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ASSESSING EUROPEAN CENTRAL BANK'S CREDIBILITY DURING THE FIRST YEARS OF THE EUROSYSTEM: A BAYESIAN EMPIRICAL INVESTIGATION*

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In this paper we extend Svenssons (*CEPR Discussion Paper 940*, April 1994) 'simplest test' of inflation target credibility inside a Bayesian econometric framework and obtain various estimates of the European Central Bank's monetary policy credibility. Overall, our empirical evidence suggests that the strategy followed by the European Central Bank was successful in building a satisfactory degree of reputation. However, we find some significant credibility reversals concerning both anti-inflationary and anti-deflationary credibility. These reversals, in turn, are closely related to the evolution of the cyclical macroeconomic conditions in the euro area.

1 Introduction

The diffusion of monetary policy rules based on inflation targeting has reiterated the crucial role exerted by central bank credibility. If inflation expectations are well anchored to an explicitly announced inflation target, fewer movements in the policy instrument are required, others things being equal, to achieve a given change in the real economy. A higher degree of credibility, moreover, introduces considerable mean reversion of inflation towards the inflation target. These effects jointly translate into a better trade-off between inflation variability and output gap variability (Svensson, 2000a, 2003).

Empirical work assessing the credibility of inflation-targeting regimes has recently marked a significant progress (see Tronzano (2005) for a critical survey of this literature), although existing contributions do not derive a quantitative estimate of the degree of inflation target credibility and its evolution over time.

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This paper contributes to this literature outlining an extension of Svensson's (1994a) 'simplest test' of inflation target credibility inside a Bayesian econometric framework. Since the policy strategy of the European Central Bank (ECB) can be interpreted as a flexible inflation-targeting regime (Svensson, 2000b), we apply the above framework to the initial years of the European Monetary Union (EMU), deriving some estimates about the agents' subjective degree of confidence in the inflation targets announced by monetary authorities.

The case study addressed in the present paper deserves special interest because, in the absence of a track record about its commitment to price stability, the newly created ECB was faced with the crucial problem of building a satisfactory reputation towards market participants. At the start of Stage Three of EMU, market participants were very uncertain about the future monetary policy stance, compared with the Bundesbank tough anti-inflationary reputation. The 'genetic' nature of ECB credibility has therefore an intrinsically dynamic character, evolving closely in line with the initial results achieved in terms of price stability (Bini Smaghi, 1996).

In this perspective, this paper improves on existing research in many respects. First, our approach yields a time-varying estimate about the degree of monetary policy credibility, thus filling a relevant gap in the literature. Second, alternative credibility patterns can be inferred conditional on alternative prior assumptions, namely assuming different initial degrees of uncertainty about the model's parameters. Finally, since the Svensson (1994a) test assumes an upper and a lower threshold for the inflation rate, our approach allows us to estimate the degree of monetary policy credibility both as an anti-inflationary and as an anti-deflationary device.

The structure of the paper is as follows. Section 2 lays down the theoretical background, outlining how the Svensson (1994a) test can be extended inside a Bayesian econometric framework. Section 3 explains how this approach can be implemented. We motivate the choice of the nominal interest rate and of the inflation target range, and sketch out the main features of the Markov chain Monte Carlo methodology underlying the empirical investigation. Section 4 contains our empirical findings. Using alternative proxies for the expected real interest rate, we derive some credibility indicators for ECB's monetary policy, and explore their robustness to alternative prior assumptions. Section 5 concludes.

2 Bayesian Analysis of Inflation Target Credibility

2.1 Theoretical Background

Assume that the central bank announces an upper (π_{max}) and a lower (π_{min}) bound for the domestic inflation rate. Following Svensson (1994a), target-consistent (t.c.) maximum and minimum real yields can be constructed,

respectively, subtracting the lower ($\pi_{\min}$) and the upper ($\pi_{\max}$) inflation targets from a nominal interest rate on government bonds. Defining the nominal yield on a default-less government bond as (i_t), the t.c. maximum and minimum real yields correspond therefore, respectively, to $i_t - \pi_{\min}$ and to $i_t - \pi_{\max}$. The above values define a t.c. band, while the Svensson (1994a) test consists in assessing whether the real interest rate falls or not inside this interval.

