition, our reaction function includes a proxy for the neutral rate of interest, which is measured subject to error. To the extent that these errors are correlated with other regressors, ordinary least squares (OLS) would give biased estimates.

3.1 Linear Reaction Functions

We start with estimating a large number of competing linear reaction functions, in which we use the real-time output growth gap as a proxy for the cyclical stance in the economy:

$$i_t = \rho i_{t-1} + (1-\rho)(\alpha + \beta_\pi \pi^f_{t+j|t} + \beta_y(\triangle y^f_{t+k|t} - \triangle y^*_t) + r^*_t). \quad (2)$$

While this reaction function is not an outcome of explicit optimization based on a structural model and the central bank's preferences, it is comparable to an inflation-forecast-targeting procedure, advocated by Svensson and Woodford (2005), as a way to implement optimal state-contingent policy.[16]

In equation (2), the MRO rate, the average EONIA rate, or the end-of-quarter EONIA rate i_t measures the monetary policy stance and the term i_{t-1} captures interest rate smoothing. The term $\pi^f_{t+j|t}$ refers to the ECB's projection of j-quarters-ahead HICP inflation and $\triangle y^f_{t+k|t}$ to the ECB's projection of k-quarters-ahead real GDP growth. Potential output growth ($\triangle y^*_t$) is proxied by long-run output growth projections. The underlying assumption is that the medium-run growth projection for the euro area corresponds to the assessed real time euro-area growth potential.[17]

In the original Taylor (1993) formulation, the neutral real interest rate is set to a constant, equal to 2 percent. This implies together with a 2 percent inflation target that the equilibrium nominal rate would be 4 percent. There is compelling evidence that equilibrium real interest rates are variable and have been trending downward both in the United States and in the euro area recently.[18] While the

[16]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-term 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 we don't expect a change in the reaction function itself.

[17]Another option would have been to use potential output estimates. However, the real-time estimates for euro-area potential output are only available from 2009:Q2 at a quarterly frequency and from 2006 at an annual frequency in the ECB projection data. It is also worth noting that in the ECB's New Area-Wide Model (NAWM), the reaction function has been specified in terms of deviations of output growth from its long-run empirical mean (Christoffel, Coenen, and Warne 2008).

[18]Our specification of the interest rate rule, which includes a proxy for the natural rate of interest, is akin also to Wicksell (1898), who argued that in order to maintain price stability, monetary policy should aim to track some measure of neutral rate determined purely by real factors (such as productivity of capital). King and Wolman (1999) and Woodford (2003) have shown that such a rule can result from optimizing central bank behavior in a standard New Keynesian model. In this formulation of the policy rule, when the equilibrium real rate rises, the central bank sets the interest rate higher so as to keep the output (growth) close to its equilibrium level (see also Cúrdia et al. 2015).

equilibrium real interest rate is difficult to estimate and is subject to large uncertainty, there is no reason why a time-varying equilibrium rate could not be incorporated into a policy rule.[19] In line with Clarida (2012) and Neuenkirch and Tillmann (2014), we append the reaction function with the long-term real interest rate as a proxy for the equilibrium real rate (r_t^*). We use yields on German government bonds of different maturities and calculate the real rate by subtracting either ex ante or ex post inflation from the nominal yield.[20]

In order to interpret the expression "below, but close to 2 percent," we need to solve the implicit inflation target in equation (2). Assuming that (expected) inflation is at its target level (π^*), output growth is at the potential level ($\triangle y_t^*$), the natural rate is constant (r^*), and the policy rate is constant over time (i), we can present the steady-state version of equation (2) in the following form: $i = \alpha + \beta_\pi \pi^* + r^*$. When combined with the Fisher equation ($i = \pi^* + r^*$), we can find the implicit inflation target $\pi^* = -\alpha/(\beta_\pi - 1)$.[21]

When estimating reaction functions, forecast horizons for forward-looking variables are typically assumed to be relatively short, reflecting a poorer forecast accuracy over a longer period of time.[22] However, we consider forward-lookingness of the ECB's policy responses without fixing forecasts horizons a priori by varying forecast horizons of inflation and output growth from zero (i.e., nowcast) to four quarters. Correspondingly, when constructing proxies for potential output growth, we use output growth projections from 8 to 11 quarters ahead.[23]

[19] For discussion see, e.g., Taylor (2018).

[20] Basing the proxy for the time-varying natural rate on German bunds instead of generic GDP-weighted composite euro-area bond yields is motivated in this context by the fact that German bund yields arguably do not contain the default risk premiums in the latter half of the sample.

[21] Since the implicit inflation target $\pi^* = -\alpha/(\beta_\pi - 1)$ is a ratio of estimation coefficients, its 95 percent confidence band can be computed with the help of the standard deviations of the coefficients α and β_π, and their correlation. Notice that the confidence band of the implicit inflation target is typically not symmetric.

[22] For example, when estimating reaction functions for the ECB, both Gerlach and Lewis (2014) and Neuenkirch and Tillmann (2014) consider one-year-ahead forecasts of inflation and output growth.

[23] We instrument our measure of potential output growth (eight-quarters-ahead growth forecast) with eight-quarters-ahead growth forecasts from past data

Among the resulting large number of reaction function candidates, we then use the following criteria to choose our preferred specifications in order to assess the ECB's de facto inflation target:

(i) The computed inflation target must have a bounded 95 percent confidence interval, which implies that the Taylor principle holds at the 5 percent level., i.e., $\beta_\pi > 1$ at the 5 percent level. If the 95 percent confidence interval of $(\beta_\pi - 1)$ includes zero, the computed inflation target $\pi^* = -\alpha/(\beta_\pi - 1)$ does not have a bounded confidence interval.

(ii) The 95 percent confidence interval of the inflation target should include some values between 1.5 percent and 2.0 percent. If this is not the case, we conclude that the estimated reaction function is not consistent with the definition of price stability and therefore it is not a good description of euro-area monetary policy. However, we do not (automatically) exclude models with a point estimate of π^* below 1.5 percent or above 2.0 percent, as long as the 95 percent confidence interval includes some values between 1.5 percent and 2.0 percent.

(iii) We require that the estimated parameter for projected inflation should be larger than that for projected real GDP growth: $\beta_\pi > \beta_y > 0$.[24]

We end up with 750 different specifications altogether, 13 of which meet the selection criteria described above. Typically, these specifications include the one-year-ahead inflation projection and

vintages. Then to instrument for the output growth gap (output growth nowcast, or one- to four-quarters-ahead forecast – potential output growth proxy), we use output growth nowcasts or forecasts from past data vintages (so that both elements entering the instrument for the output growth gap are from the same data vintage). Furthermore, we also use inflation nowcasts or forecasts from past data vintages as instruments. To be more specific, if output (inflation) forecast j = 0, 1, 2, 3, 4 periods ahead appears in the reaction function, we use the same forecast horizon from previous data vintages as an instrument. Finally, we instrument the nominal interest rate and the natural rate proxy with their lags. For all variables, we have used lags 2–4. Using different lags would give similar results.

[24]This is natural in the context of the ECB, as it does not have a dual mandate like the Federal Reserve. Furthermore, even if the parameters we estimate are not structural, also in the structural model of the euro area used at the ECB (NAWM), the estimated reaction function has this property.

the nowcast or one-quarter-ahead real GDP gap projection.[25] In these specifications, the ECB reacts rather strongly to projected inflation (the point estimate of the coefficient of inflation forecast ranges between 2.8 and 5.4, depending on specification). The reaction to the GDP growth gap is considerably more muted (typically the point estimate is roughly 0.4 or 0.5).