If the real interest rate falls outside the above band, the announced inflation targets ($\pi_{\min}$, $\pi_{\max}$) are not credible, since agents could realize a safe minimum profit which is inconsistent with an equilibrium on efficient capital markets.[1] Note, moreover, that since r_t^e, the real interest rate, is bounded between a lower and an upper threshold ($i_t - \pi_{\max} \leq r_t^e \leq i_t - \pi_{\min}$), the arbitrage condition allows us to assess the credibility of monetary policy both as an anti-inflationary and as an anti-deflationary device.

Although the Svensson (1994a) test is quite intuitive, there are some basic shortcomings associated with this approach. First, one can simply check whether a constraint on the real interest rate is satisfied or not, without being able to derive any information about the degree of monetary policy credibility.[2] Moreover, although the credibility constraint can be checked at each time interval, this framework cannot reveal how central bank reputation evolves over time. Any assessment about agents' subjective confidence in the consistency of monetary policy with official inflation targets is actually precluded in this set-up.

2.2 Extending the Svensson (1994a) Test in a Bayesian Framework

Consider the credibility constraints defined in the original test corresponding to the absence, respectively, of an inflationary or of a deflationary bias in monetary policy:[3]

[1]More specifically, if the real interest rate falls below the t.c. minimum real yield, agents could realize a safe minimum profit borrowing in real terms and lending in nominal terms. The converse argument holds if the real interest rate exceeds the t.c. maximum real yield. The arbitrage condition underlying the Svensson (1994a) test assumes the existence of reliable quotations for real interest rates. However, absent a well-functioning market for real bonds, this test can also be performed computing some proxy for expected future real yields on the basis of available information. Since the latter approach is followed in our empirical investigation, the real interest rate is always labelled as $\{r_t^e\}$ in the present paper.

[2]Even if the credibility constraint is satisfied, market agents could still assign a positive probability to future inflation rates falling outside the declared target range. In other words, using Svensson (1994a) terminology, whenever r_t^e falls inside the t.c. band 'credibility in expectation' does not imply that 'absolute credibility' holds. The crucial issue for monetary policy credibility, however, is whether the central bank is able to maintain *ex ante* inflation expectations within a t.c. band, since *ex post* inflation could go outside the band for reasons outside the control of monetary authorities. In other words, using Svensson's terminology, the crucial issue is that of assessing if 'credibility in expectations' holds. We thank an anonymous referee for having attracted our attention to this point.

[3]The approach followed in the present section is closely related to the methodology outlined in Tronzano *et al.* (2000) in order to modify the Svensson (1991) test of target zone credibility.

$$r_t^e \geq i_t - \pi_{\max} \qquad \text{(anti-inflationary credibility)}$$
$$r_t^e \leq i_t - \pi_{\min} \qquad \text{(anti-deflationary credibility)}$$

Introducing the auxiliary variables

$$z_{\mathrm{u},t} = r_t^e - (i_t - \pi_{\max})$$
$$z_{\mathrm{l},t} = r_t^e - (i_t - \pi_{\min})$$

these credibility constraints may equivalently be expressed as

$$z_{\mathrm{u}} > 0 \qquad \text{(anti-inflationary credibility)}$$
$$z_{\mathrm{l}} < 0 \qquad \text{(anti-deflationary credibility)}$$

while a quantitative assessment about the degree of inflation target credibility may be derived analysing the stochastic properties of the series $\{z_{\mathrm{u}}, z_{\mathrm{l}}\}$ inside a Bayesian framework.

The simplest way to model $\{z_{\mathrm{u}}, z_{\mathrm{l}}\}$ is to assume that these series may be characterized as a constant term plus a random disturbance, namely

$$z_{\mathrm{u}} = \mu_{\mathrm{u}} + \varepsilon_t \tag{1}$$

$$z_{\mathrm{l}} = \mu_{\mathrm{l}} + \varepsilon_t \tag{2}$$

where ε_t is an independent and identically distributed error term distributed as $N(0, \sigma^2)$.

If these equations are estimated inside a Bayesian framework, the means of the above processes $(\mu_{\mathrm{u}}, \mu_{\mathrm{l}})$ can be treated as random variables about which agents may form subjective probability statements. The constraints underlying the Svensson (1994a) test correspond therefore to the posterior probability of μ_{u} being greater than zero (anti-inflationary credibility) and to the posterior probability of μ_{l} being lower than zero (anti-deflationary credibility). A major advantage of this set-up is that these probabilities yield a quantitative assessment about the degree of monetary policy credibility. Moreover, since these probabilities can recursively be updated, as soon as new information is available, our approach allows us to infer how the degree of inflation target credibility evolves over time.

More formally, focusing for instance on the anti-inflationary credibility constraint, the degree of monetary policy credibility, at time t, can be expressed as

$$\Pr\{\mu_{\mathrm{u}} > 0 | z_{\mathrm{u}(t)}, z_{\mathrm{u}(t-1)}, \ldots, z_{\mathrm{u}(1)}\} = 1 - \int_{-\infty}^{0} f(\mu_{\mathrm{u}} | z_{\mathrm{u}(t)}, z_{\mathrm{u}(t-1)}, \ldots, z_{\mathrm{u}(1)})\, \mathrm{d}\mu_{\mathrm{u}} \tag{3}$$

where $f(\mu_{\mathrm{u}}|z_{\mathrm{u}(t)})$ is the posterior probability density function (pdf) for μ_{u} conditional on a prior pdf for μ_{u} and on sample information at time t.[4]

[4]A similar expression obviously holds in the specular case, i.e. when assessing the absence of a deflationary bias in monetary policy. The relevant posterior probability in this case corresponds to $\Pr\{\mu_{\mathrm{l}} < 0 | z_{\mathrm{l}(t)}, z_{\mathrm{l}(t-1)}, \ldots, z_{\mathrm{l}(1)}\}$.

The above discussion relies on the assumption that the time series $\{z_u, z_l\}$ may be modelled as serially uncorrelated processes. This assumption, however, is not supported by data in the present context. A preliminary data inspection, using alternative proxies for the expected real interest rate (r_t^e), shows actually that $\{z_u, z_l\}$ can always be characterized as first-order autoregressive processes exhibiting a high degree of persistence. Nevertheless, this empirical framework can be adapted to allow for the existence of serial correlation if equations (1)–(2) are replaced with the following alternative specifications:

$$z_{u(t)} = \theta_u + \rho z_{u(t-1)} + \varepsilon_t \tag{4}$$

$$z_{l(t)} = \theta_l + \rho z_{l(t-1)} + \varepsilon_t \tag{5}$$

where ρ is the autoregressive parameter, and $\theta_u = \mu_u(1 - \rho)$ and $\theta_l = \mu_l(1 - \rho)$ are the means of the corresponding conditional models.[5]

From the alternative specification outlined in equations (4)–(5) it is apparent that, excluding the case of an explosive stochastic process ($|\rho| > 1$), the credibility conditions are satisfied whenever $\theta_u > 0$ (absence of an inflationary bias in monetary policy) and $\theta_l < 0$ (absence of a deflationary bias). Focusing on the former constraint, this in turn will hold for the parameter space $\{(\mu_u, \rho) \in \Re^2: \mu_u > 0, \rho < 1\}$, i.e. when the unconditional mean of z_u is greater than zero and this process is mean-reverting. The anti-deflationary credibility constraint, on the other hand, will hold for the parameter space $\{(\mu_l, \rho) \in \Re^2: \mu_l < 0, \rho < 1\}$, i.e. when the unconditional mean of z_l is lower than zero and this process is mean-reverting.

To sum up, given the existence of serial correlation in $\{z_u, z_l\}$, our empirical test requires not only to assess a constraint on their conditional means (θ_u, θ_l), but also to compute the probability of a stationary stochastic process governing the evolution of the above series. This empirical methodology allows us then to distinguish between the following measures of 'overall' and 'long-run' inflation target credibility.

2.2.1 Overall Inflation Target Credibility (Absence of an Inflationary Bias in Monetary Policy). Overall inflation target credibility in this case is defined as the probability of a positive conditional mean (θ_u) in equation (4) at each point in time, i.e.

$$\Pr\{\theta_u > 0 | z_{u(t)}, z_{u(t-1)}, \ldots, z_{u(1)}\} = 1 - \int_{-\infty}^{0} f(\theta_u | z_{u(t)}, z_{u(t-1)}, \ldots, z_{u(1)}) \, d\theta_u \tag{6}$$

where $f(\theta_u | z_{u(t)}, z_{u(t-1)}, \ldots, z_{u(1)})$ is the posterior pdf for θ_u.

[5]Note that, in this alternative set-up, the autoregressive parameter is common to both equations, since z_l is obtained through a simple downward shift on z_u.