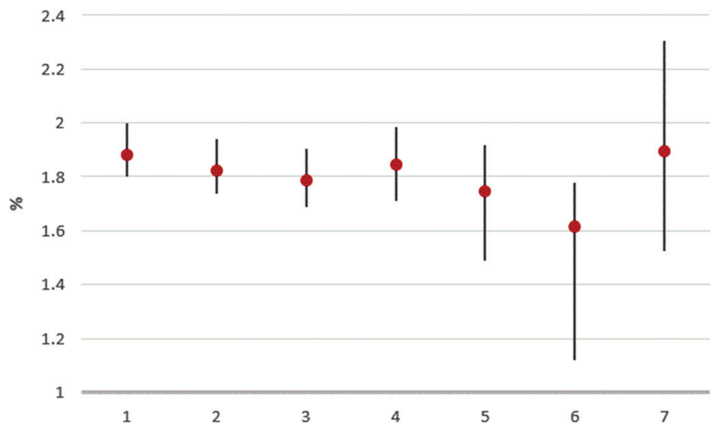
Figure 3 shows the computed inflation targets and their 95 percent confidence intervals based on sampling uncertainty from those seven model variants where the width of the confidence band is 100 basis points or narrower. In figure 3, the implied point estimate for the inflation target typically lies close to 1.8 percent. In the wider set of 13 specifications where the maximum width of the confidence band is 200 basis points, there are also a few rules with the inflation target at or below 1.6 percent. A rule with an inflation target of 2 percent or above is a rare exception. Furthermore, while the lower bound of the 95 percent confidence interval can be rather low in some rules, the upper bound typically lies below 2 percent. According to recursive estimations, the computed inflation target is relatively stable over time, apart from the period of the financial crisis.[26] In the specifications presented in figure 4, the point estimates across the models vary between 1.49 percent and 1.87 percent.

Finally, we augment equation (2) with the past inflation gap term. We allow the number of lags in the inflation gap term to vary from one to eight quarters. In this case, our preferred specification, in which all estimated coefficients are reasonable (i.e., of the expected sign and of meaningful size) includes the one-year-ahead inflation forecast, GDP growth nowcast, and a natural rate proxy based on the ex post real yield of 10-year German bunds. The monetary policy stance is measured by EONIA (average over the quarter) and the inflation gap is based on the past six quarters. The point estimate

[25]There are also five specifications which meet selection criteria (i) and (iii) but do not meet criterion (ii). All five specifications involve the two-quarters-ahead inflation projection. In these specifications the point estimate of the de facto inflation target is roughly 3 percent, while the lower bound of the 95 percent confidence band is typically at roughly 2.5 percent; the upper bound of the confidence band ranges from close to 4 percent to over 10 percent, depending on specification.

[26]Estimation results are available upon request.

Figure 3. Inflation Target: Point Estimates and 95 Percent Confidence Bands



Sources: ECB and authors' own calculations.
Notes: All specifications (1–7) displayed in the figure include the one-year-ahead inflation projection. Specifications 1–5 also include the GDP growth nowcast, while specification 6 includes the one-quarter-ahead, and specification 7 the two-quarters-ahead, GDP growth forecast. In specifications 1–6, the monetary policy stance is measured by EONIA (quarterly average), while in specification 7 the stance is measured by the MRO rate (end of period). The natural rate of interest is proxied by the real yield on German government bonds of different maturities: (1) five years (ex post), (2) three years (ex post), (3) two years (ex post), (4) five years (ex ante), (5) three years (ex ante), (6) one year (ex post), and (7) five years (ex ante).

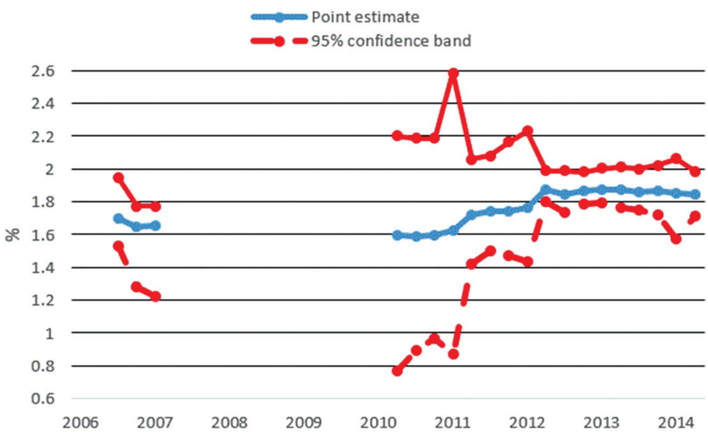
for the de facto inflation target is $\hat{\pi}^* = 1.77\%$ with a 95 percent confidence interval (capturing only sampling uncertainty) of 1.62–1.91 percent.[27]

To summarize, our estimations so far suggest that the ECB's monetary policy decisions are based on relatively short-term macroeconomic projections and the ECB's de facto inflation target lies between 1.7 percent and 1.8 percent. This finding is in line with the analysis of the inflation forecasts in the previous section.

It is useful to compare our results with survey-based measures of inflation expectations. Long-run inflation expectations in the ECB Survey of Professional Forecasters are more dispersed, but their

[27] Estimation results are available upon request.

Figure 4. Recursive Expanding Window Estimations



Sources: ECB and authors’ own calculations.
Notes: The presented specification includes the four-quarters-ahead inflation projections, output growth nowcasts, and the ex ante real natural interest rate. The end of the estimation window is extended recursively from 2006:Q1 to 2014:Q2. Point estimates are not shown for periods for which the confidence band isn’t bounded.

mean is comparable to our estimates of the de facto target. The distribution of long-term point estimates reveals that inflation expectations have been hovering between 1.7 and 2.0 percent during 2002–14. When looking at the aggregate probability distribution of long-term inflation expectations, the distribution is considerably wider than shown in figures 3 and 4. Even if most of the probability mass is between 1.5 and 1.9 percent, there is a considerable probability mass also between 0.5 and 1.4 percent and between 2.0 and 2.9 percent, and even beyond (see ECB 2019).

3.2 Reaction Functions where Cyclical Variable Is Output Growth

Measuring output gap and potential output in real time is notoriously difficult, and it is unlikely to be a good practice in policymaking to base policy on such uncertain measures of cyclical position of the economy. Indeed, the ECB does not discuss its output gap measures explicitly when it communicates its policy to the public.

Consequently, it is useful to consider reaction functions which do not directly rely on the output gap. The caveat is that the linear specification does not allow us to infer the de facto inflation target. However, with the inclusion of the nonlinear CL term, we can again indirectly infer the value of the de facto inflation target without a need to rely on an output gap measure.

3.2.1 Linear Forward-Looking Reaction Functions

For completeness, we discuss first the results from the linear specifications of the following form:

$$i_t = \rho i_{t-1} + (1-\rho)(\alpha + \beta_\pi(\pi^f_{t+j|t} - \pi^*) + \beta_y \triangle y^f_{t+k|t} + Dr^n_t). \quad (3)$$

In equation (3), i_t is the EONIA rate and the term $\pi^f_{t+j|t}$ refers to the ECB's projection of j-quarters-ahead HICP inflation and $\triangle y^f_{t+k|t}$ to the ECB's projection of k-quarters-ahead real GDP growth (instead of output growth gap as in equation (2)). Both ex ante and ex post proxies of the neutral real interest rate (r^n_t) based on the composite nominal yield of 10-year euro-area government bonds (see figure A.2 in appendix A) are considered; when the natural real rate enters (does not enter) into a reaction function, the dummy variable D is equal to one (zero). We set the inflation target to a number close to 2 percent, more specifically $\hat{\pi}^* = 1.9\%$.[28]

When estimating equation (3) with and without the natural real interest rate proxies, we again vary projection horizons from zero (nowcast) to four quarters.[29] We estimate 75 competing specifications altogether and choose the preferred specification following model selection criteria by which the estimated coefficients for forward-looking variables must imply that the interest rate reacts sufficiently strongly to projected inflation and output in order to stabilize the economy, and the estimated parameter for projected inflation should be larger than the one for projected real GDP growth.

[28] In the NAWM model of the ECB, the operational definition of price stability is also set at 1.9 percent (Christoffel, Coenen, and Warne 2008).

[29] We employ as instruments lagged variables from the same data vintage that is used in the monetary policy rule. We instrument inflation and output growth forecasts and nowcasts with lags 2–5 of (realized) inflation and output growth. As further instruments we use lags 3–4 of the nominal interest rates and lags 2–3 of the natural rate proxies. Using different lags would give similar results.

We also assess parameter stability as well as relevance of the real interest rate variable in the reaction function by running estimations in which we extend the pre-crisis sample (1999:Q4–2008:Q2) recursively quarter by quarter until the whole sample 1999:Q4–2014:Q2 is reached.

As in the previous section, the results support specifications 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.[30]

Table 1 summarizes our preferred linear specification, based on a four-quarters-ahead inflation gap and one-quarter-ahead output growth. According to this specification, the ECB reacts to a projected inflation gap about three times stronger than to a projected cyclical stance measured by output growth. The interest rate smoothing is rather high as expected and the relatively large coefficient for the inflation gap implies that the Taylor principle clearly holds: the real ex ante interest rate increases when inflation rises. Inclusion of a time-varying natural rate has only a small effect on the coefficient on output growth. The effect on the coefficient for expected inflation gap is somewhat larger, but this difference is partly mechanical, because we measure the real interest rate as a difference between a composite nominal yield of 10-year euro-area government bonds and real-time estimates of the current or one-period-ahead inflation forecast. Overall, it seems reasonable that the ECB conditions its interest rate decisions on the short end of the

[30]We obtain statistically significant coefficients also for the nowcast as well as one-quarter-ahead or four-quarters-ahead inflation, if the forecast horizon for real GDP growth is very short, i.e., zero (nowcast) or one quarter. Notably, a specification with the four-quarters-ahead inflation and one-quarter-ahead real GDP growth (i.e., $\pi^f_{t+4|t}$ and $\triangle y^f_{t+1|t}$) produces satisfactory coefficient estimates with either of the two proxies of the natural real interest rate, as well as without a natural rate proxy. Regarding parameter stability, we have estimated reaction functions with the four-quarters-ahead inflation ($\pi^f_{t+4|t}$) and one-quarter-ahead GDP ($\triangle y^f_{t+1|t}$) for the (pre-Lehman) period of 1999:Q4–2008:Q2, and then expanded the sample one quarter at a time until 2014:Q2. We obtain more stable coefficients for inflation and output growth with a natural interest rate proxy in the specification than without it. In addition, the specification using the ex ante natural real interest rate seems to work even better than the ex post natural real interest rate. All results are available upon request.

Table 1. Baseline Linear Reaction Function with Output Growth as Cyclical Variable

$i_t = \rho * i_{t-1} + (1-\rho) * (\alpha + \beta_\pi * (\pi^f_{t+4\vert t} - 1.9) + \beta_y * \Delta y^f_{t+1\vert t} + \tilde{r}^{10yr}_t)$				
	Coefficient	**Std. Error**	**t-statistic**	**Prob.**
ρ	0.84	0.044	19.23	0.0000
α	−0.95	0.737	−1.29	0.2049
β_π	4.45	0.832	5.34	0.0000
β_y	1.48	0.507	2.92	0.0057
J-statistic	6.07			
Prob(J-statistic)	0.73			

Notes: This table shows the GMM estimation results of our preferred linear reaction function of the ECB. The estimation sample is 1999:Q4–2014:Q2. See the main text for the definition of the variables and table B.1 (in appendix B) for alternative competing linear specifications. The reported J-statistic is the Sargent-Hansen test for validity of the instruments.

forecast horizon due to increasing difficulties to predict inflation and growth in the medium and longer term.

3.2.2 Symmetric Responses to Past Inflation Gaps

Next, we augment our preferred linear specification with a backward-looking "credibility loss term" CL_t so that

$$\begin{aligned} i_t = \rho i_{t-1} + (1-\rho)(\alpha + \beta_\pi(\pi^f_{t+4|t} - \pi^*) \\ + \beta_y \triangle y^f_{t+1|t} + \gamma CL_t + r^n_t), \end{aligned} \tag{4}$$

where the CL_t term is specified as in equation (1).

As discussed at the beginning of this section, this term captures the idea that the central bank may set the interest rate higher (lower) today if the past inflation gap is positive (negative) even if inflation is projected to be at the target in the near future.[31,32] Concerns for

[31] Monetary policy credibility measures proposed by de Mendonca and de Guimarães e Souza (2009) is also based on past deviations of inflation from the target.

[32] Using quite similar an approach, Dovern and Kenny (2017) investigate the impacts of "too low for too long" on long-term inflation expectations of professional forecasters in the euro area. They define an inflation "performance gap"

past inflation gaps may reflect, e.g., the central bank's desire and commitment to correct past errors. Note also that the credibility loss term weights large average past deviations of inflation from the target (π^*) more than small ones. Note that in Bernanke's (2017b) proposal of temporary price-level targeting, the key additional element in the policy rule is the term which captures the cumulative inflation shortfall since the beginning of zero lower bound until the exit date (see also Hebden and López-Salido 2018). The CL term captures a similar idea, but it introduces additional inertia in policymaking also at normal times when inflation deviates from the target.

When estimating equation (4), we allow for the length of the time span, i.e., the number of lags (q) over which the average past inflation is measured, to vary from one to eight quarters.[33] We also consider a number of different inflation targets π^*, at or below 2 percent; the lowest inflation target rate examined is chosen to be 1.6 percent in light of figure 1 and the results from section 3.1. This exercise allows us to draw additional indirect inference concerning both the ECB's de facto inflation target and the ECB's concerns of past inflation gaps.

Estimation results are summarized in table B.2 in appendix B. Based on our model evaluation criteria, longer credibility loss time spans, ranging up to six to eight lags, and lower inflation target rates (perhaps even as low as 1.6 percent or 1.7 percent) produce the most satisfactory and relatively robust coefficient estimates (estimated parameters seem to be relatively stable when the sample rolls recursively over the financial crisis toward 2014:Q2[34]). Our preferred nonlinear specification is reported in table 2. Compared with the linear specification in table 1, we now obtain smaller coefficients for interest rate smoothing and projected inflation gap while the ECB seems to react relatively strongly to past inflation gaps. The estimated output growth coefficient is roughly unchanged relative to the preferred linear specification.

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as the difference between recent long-term inflation expectations and a moving average of past inflation rates.

[33] We do not instrument for the CL terms (which include past values of inflation), while the rest of the right-hand-side variables are instrumented as explained in section 3.2.1.

[34] The results are available upon request.

Table 2. Baseline Reaction Function with Symmetric Response to Past Inflation Gap

$$i_t = \rho * i_{t-1} + (1-\rho) * (\alpha + \beta_\pi * (\pi^f_{t+4|t} - 1.7) + \beta_y * \Delta y^f_{t+1|t} + \gamma * CL_t + \tilde{r}^{10yr}_t) \text{ where } CL_t = (\bar{\pi}_{t-1,t-7} - 1.7)|\bar{\pi}_{t-1,t-7} - 1.7|$$

	Coefficient	**Std. Error**	**t-statistic**	**Prob.**
ρ	0.77	0.051	15.30	0.0000
α	−1.51	0.396	−3.83	0.0004
β_π	3.61	0.798	4.53	0.0001
β_y	1.25	0.317	3.94	0.0013
γ	1.07	0.417	2.56	0.0145
J-statistic	6.58			
Prob(J-statistic)	0.68			

Notes: This table shows the GMM estimation results of our preferred reaction function of the ECB including symmetric reactions to past inflation gaps. The estimation sample is 1999:Q4–2014:Q2. See the main text for the definition of the variables and table B.2 (in appendix B) for alternative competing linear specifications. The reported J-statistic is the Sargent-Hansen test for validity of the instruments.

In sum, we find that a concern for past errors seems to have played a role in the ECB's policy decisions. Quite intuitively, however, the ECB has responded only to persistent inflation gaps as indicated by the long lags of the credibility loss term.[35] Consistently with the findings from section 3.1, these results also suggest that the ECB's de facto inflation target has been considerably below 2 percent, perhaps even as low as 1.6 percent or 1.7 percent.[36] Hence, the results for the de facto inflation target do not seem to be overly sensitive to the choice of the cyclical variable or even the inclusion of the past inflation gap term.[37]

[35] This is reasonable, since monetary policy is not expected to respond to temporary shocks to inflation such as large variations in energy prices.

[36] Bletzinger and Wieland (2017), using the ECB Survey of Professional Forecasters and European Commission estimates for potential growth, and considering a target range of 1.5–2.0 percent, conclude that the ECB point inflation target is 1.7 percent. Furthermore, when estimating first-difference policy rules by Orphanides (2003), Hartmann and Smets (2018) conclude that the ECB's implicit target is 1.81 percent.