2.2.2 Overall Inflation Target Credibility (Absence of a Deflationary Bias in Monetary Policy). Overall inflation target credibility in this alternative case is defined as the probability of a negative conditional mean (θ_l) in equation (5) at each point in time, i.e.

$$\Pr\{\theta_l < 0 | z_{l(t)}, z_{l(t-1)}, \ldots, z_{l(1)}\} = 1 - \int_0^{\infty} f(\theta_l | z_{l(t)}, z_{l(t-1)}, \ldots, z_{l(1)}) \mathrm{d}\theta_l \qquad (7)$$

where $f(\theta_l | z_{l(t)}, z_{l(t-1)}, \ldots, z_{l(1)})$ is the posterior pdf for θ_l.

2.2.3 Long-run Inflation Target Credibility. Long-run credibility is related to the stationarity of the $\{z_u, z_l\}$ series which is necessary in order to exclude that the above processes will hit the zero threshold with probability one. Long-run inflation target credibility is therefore defined as the probability of a mean-reverting process for z_t at each point in time, i.e.[6]

$$\Pr\{\rho < 1 | z_t, z_{t-1}, \ldots, z_1\} = \int_{-\infty}^{1} g(\rho | z_t, z_{t-1}, \ldots, z_1) \mathrm{d}\rho \qquad (8)$$

where $g(\rho | z_t, z_{t-1}, \ldots, z_1)$ is the marginal posterior pdf for the autoregressive parameter in the model defined by equations (4)–(5).

3 Implementing our Approach: Variables Selection and Econometric Framework

The nominal interest rate used in the present paper is the yield on 10-year German government bonds. This monthly series was obtained from Datastream, which represents a more reliable source with respect to alternative ones which take only a limited number of closing prices to calculate yields.

The focus on a medium- to long-term maturity is in line with earlier empirical investigation relying on the original version of the Svensson test (Svensson, 1994a; De Grauwe, 1996). In the specific context of this paper, moreover, this focus is consistent with the medium-term orientation underlying the ECB monetary policy strategy. As regards the choice of the sovereign issuer, strong support for the use of 10-year German government bonds is provided by the empirical analysis on yield differentials between euro zone government bonds carried out in Codogno *et al.* (2003). These authors use post-EMU spreads of euro area versus Germany, pointing out that 'German bond yields are taken as the reference rates since *German bonds have maintained their benchmark status* and have continued to display lower yields' (Codogno *et al.*, 2003, p. 508, emphasis added).[7]

[6]We are using the simple notation z_t interchangeably for z_u and z_l, since they represent two identical stochastic processes, respectively, rescaled upwards or downwards.

[7]In line with our empirical investigation, Codogno *et al.* (2003) focuses on the 10-year maturity of the term structure, since this is the most actively traded in the euro zone securities

The ECB has initially defined price stability 'as a year-on-year increase in the Harmonized Index of Consumer Prices for the euro area below 2%' (ECB, 1999, p. 46). This definition can be regarded as ambiguous since it does not specify a lower bound for domestic inflation (Svensson, 1999). In May 2003 the Governing Council stated that 'in the pursuit of price stability it will aim to maintain inflation rates close to 2% over the medium term. This clarification underlines the ECB's commitment to provide a sufficient safety margin to guard against the risks of deflation' (ECB, 2003, p. 8).

In the light of these developments, we set the upper ECB inflation target to 2.5 per cent ($\pi_{max} = 2.5$ per cent), while we select two alternative values for the lower threshold (setting π_{min}, respectively, equal to 1.0 per cent or to 1.5 per cent).[8]

The upper inflation target is consistent with the computations performed in Cecchetti and Wynne (2003), implying that the original 2 per cent ceiling needs an upward revision in order to account for a measurement bias in the harmonized index of consumer prices (HICP), some noisiness in monthly inflation statistics, and central bankers' aversion to deflation. Further support in this direction comes from Werner Sinn (2003), where an upper target of 2.5 per cent is recommended, until euro zone convergence is concluded, to foster real wage adjustments in more developed European countries.

Turning to the lower ECB inflation target, the 1 per cent benchmark is supported by the analysis performed in Werner Sinn and Reutter (2001).[9] Although a minimum inflation rate of about 1 per cent is justified on the basis of the Balassa–Samuelson effect, this benchmark is likely to be still too conservative when potential upwards distorsions in the HICP are properly

market. The analysis performed by these authors refers to the first four years of the Eurosystem. In more recent years, German long-term interest rates have occasionally incorporated a small default premium component, when Germany ran into the excessive deficit procedure. Notwithstanding this fact, these data are anyway the most appropriate to approximate a default-less nominal government bond yield inside the euro area.