[37] As a further robustness check, we have also estimated a number of linear reaction functions without any real activity measure. These specifications are based

3.2.3 Asymmetric Responses to Past Inflation Gaps

Next, we consider possible asymmetry in the ECB's policymaking, i.e., we allow for different responses to positive and negative past inflation gaps. We estimate the following specification:

$$\begin{aligned} i_t = \rho * i_{t-1} + (1-\rho) * (\alpha + \beta_\pi * (\pi^f_{t+4|t} - \pi^*) + \beta_y * \triangle y^f_{t+1|t} \\ + \gamma_1 * CL^+_t + \gamma_2 * CL^-_t + r^n_t), \end{aligned} \tag{5}$$

where

$$\begin{aligned} CL^+_t &= D^{CL}_t * CL_t \\ CL^-_t &= (1 - D^{CL}_t) * CL_t. \end{aligned}$$

In equation (5), the dummy variable D^{CL}_t is equal to one (zero) if $CL_t > 0$ ($CL_t < 0$). The coefficient γ_1 captures monetary policy reactions to past positive inflation gaps, and the coefficient γ_2 to past negative inflation gaps. In order to measure the ECB's credibility concerns in a meaningful way, the parameters γ_1 and γ_2 must be positive, but their sizes may differ.

Again, we run several competing specifications in order to draw some inference concerning both the ECB's de facto inflation target and the ECB's concerns of past inflation gaps. In table B.3 in appendix B, the credibility loss term is based on one to eight lags of actual inflation and the inflation target varies from 1.6 to 2.0 percent. Consistent with our results for symmetric reaction functions, table B.3 in appendix B indicates that the time span of the past inflation gap should be rather long, ranging from six to eight quarters (the ECB reacts only to rather persistent inflation gaps). However, as our preferred specification in table 3 reveals, now the inflation target closer to 2 percent seems more appropriate but the ECB's policy is asymmetric: it responds more aggressively to positive than to negative inflation gaps (i.e., the parameter estimate for γ_1 is significantly larger than for γ_2).[38] Such an asymmetric

on the assumption that the ECB policy responds only to projected inflation. The results are not sensitive to the inclusion or exclusion of a cyclical variable.

[38]Note that a time-invariant potential output can be calculated as $\triangle y^* = (\pi^* - \alpha)/\beta_y$. According to the symmetric reaction function (asymmetric reaction function), the average projected potential output growth is 2.5 percent

Table 3. Baseline Reaction Function with Asymmetric Response to Past Inflation Gap

$$i_t = \rho * i_{t-1} + (1-\rho) * (\alpha + \beta_\pi * (\pi^f_{t+4|t} - 2.0) + \beta_y * \Delta y^f_{t+1|t}$$
$$+ \gamma_1 * CL^+_t + \gamma_2 * CL^-_t + r^n_t) \text{ where } CL_t = (\bar{\pi}_{t-1,t-7} - 2.0)|\bar{\pi}_{t-1,t-7} - 2.0|$$

	Coefficient	**Std. Error**	**t-statistic**	**Prob.**
ρ	0.79	0.046	16.94	0.0000
α	−1.92	0.755	−2.54	0.0153
β_π	1.23	0.585	2.10	0.0424
β_y	1.69	0.379	4.47	0.0001
γ_1	8.00	2.606	3.07	0.0039
γ_2	0.63	0.312	2.01	0.0518
J-statistic	6.66	F-statistic ($\gamma_1 = \gamma_2$)		6.84
Prob(J-statistic)	0.67	Prob(F-statistic)		0.013

Notes: This table shows the GMM estimation results of our preferred asymmetric reaction function of the ECB. The estimation sample is 1999:Q4–2014:Q2. See the main text for the definition of the variables and table B.3 (in appendix B) for alternative competing linear specifications. The reported J-statistic is 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.

reaction to past inflation gaps implies that, over a long period of time, inflation will be below 2 percent, i.e., asymmetry itself lowers the de facto inflation target.[39]

As for the estimated coefficient for inflation, this policy rule suggests that the ECB is considerably backward looking. The estimated coefficient for the one-year-ahead inflation forecast is small, three to four times smaller than in the previous estimations (see tables 1

(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 the projected potential output growth. As already discussed in section 2, the ECB's projections of real GDP growth converge to values between slightly below 2 percent and 3 percent.

[39] According to the asymmetry analysis by Hartmann and Smets (2018), the ECB's accommodative policy responses are mainly due to decreasing output growth projections, and tightening policy responses are mainly due to above the target inflation projections.

and 2). At the same time, the point estimate for the output growth term is somewhat higher.

In order to assess whether asymmetric policy responses reflect the zero lower bound of interest rates, we have reestimated the reaction function (5) using a shadow rate instead of EONIA for a longer sample 1999:Q1–2016;Q4. The results are qualitatively unchanged.[40]

In summary, the ECB's definition of price stability seems to manifest itself in two alternative ways. Either the de facto target of the ECB is significantly below 2 percent and policy responses to past inflation gaps are symmetric, or the ECB's inflation target is close to 2 percent and it reacts more strongly to past positive than to past negative inflation gaps. The two policy rule specifications also have other interesting differences: in the case of the symmetric specification, the policy response to the projected inflation is clearly higher (three times higher) and the response to past inflation gaps substantially lower than in the case of the asymmetric specification. While in both cases a reaction to past inflation gaps implies that the ECB attempts to correct past inflation misses, this behavior is particularly strong under the asymmetric specification. Given that there is no substantial difference in the interest rate smoothing coefficient, the ECB appears to be more forward looking under the symmetric specification. As for now, there is no clear statistical criteria by which we could give preference to either of the two reaction function specifications.

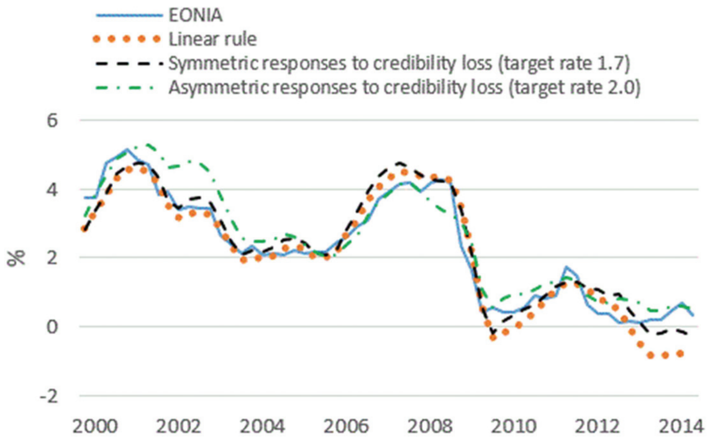
4. Predictive Performance of Different Reaction Functions

4.1 In-Sample Predictions

The performance of our preferred reaction functions from tables 1 to 3 can be assessed by comparing their in-sample predictions with the EONIA interest rate. Figure 5 indicates that the asymmetric reaction function deviates at times significantly from the EONIA rate and from predictions of the two other functions, especially at the beginning of the sample, when the euro-area inflation was quite often above 2 percent. During 2005–07, however, the asymmetric

[40]Estimation results are available upon request.

Figure 5. Dynamic In-Sample Predictions of Different Reaction Functions



Sources: ECB, Thomson Reuters, and authors' own calculations.
Note: The dynamic in-sample predictions are based on our preferred specifications of the ECB's reaction function reported in sections 3.2.1–3.2.3.

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 EONIA and also above predictions of the two other reaction functions. 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.

The linear reaction function, which only responds to the expected future path of the economy and not at all to past inflation gaps, generates the lowest interest rate path (i.e., the most accommodative monetary policy stance) at the end of the sample. This reflects relatively strong responses to the projected slowdown of inflation during this period. The symmetric nonlinear reaction function with a low de facto target inflation generates a similar path but yields a somewhat less accommodative policy stance, because it puts weight on a past positive inflation gap (see figure A.3 in appendix A) and the impact of the projected slowdown of inflation is smaller. Excluding the end of the sample, the linear and symmetric nonlinear reaction functions give rather similar predictions for the interest rate path until about 2012. According to these specifications, the zero lower bound would have been reached in 2009, i.e., much earlier than it was actually reached. Instead, according to the asymmetric nonlinear reaction function the zero lower bound would not have been reached at all.

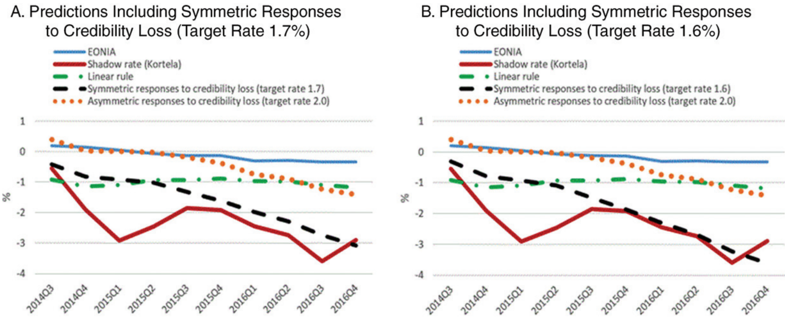
4.2 Out-of-Sample Predictions and Comparison with Shadow Rates

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? Assuming that one of our preferred policy rule specifications provides a reasonable description of the ECB monetary policy until 2014, the same policy strategy should have been applied also afterwards for this policy to be time consistent. In fact, the ECB has recently emphasized in its communication that the reaction function has not changed despite the zero lower bound period and the instruments of monetary policy (Hutchinson and Smets 2017).

In July 2013, the ECB introduced explicit forward guidance to inform markets and the public on its future intentions with regard to key policy rates, and in January 2015 the ECB launched an expanded asset purchase program (APP) to address risks of too-prolonged a period of low inflation. Previously, the ECB had emphasized in its communication that it does not pre-commit on monetary policy decisions. Also, other unconventional monetary policy measures were adopted in 2015 and 2016 in order to maintain an accommodative stance of monetary policy. The deposit rate was cut in June and September 2014 to −0.2 percent, reaching for the first time a negative territory.[41]

[41]Since mid-2014, in order to provide financing to euro-area credit institutions, two series of targeted longer-term refinancing operations (TLTROs) were introduced: the first series of eight operations (LTRO-I) was announced in June 2014, and a second series of four operations (LTRO-II) in March 2016. In September 2014, the ECB made announcements of the third covered bond purchase program (CBPP3), an asset-backed securities purchase program (ABSPP), and a further deposit facility rate cut. APP purchases were started in March 2015 and they

Figure 6. Shadow Rate by Kortela (2016) and Predictions Based on Different Reaction Functions



Sources: ECB, authors' own calculations, and Kortela (2016) for the shadow rate.
Notes: The symmetric responses to a credibility loss refer to a reaction function with a low de facto inflation target (1.7 percent or 1.6 percent). The asymmetric responses to a credibility loss refer to a reaction function with an inflation target of 2.0 percent.

To analyze the recent euro-area monetary policy stance, we use our preferred reaction functions (estimated for the period 1999:Q4–2014:Q2) to produce dynamic out-of-sample forecasts for the period 2014:Q3–2016:Q4. Our aim is to assess how closely the whole path of dynamically predicted interest rate matches to the measure of the ECB's monetary policy stance. In each quarter, the prediction is conditional on the Eurosystem/ECB staff real-time forecasts and the lagged prediction of the interest rate from the corresponding rule.

In figure 6A, the implied interest rates are compared with the shadow rate estimated by Kortela (2016). He argues that the euro-area shadow rate had gradually decreased to about −3 percent by the end of 2016, while a temporary increase was experienced in 2015. The dynamic out-of-sample forecast of the interest rate implied

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were recalibrated in December 2015, March 2016, and December 2016. The ECB took a number of nonstandard measures already in the earlier phase of the crisis, but these measures were mainly targeted to provide ample liquidity for the euro-area banks and they were taken in tandem with standard interest rate cuts.

by our linear rule remains negative and stable around −1 percent throughout the whole zero lower bound period; it is roughly 1 percentage point below the EONIA rate but considerably higher than the shadow rate for most of the period.

The nonlinear reaction functions taking into account a credibility loss imply falling interest rates over the period 2014:Q3–2016:Q4. The symmetric nonlinear reaction function with a low de facto inflation target of 1.7 percent seems to track the shadow rate considerably better than the asymmetric nonlinear reaction function with an inflation target of 2 percent. This suggests, tentatively, that the ECB’s definition of price stability is best characterized by an inflation target that is markedly below 2 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 B.2 in appendix B, the implied predictions are even closer to the shadow rate (figure 6B).

Finally, as a robustness check, we compare the same out-of-sample predictions to another shadow interest rate estimated by Wu and Xia (2016).[42] As shown in appendix C, their shadow rate is steadily decreasing to about −5 percent in 2016. Compared with Kortela’s (2016), their analysis indicates even more accommodative a monetary policy stance in the euro area in recent years. The main technical difference between Kortela and Wu and Xia is that Kortela allows for a time-varying lower bound for the euro area, reflecting the expected path of the deposit facility rate. The Wu and Xia methodology is based on a constant lower bound assumption. Nevertheless, also in Wu and Xia’s case, the symmetric reaction functions with a low de facto inflation target (1.6 percent or 1.7 percent) seem to characterize most accurately the conducted policy in the euro area. In general, estimated shadow rates are of course subject to large uncertainty. As reported in Hartmann and Smets (2018), the shadow rates vary between close to −8 percent and 0 percent in the period 2014–17.

[42]The shadow interest rate constructed by Wu and Xia (2016) is based on an analytical representation for bond prices in an SRTSM model (https://www.quandl.com/data/SHADOWS/EUROPE-European-Central-Bank-Shadow-Rate).

5. Conclusions

In the recent discussion of the ECB's monetary policy, there has been a vivid debate on what the ECB's de facto target is, whether the reaction function is symmetric, and, if it is, around which inflation target. Increased clarity about the central bank's reaction function and inflation target helps to anchor inflation expectations by reducing uncertainty about the central bank's future actions.[43] In this paper, we have shed some more light on the ECB's de facto inflation target, possible asymmetry of policy responses, and its reaction function in general. To do this, we have estimated a large number of competing specifications for the ECB's reaction function. We have used extensively the real-time projections from the Eurosystem/ECB staff macroeconomic projection exercises conducted in 1999:Q4–2016:Q4. A quarterly real-time data set has enabled us to assess realistically the ECB Governing Council's monetary policy decisionmaking by estimating the reaction functions with the same information it has available when it decides on the monetary policy stance. After estimating reaction functions including different levels of the de facto inflation target, different cyclical variables, a time-varying natural rate, varying degrees of backward-looking and forward-looking information contained in our real-time data, and asymmetry, we have arrived at the following robust findings.

First, the de facto inflation target of the ECB is well below 2 percent, perhaps even as low as 1.6–1.8 percent. This finding is also consistent with the fact that the Eurosystem/ECB staff medium-term inflation projections have had a tendency to converge rapidly on values well below 2 percent.

Second, the reaction function specifications which include both forward-looking information from the projections and past inflation developments seem to characterize best the ECB's monetary policy decisions during the whole sample. We find some evidence on asymmetry around the presumed 2 percent inflation target, but the dynamic out-of-sample predictions of the symmetric reaction

[43]See, e.g., Taylor (2018) for general discussion on the benefits of rule-based policy and Bernanke and Mishkin (1997) and Bundick and Smith (2018) for the importance of a specific numerical inflation target for anchoring inflation expectations in the United States.

function with a 1.6–1.7 percent de facto target is better in line with the evolution of shadow rates than the asymmetric reaction function during the zero lower bound period.

Our results suggest that, in general, the ECB’s policy reaction function follows the basic optimality principles in accordance with its mandate. We find that the ECB Governing Council responds relatively strongly to the expected short-term future course of the economy—i.e., its forecasts for inflation and the measure of real economic activity—but it also aims at correcting past persistent deviations of inflation from the target. The forward-looking nature of its policy is motivated by the fact that monetary policy affects the economy only gradually, hence inflation and output forecasts should be an integral part of the inflation-targeting strategy. That policy has also a backward-looking element, consistent with the ECB communication, according to which the launch of asset purchase programs and other unconventional policy measures can be justified as a response to too-prolonged a period of low inflation.[44] At the same time, however, asymmetric responses to inflation and/or a low de facto inflation target indicated by our findings may hamper the ECB’s ability to achieve its inflation aim. There are a number of reasons for this.