[8]One referee pointed out that it is difficult to translate the ECB's price stability definition into a specific target band, since the upper and lower inflation thresholds have never been officially announced. We agree with this critical remark, but we think it does not undermine the empirical strategy taken in the present paper. Svensson (2000b) maintains that the Eurosystem monetary strategy conforms to a flexible inflation-targeting regime, while a midpoint value for the inflation target can be inferred from the reference value established for M3 growth. Moreover, as further explained in the present section, the assumed values for the upper and lower inflation thresholds are fully consistent with many arguments put forward in the recent literature. On the whole, although our approach suffers from some limitations in relation to the ambiguous ECB's definition of price stability, we deem it displays substantial advantages by providing plenty of accurate information about the degree of monetary policy credibility.

[9]The main point of this paper is that the structural features of Euroland are markedly different from those of Germany, implying a looser monetary policy in order to account for substantial relative price changes in the process of monetary integration. More specifically, this paper obtains a lower ECB inflation target of 0.94 per cent for EU11, of 1.05 per cent for EU15 and of 1.13 per cent for EU21.

accounted for.[10] Since recent deflationary pressures have made policy makers more 'deflation-averse' (as witnessed by the ECB strategy revision in May 2003), there is a strong motivation for assuming an alternative, less conservative minimum inflation threshold, setting $\pi_{\min}$ equal to 1.5 per cent.

This taken into account, although we retain two alternative values as minimum inflation thresholds, we claim that the less conservative one ($\pi_{\min}$ = 1.5 per cent) is most suitable to evaluate the dynamic pattern of ECB anti-deflationary credibility.

For estimation we use a Bayesian approach based on Markov chain Monte Carlo posterior simulation. For a survey of these methods, see Chib (2001). In particular, the model we estimate is a simple stationary first-order autoregressive model with Gaussian errors which can easily be treated with a simple two-block Gibbs sampling algorithm. Given the prior structure it is easy to see that the conditional posteriors of (θ, ρ) and h are conditionally conjugate (i.e. they have the same functional form of the priors) and so they can be easily simulated.

With respect to the methodology used in Tronzano *et al.* (2000), where the usual analytical results valid in a linear regression model (see Zellner, 1971) are used, the methodology used in this paper is entirely based on simulation and it is therefore readily adaptable to allow for features such as non-Gaussianity, heteroscedasticity, shifts and drifts in the parameters.

4 Empirical Findings

4.1 Alternative Proxies for the Expected Real Interest Rate

The definition of accurate measures for the expected real interest rate is crucial in order to derive sensible results from the theoretical framework outlined in the present paper. In Svensson's (1994a) original contribution a pure backward-looking approach is taken, i.e. expected real yields are simply approximated through *ex post* real interest rates. The recent development of various techniques to extract market expectations from financial instruments (see Soderlind and Svensson (1997) for a survey about this topic) suggests that the original approach taken in Svensson (1994a) may be profitably extended incorporating some relevant forward-looking components in the empirical analysis.[11]

[10]As documented in Cecchetti and Wynne (2003), if measured HICP inflation is 1 per cent the probability that prices are actually falling is still quite high (about 0.35), whereas increasing the lower target for the HICP to 1.5 per cent this probability is significantly reduced (to about 0.10).

[11]In a previous version of this work, our empirical investigation relied on official Organization for Economic Cooperation and Development (OECD) economic forecasts on long-term interest rates and inflation in the euro area. However, as pointed out by an anonymous referee, these variables are far from being representative of market expectations. The present version of the paper uses alternative forward-looking variables for nominal interest

In the light of the above discussion, our investigation relies on two alternative approaches to compute the expected real interest rate.

The former is purely backward-looking, i.e. following Svensson (1994a), future real yields are fully approximated through *ex post* real interest rates. To this purpose, we subtract from the nominal interest rate the yearly inflation rate in the euro area, computed through the HICP. This leads to a time-varying measure for r_t^e relying on purely adaptive expectations.

The latter approach combines this backward-looking indicator with some forward-looking components relying on market-based expectations. To this purpose, we use the implicit one-year forward rate on German government bonds (for a 10-year maturity). This implicit rate was obtained from the zero coupon rates on 1-, 10- and 11-year bonds reported on the Bundesbank website. The implicit forward rate $f_t^{(1,10)}$ is calculated as follows:

$$f_t^{(1,10)} = 100 \times \left[\left(\frac{p_t^{(1)}}{p_t^{(11)}} \right)^{1/10} - 1 \right] \tag{9}$$

where $p_t^{(j)}$ is the spot price at time t of a j-year zero-coupon bond.

We then subtract from this forward rate the expected inflation rate in the euro area obtained from the Consensus Economics forecasts. This leads to a proxy for the expected real interest rate which incorporates purely forward-looking expectations.[12] The above proxy is finally combined with the *ex post* real interest rate, producing a weighted average indicator based both on backward- and on forward-looking expectations. We label this variable as 'hybrid forward-looking' indicator and assign an equal weight to its different components.

While the former approach is in line with previous research based on Svensson's test, the latter approach receives strong support by the literature on inflation dynamics, documenting that survey data on inflation expectations significantly depart from fully rational expectations, and that purely

rates and inflation which fully reflect market-based expectations. We would like to thank the referee for his insightful critical remarks which led to a substantial refinement of the final data set thus significantly improving the quality of our empirical findings.

[12]In recent years, many central banks have begun to publish systematic data on implicit forward rates, i.e. to extract the expected future time paths of nominal interest rates (for various settlement dates and maturity horizons), from current data on government bond yields (see BIS (2005) for a technical discussion of the main estimation procedures). Implicit forward rates are usually computed fitting to spot interest rates various parametric models (such as those outlined in Nelson and Siegel (1987) or in Svensson (1994b)) defined over the entire maturity domain, and incorporating the shapes typically associated with the yield curves. Assuming that the forward rate premium is negligible, i.e. the so-called expectations hypothesis for the term structure, implicit forward rates represent a good proxy of market expectations about the future time path of nominal interest rates. Turning to Consensus Economics forecasts, they are widely recognized as one of the most reliable proxies of the private sector's inflationary expectations. On the whole therefore the forward-looking variables that we use to define the expected real interest rate rely entirely on a market-based approach.

forward-looking Phillips curve models are often severely at odds with the data.[13] As regards the influence assigned to *ex post* and *ex ante* elements in the 'hybrid forward-looking' indicator, the choice of symmetric weights is broadly consistent with the existing literature and ensures, in our opinion, a reasonable degree of accuracy to our credibility estimates.[14]

4.2 Assessing ECB's Monetary Policy Credibility

4.2.1 Backward-looking Expectations. We use monthly data ranging from the official start of EMU in January 1999 until December 2007. Estimation was carried out recursively, starting from the sample 1999.1–2000.12 (24 observations) and adding one observation at each iteration. We analyse a 'benchmark scenario', based on loose prior assumptions for all model parameters.[15] More specifically, the following weakly informative proper priors were selected:

$$\theta \sim N\left(\mu_\theta, h_\theta^{-1}\right) \qquad \mu_\theta = 0 \qquad h_\theta^{-1} = 0.9 \tag{10}$$

$$\rho \sim N\left(\mu_\rho, h_\rho^{-1}\right) \qquad \mu_\rho = 0.95 \qquad h_\rho^{-1} = 0.9 \tag{11}$$

$$S \cdot h \sim \chi_v^2 \qquad S = 0.05 \qquad v = 1 \tag{12}$$

The prior for the constant term (θ) is centred on zero, while the prior 95 per cent confidence interval ranges from –2.06 to +2.06. The prior for the autoregressive parameter (ρ) is centred on 0.95 and is not truncated over the stationarity set, thus allowing us to estimate the posterior probability that ρ belongs to the above set. The prior on the precision error term (h), finally, is also quite loose, with a prior mean of 20 and a prior variance of $2/(0.05)^2 = 800.0$.

Consider first long-run inflation target credibility. Figure 1 plots the posterior mean for ρ and its 80 per cent confidence interval.

As revealed by this figure, long-run credibility is in doubt only at the very beginning of the sample. Since 2002 onwards the posterior mean of ρ is consistently declining and the confidence interval is in line with the long-run credibility constraint. These results are confirmed by the posterior probability of a stationary stochastic process for z_t (Fig. 2), which exhibits a large drop

[13]As discussed in Roberts (1997), survey data on inflation expectations are neither purely adaptive nor purely rational. While confirming this empirical regularity, this paper emphasizes how a departure from a fully rational expectations assumption is important in a context where the macroeconomic effects of a new policy regime are explored.