Firstly, 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 help the central bank to achieve its inflation aim faster and more efficiently when 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 in the standard New Keynesian type of models.

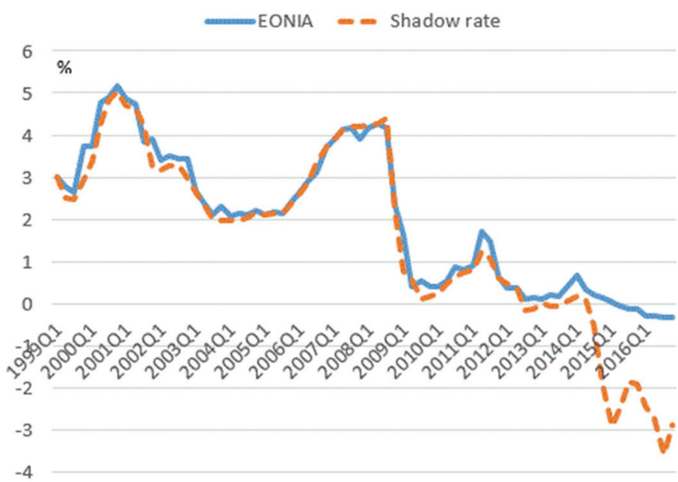
Secondly, for a given equilibrium real interest rate, anchoring of inflation expectations to a relatively low level also leads to low nominal rates over the business cycle. This reduces the scope to absorb shocks in economic downturns and increases the likelihood of hitting the zero lower bound. With forward-looking price-setting behavior,

[44]See http://www.ecb.europa.eu/press/key/date/2018/html/ecb.sp180314_1.en.html.

the expectation that monetary policy has less scope to absorb negative shocks in the future can further lower the current inflation. Miles et al. (2017) have also recently stressed that in the current low inflation environment, overshooting the target is necessary and the targeted rate of inflation should not be too low.[45]

Appendix A. Additional Figures and Tables

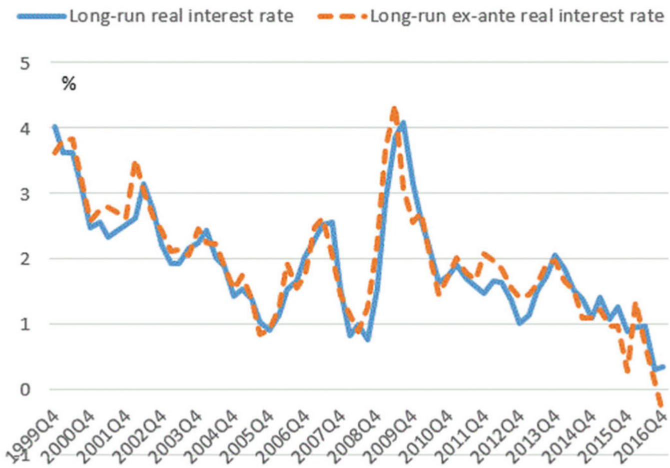
Figure A.1. EONIA and Shadow Rate at End of Each Quarter



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

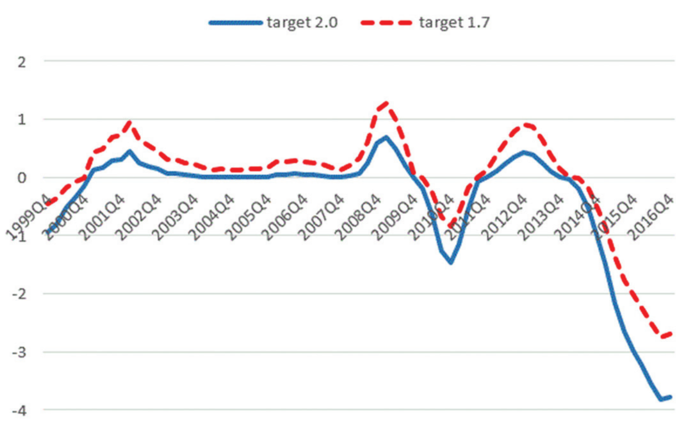
[45]In the United States, too, the level and symmetry of the targeted rate of inflation has been discussed recently. See, for example, speeches by Evans: https://www.chicagofed.org/publications/speeches/2017/11-15-2017-low-inflation-and-symmetry-of-two-percent-target-charles-evans-london-ubs, https://www.chicagofed.org/publications/speeches/2017/09-25-17-puzzle-low-inflation-implications-monetary-policy.

Figure A.2. Proxies of Long-Run Natural Real Interest Rate



Sources: ECB, Thomson Reuters, and authors' own calculations.
Note: The long-run real interest rate is equal to the difference of a euro-area composite nominal yield of 10-year government bonds and the real-time nowcast or one-quarter-ahead forecast of inflation rate.

Figure A.3. Values of Credibility Loss Term



Sources: ECB and authors' own calculations.
Note: The horizon over which the average inflation is measured is seven quarters ($\bar{\pi}_{t-1,t-7}$). See the main text for the definition of the credibility term.

Table A.1. Characteristics of Projection Data

	$\Delta\pi^f_{t\|t}$	$\Delta\pi^f_{t+4\|t}$	$\Delta\pi^f_{t+8\|t}$	$\Delta\pi^f_{t+11\|t}$	HICP Change
Mean	1.78	1.60	1.64	1.76	1.75
Standard Dev.	0.97	0.34	0.22	0.20	0.98
Sample Size	69	69	68	17	69
	$\Delta y^f_{t\|t}$	$\Delta y^f_{t+4\|t}$	$\Delta y^f_{t+8\|t}$	$\Delta y^f_{t+11\|t}$	GDP Growth
Mean	1.10	1.67	2.05	2.12	1.33
Standard Dev.	1.57	0.81	0.48	0.49	1.99
Sample Size	69	69	68	17	69

Sources: ECB and authors' own calculations.
Note: The sample spans from 1999:Q4 to 2016:Q4 (69 quarters in total).

Appendix B. Summary of Estimations

Table B.1. Coefficients of Inflation and GDP Growth in Reaction Function (1), with Different Projection Horizons for Inflation (rows) and Output Growth (columns)

	$\Delta y^f_{(t\|t)}$		$\Delta y^f_{(t+1\|t)}$		$\Delta y^f_{(t+2\|t)}$		$\Delta y^f_{(t+3\|t)}$		$\Delta y^f_{(t+4\|t)}$	
A. Linear Policy Reaction Function without a Natural Rate of Interest										
$\pi^f_{(t\|t)}$	−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^{10yr}_t as a Proxy for the Natural Rate of Interest										
$\pi^f_{(t\|t)}$	−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 $\tilde{r}^{10yr}_t$ as a Proxy for the Natural Rate of Interest										
$\pi^f_{(t\|t)}$	−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**

Notes: 1. For each pair of numbers, the first entry is the coefficient of inflation, β_π, while the second entry is the coefficient of real GDP growth, β_y. 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 β_π and β_y 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 gray 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 (panels A, B, and C), with and without a natural rate proxy.