[14]Empirical results obtained in Fuhrer (1997) from US data point out a significantly higher influence of lagged inflation versus expected future inflation in explaining price fluctuations. Chadha *et al*. (1992) report an estimated weight of 0.55 on past inflation for the Group of Seven countries whereas, according to the estimates performed in Gali and Gertler (1999), the weight of expected future inflation is significantly higher (ranging from 0.59 to 0.68).

[15]The robustness of our empirical findings to alternative prior assumptions is discussed in Section 4.3.

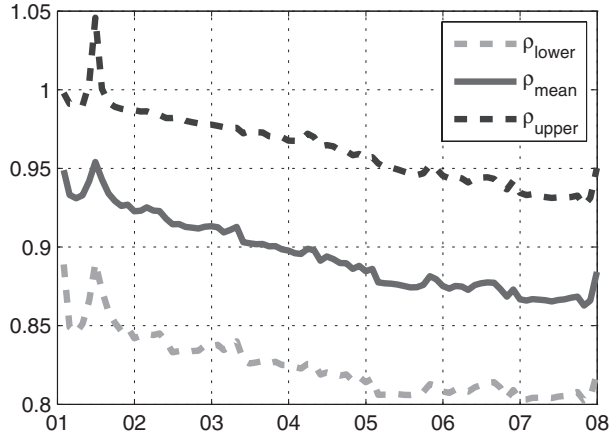

FIG. 1 Posterior mean and confidence interval for ρ; backward-looking expectations

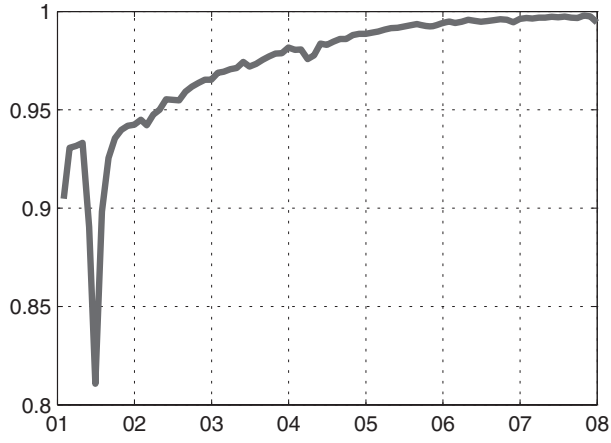

FIG. 2 Posterior probability of $\rho < 1$; backward-looking expectations

in June 2001, while suddenly recovering in subsequent months, and exceeding 0.9 for most of the remaining periods.

These results have a good economic intuition, given the high degree of uncertainty usually associated with the initial stages of a new policy regime. This evidence is highly supportive of the overall consistency of the monetary policy strategy pointing out that, after a relatively short learning process, the ECB was quickly able to establish a good reputation about its long-run commitment to the declared inflation targets.

Figure 3 plots the posterior mean for θ_u and the 80 per cent confidence bounds for this parameter.

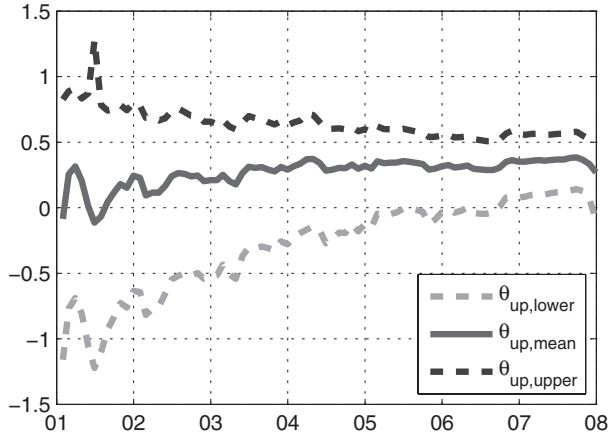

FIG. 3 Posterior mean and confidence interval for θ_u; backward-looking expectations