Table B.2. Symmetric Monetary Policy Responses to Credibility Loss in Reaction Function (2)

	Target 1.6	**Target 1.7**	**Target 1.8**	**Target 1.9**	**Target 2.0**
A. Reaction Functions that Include the Long Real Interest Rate r_t^{10yr} as a Proxy for the Natural Rate					
$\bar{\pi}_{t-1,t-1}$	−0.61	−0.65	−0.68	−0.70	−0.61
$\bar{\pi}_{t-1,t-2}$	−0.49	−0.40	−0.20	−0.14	−0.13
$\bar{\pi}_{t-1,t-3}$	−0.11	−0.10	−0.11	−0.13	−0.17
$\bar{\pi}_{t-1,t-4}$	0.11	0.11	0.10	0.08	0.02
$\bar{\pi}_{t-1,t-5}$	0.94*	0.70*	0.58*	0.50*	0.44*
$\bar{\pi}_{t-1,t-6}$	1.21*	1.02*	0.82*	0.64*	0.09
$\bar{\pi}_{t-1,t-7}$	**1.50***	**0.94***	0.24	0.19	0.53
$\bar{\pi}_{t-1,t-8}$	**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					
$\bar{\pi}_{t-1,t-1}$	−0.53	−0.44	−0.07	−0.02	0.01
$\bar{\pi}_{t-1,t-2}$	0.20	0.16	0.13	0.11	0.09
$\bar{\pi}_{t-1,t-3}$	0.06	0.06	0.06	0.06	0.05
$\bar{\pi}_{t-1,t-4}$	−0.43	−0.10	0.02	0.05	0.06
$\bar{\pi}_{t-1,t-5}$	−0.44	−0.44	−0.24	−0.01	0.08
$\bar{\pi}_{t-1,t-6}$	0.29	0.29	0.31	0.31	0.29
$\bar{\pi}_{t-1,t-7}$	**1.42***	**1.07***	0.76	0.62	0.58
$\bar{\pi}_{t-1,t-8}$	3.20*	1.30	1.19	1.16	0.96

Notes: 1. The table reports estimates of the coefficient γ for the credibility loss term CL_t, for different spans of past inflation (rows) and inflation targets (columns). 2. Coefficient estimates γ 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 (β_π and β_y, not shown in the table) are positive and statistically significant, and in addition $\beta_\pi > \beta_y$. 4. We have added a gray 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 panels of the table, A and B).

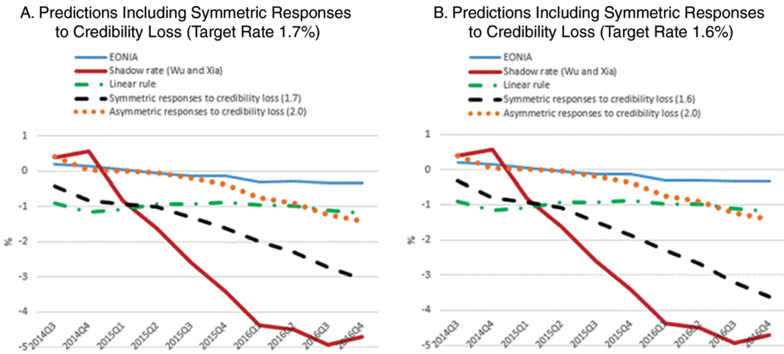
Table B.3. Asymmetric Monetary Policy Responses to Credibility Loss in Reaction Function (3)

	Target 1.6		**Target 1.7**		**Target 1.8**		**Target 1.9**		**Target 2.0**	
A. Reaction Functions that Include the Long Real Interest Rate r_t^{10yr} as a Proxy for the Natural Rate										
$\bar{\pi}_{t-1,t-1}$	0.60	0.36*	0.61	0.26	0.62	0.15	0.63	0.03	−1.55	−0.35
$\bar{\pi}_{t-1,t-2}$	0.68	0.45	0.68	0.31	0.60	0.14	−1.24	−0.08	−1.42	−0.10
$\bar{\pi}_{t-1,t-3}$	−0.91	0.25	−1.00	0.15	−1.03	0.07	−0.47	−0.04	−0.29	−0.15
$\bar{\pi}_{t-1,t-4}$	−2.31	0.61*	−2.17	0.44*	−2.19	0.34	0.49	−0.01	0.02	0.00
$\bar{\pi}_{t-1,t-5}$	−3.17	1.09*	−3.83	0.82*	−4.37	0.62*	−4.80	0.48*	−5.32	0.39*
$\bar{\pi}_{t-1,t-6}$	2.61*	0.95	2.96*	0.97*	−0.51	0.83*	−1.06	0.68*	−1.97	0.57*
$\bar{\pi}_{t-1,t-7}$	2.89*	1.00	3.67*	0.77	**4.73***	**0.64**	**6.14***	**0.61**	**8.00***	**0.63***
$\bar{\pi}_{t-1,t-8}$	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										
$\bar{\pi}_{t-1,t-1}$	0.43	0.51*	0.42	0.44*	0.41	0.37*	0.38	0.31*	0.34	0.24*
$\bar{\pi}_{t-1,t-2}$	0.65	0.54*	0.68	0.48*	0.71	0.41*	0.71	0.34	0.68	0.27
$\bar{\pi}_{t-1,t-3}$	−1.66	0.72*	−1.74	0.57*	−1.81	0.45*	2.75	0.24	−0.59	0.09
$\bar{\pi}_{t-1,t-4}$	−1.24	0.53*	−1.31	0.43*	−1.43	0.36*	−1.62	0.30*	−1.91	0.25*
$\bar{\pi}_{t-1,t-5}$	−1.86	0.96*	−2.08	0.76*	−2.35	0.61*	−2.74	0.50*	−3.34	0.42*
$\bar{\pi}_{t-1,t-6}$	0.74	0.26	0.37	0.40	−2.62	1.15*	−2.98	0.91*	−3.55	0.74*
$\bar{\pi}_{t-1,t-7}$	2.4*	0.64	3.06*	0.43	3.88*	0.31	4.92*	0.28	**6.21***	**0.31**
$\bar{\pi}_{t-1,t-8}$	3.65*	−8.67	4.57*	−4.26	5.83*	−1.85	7.46*	−0.77	9.69*	−0.14

Notes: 1. The table reports estimates of monetary policy reactions to a positive past inflation gap (coefficient γ_1, left entry in each pair of numbers) and a negative past inflation gap (coefficient γ_2, right entry in each pair of numbers), 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 (γ_1) 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., γ_1 is significantly larger than γ_2, at least at the 5 percent level). 4. We have added a gray background color to the combinations of past inflation span and inflation target ($\bar{\pi}_{t-1,t-7}$ and target 2.0), which satisfy the criteria (i), (ii), and (iii) in both types of reaction functions considered here (i.e., in panels A and B of the table).

Appendix C. Alternative Shadow Rate by Wu and Xia (2016)

Figure C.1. Predictions Based on Different Reaction Functions



Sources: ECB, authors' own calculations, and Wu and Xia (2016) for the shadow rate.
Note: The symmetric responses to a credibility loss refer to a reaction function with a low de facto inflation target (1.6 percent or 1.7 percent). The asymmetric responses to a credibility loss refer to a reaction function with an inflation target of 2.0 percent.

References

Aguiar, A., and M. M. F. Martins. 2008. "Testing for Asymmetries in the Preferences of the Euro-Area Monetary Policymaker." *Applied Economics* 40 (13): 1651–67.

Alessi, L., E. Ghysels, L. Onorante, R. Peach, and S. Potter. 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 and Economic Statistics* 32 (4): 483–500.

Apel, M., and C. A. Claussen. 2017. "Inflation Targets and Intervals — An Overview of the Issues." *Economic Review* (Sveriges Riksbank) 2017 (1): 83–103.

Belke, A., and J. Klose. 2011. "Does the ECB Rely on a Taylor Rule During the Financial Crisis? Comparing Ex-post and Real Time

Data with Real Time Forecasts." *Economic Analysis and Policy* 41 (2): 147–71.

Bernanke, B. 2017a. "Monetary Policy in a Low Interest World: Comment." In *Brookings Papers on Economic Activity* (Spring): 380–89.

———. 2017b. "Monetary Policy in a New Era." Speech at the Peterson Institute Conference on Rethinking Macroeconomic Policy, Washington, DC, October 12–13.

Bernanke, B., and F. Mishkin. 1997. "Inflation Targeting: A New Framework for Monetary Policy?" *Journal of Economic Perspectives* 11 (2): 97–116.

Bletzinger, T., and V. Wieland. 2017. "Lower for Longer: The Case of the ECB." *Economics Letters* 159 (October): 123–27.

Bullard, J. 2018. "A Primer on Price Level Targeting in the U.S." Speech at the Federal Reserve Bank of St. Louis, St. Louis, Missouri, January 10.

Bundick, B., and A. L. Smith. 2018. "Did Communicating a Numerical Inflation Target Anchor U.S. Inflation Expectations?" *The Macro Bulletin* (Federal Reserve Bank of Kansas City) January 17: 1–4.

Charemza, W., and D. Ladley. 2016. "Central Banks' Forecasts and Their Bias: Evidence, Effects and Explanation." *International Journal of Forecasting* 32 (3): 804–17.

Christoffel, K., G. Coenen, and A. Warne. 2008. "The New Area-Wide Model of the Euro Area: A Micro-Founded Open-Economy Model for Forecasting and Policy Analysis." ECB Working Paper No. 944 (October).

Clarida, R. 2012. "What Has — and Has Not — Been Learned about Monetary Policy in a Low-Inflation Environment? A Review of the 2000s." *Journal of Money, Credit and Banking* 44 (s1): 123–40.

Clarida, R., J. Galí, and M. Gertler. 1998. "Monetary Policy Rules in Practice: Some International Evidence." *European Economic Review* 42 (6): 1033–67.

Cœuré, B. 2017. "Central Bank Communication in a Low Interest Rate Environment." *Open Economies Review* 28 (5): 813–22.

Cúrdia, V., A. Ferrero, G. C. Ng, and A. Tambalotti. 2015. "Has U.S. Monetary Policy Tracked the Efficient Interest Rate?" *Journal of Monetary Economics* 70 (March): 72–83.

de Mendonca, H., and G. de Guimarães e Souza. 2009. "Inflation Targeting Credibility and Reputation: The Consequences for the Interest Rate." *Economic Modelling* 26 (6): 1228–38.

Dovern, J., and G. Kenny. 2017. "The Long-Term Distribution of Expected Inflation in the Euro Area: What Has Changed Since the Great Recession?" ECB Working Paper No. 1999.

Ehrmann, M. 2015. "Targeting Inflation from Below: How Do Inflation Expectations Behave?" *International Journal of Central Banking* 11 (Supplement 1): 213–50.

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

———. 2016. "A Guide to the Eurosystem/ECB Staff Macroeconomic Projection Exercises." (July).

———. 2019. "The ECB Survey of Professional Forecasters — Third Quarter of 2019." (July).

Fischer, B., M. Lenza, H. Pill, and L. Reichlin. 2009. "Monetary Analysis and Monetary Policy in the Euro Area 1999-2006." *Journal of International Money and Finance* 28 (7): 1138–64.

Fujiwara, I. 2005. "Is the Central Bank's Publication of Economic Forecasts Influential?" *Economic Letters* 89 (3): 255–61.

Gerlach, S. 2007. "Interest Rate Setting by the ECB, 1999-2006: Words and Deeds." *International Journal of Central Banking* 3 (3, September): 1–45.

Gerlach, S., and J. Lewis. 2014. "ECB Reaction Functions and the Crisis of 2008." *International Journal of Central Banking* 10 (1, March): 137–57.

Gorter, J., J. Jacobs, and J. de Haan. 2008. "Taylor Rules for the ECB Using Expectations Data." *Scandinavian Journal of Economics* 110 (3): 473–88.

Hartmann, P., and F. Smets. 2018. "The First Twenty Years of the European Central Bank: Monetary Policy." ECB Working Paper No. 2219.

Hebden, J., and D. López-Salido. 2018. "From Taylor's Rule to Bernanke's Temporary Price Level Targeting." Finance and Economics Discussion Series No. 2018-051, Board of Governors of the Federal Reserve System. https://doi.org/10.17016/FEDS.2018.051.

Honkapohja, S., and K. Mitra. 2018. "Price Level Targeting with Evolving Credibility." CEPR Discussion Paper No. 12739.

Hubert, P. 2015. "Do Central Bank Forecasts Influence Private Agents? Forecasting Performance versus Signals." *Journal of Money, Credit and Banking* 47 (4): 771–89.

Hutchinson, J., and F. Smets. 2017. "Monetary Policy in Uncertain Times: ECB Monetary Policy since June 2014." *The Manchester School* 85 (S2): e1–e15.

Ikeda, T. 2010. "Time-Varying Asymmetries in Central Bank Preferences: The Case of the ECB." *Journal of Macroeconomics* 32 (4): 1054–66.

King, R., and A. Wolman. 1999. "What Should the Monetary Authority Do When Prices Are Sticky?" In *Monetary Policy Rules*, ed. J. B. Taylor, 349–404 (chapter 8). University of Chicago Press.

Kortela, T. 2016. "A Shadow Rate Model with Time-Varying Lower Bound of Interest Rates." Research Discussion Paper No. 19/2016, Bank of Finland.

Lyziak, T., and M. Paloviita. 2017. "Anchoring of Inflation Expectations in the Euro Area: Recent Evidence Based on Survey Data." *European Journal of Political Economy* 46 (January): 52–73.

———. 2018. "On the Formation of Inflation Expectations in Turbulent Times: The Case of the Euro Area." *Economic Modelling* 72 (June): 132–9.

Marcellino, M., and A. Musso. 2011. "The Reliability of Real-Time Estimates of the Euro Area Output Gap." *Economic Modelling* 28 (4): 1842–56.

Miles, D., U. Panizza, R. Reis, and A. Ubide. 2017. "And Yet It Moves. Inflation and the Great Recession." Geneva Reports on the World Economy, International Center for Monetary and Banking Studies (ICMB).

Neuenkirch, M., and P. Tillmann. 2014. "Inflation Targeting, Credibility, and Non-linear Taylor Rules." *Journal of International Money and Finance* 41 (March): 30–45.

Newey, W., and K. West. 1987. "A Simple, Positive Definite, Heteroscedasticity and Autocorrelation Consistent Covariance Matrix." *Econometrica* 55: 703–8.

Orphanides, A. 2003. "Historical Monetary Policy Analysis and the Taylor Rule." *Journal of Monetary Economics* 50 (5): 983–1022.

———. 2008. "Taylor Rules." In *The New Palgrave Dictionary of Economics*, 2nd edition, ed. S. Durlauf and L. E. Blume. London: Palgrave Macmillan.

Orphanides, A., and S. van Norden. 2002. "The Unreliability of Output-Gap Estimates in Real Time." *Review of Economics and Statistics* 84 (4): 569–83.

Sturm, J.-E., and J. de Haan. 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 (1): 41–58.

Surico, P. 2003. "Asymmetric Reaction Functions for the Euro Area." *Oxford Review of Economic Policy* 19 (1): 44–57.

———. 2007. "The Monetary Policy of the European Central Bank." *Scandinavian Journal of Economics* 109 (1): 115–35.

Svensson, L. E. O., and M. Woodford. 2005. "Implementing Optimal Policy through Inflation-Forecast Targeting." In *The Inflation Targeting Debate*, ed. B. S. Bernanke and M. Woodford (chapter 2). Chicago: University of Chicago Press.

Sveriges Riksbank. 2017. "Evaluation of the Riksbank's Forecasts." Riksbank Studies (May).

Taylor, J. B. 1993. "Discretion versus Policy Rules in Practice." *Carnegie-Rochester Conference Series in Public Policy* 39 (December): 195–214.

———. 2018. "Rules Versus Discretion: Assessing the Debate Over the Conduct of Monetary Policy." Economics Working Paper No. 18102, Hoover Institution, Stanford University.

van der Cruijsen, C., D.-J. Jansen, and J. de Haan. 2015. "How Much Does the Public Know about the ECB's Monetary Policy? Evidence from a Survey of Dutch Households." *International Journal of Central Banking* 11 (4, December): 169–218.

Wicksell, K. 1898. *Interest and Prices* (translated to English in 1936 by R. F. Kahn). London: Macmillan.

Williams, J. C. 2017. "Preparing for the Next Storm: Reassessing Frameworks and Strategies in a Low R-star World." FRBSF Economic Letter No. 2017-13, Federal Reserve Bank of San Francisco.

Woodford, M. 2003. Interest and Prices: Foundations of a Theory of Monetary Policy. Princeton University Press.

———. 2007. "The Case for Forecast Targeting as a Monetary Policy Strategy." *Journal of Economic Perspectives* 21 (4): 3–24.

Wu, C., and F. D. Xia. 2016. "Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound." *Journal of Money, Credit and Banking* 48 (2–3): 253–91.