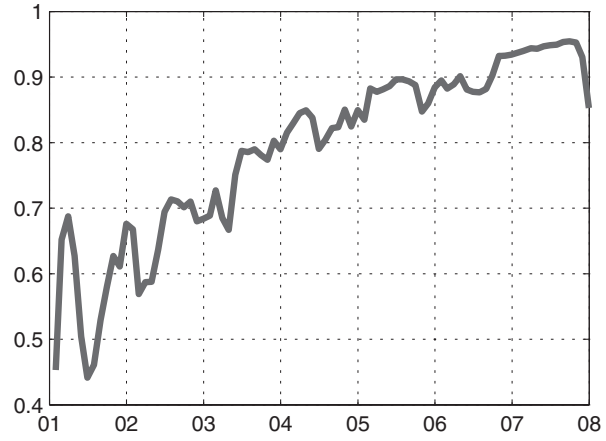

FIG. 4 Posterior probability of $\theta_u > 0$; backward-looking expectations

Overall, these estimates suggest a reasonable degree of ECB anti-inflationary credibility. The posterior mean for θ_u is positive across the whole sample, apart from some temporarily small negative values at mid-2001. Moreover, after a more volatile initial period, the posterior mean for θ_u oscillates around 0.25–0.30.

The posterior probability of $\theta_u > 0$ (Fig. 4) exhibits a clear increasing trend during the period considered, notwithstanding a significant degree of short-run volatility.

The unstable pattern of the anti-inflationary credibility indicator in 2001–2 can be explained by significant inflationary pressures, which led to a

peak in HICP inflation at mid-2001 (clearly picked up by an all time low in our credibility indicator to 0.44 in June 2001). Along this period, Euroland was hit by its first large supply shock, generated by a massive increase in energy prices, while inflation dynamics was further being fuelled by a consistent nominal depreciation of the euro against the US dollar. As revealed by various quotations from the *ECB Monthly Bulletin* during this period (see the Appendix, quotations [A] and [B]), official declarations underlined the temporary nature of various negative shocks, thus expressing the view that the medium-term outlook for price stability had remained broadly unchanged.

Focusing on the last part of the sample, the anti-inflationary credibility indicator displays two major downturns in Autumn 2005 and in the two final months of 2007. In both cases, it is interesting to point out again a strong correspondence between the short-term dynamics of our credibility indicator and the evolution of the cyclical macroeconomic conditions in the euro area. During this period, the ECB expressed severe concerns about the resurgence of inflationary pressures and underlined the existence of upside risks in the medium-term outlook for price developments. At the same time, the ECB underlined the need for a strong vigilance of monetary authorities in order to anchor inflation expectations (see the Appendix, quotations [C] and [D]).

Turning finally to the anti-deflationary credibility, none of our indicators signals any particular risk in this regard. Figure 5 plots the posterior probability of $\theta_1 < 0$ assuming, respectively, a larger ($\pi_{\min} = 1$ per cent) or a smaller ($\pi_{\min} = 1.5$ per cent) inflation target band.

In this case, we observe only one occasional downturn at the beginning of the period, while a larger inflation band yields higher estimates for this posterior probability.

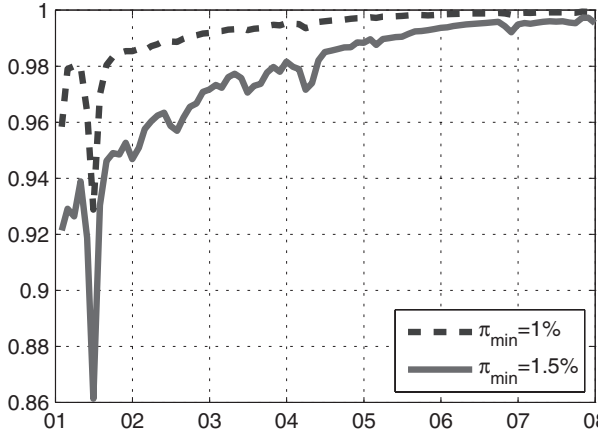

FIG. 5 Posterior probabilities of $\theta_1 < 0$; backward-looking expectations, $\pi_{\min} = 1$ per cent, $\pi_{\min} = 1.5$ per cent

The underlying intuition for the former evidence is that, under this specific expectations assumption, the credibility constraint is violated whenever HICP inflation is lower than $\pi_{\min}$.[16] Since the beginning of our recursive estimates in January 2000, actual HICP inflation was consistently above the lower inflation bound (under both definitions for $\pi_{\min}$), thus significantly reducing the danger of a deflation risk. As regards the latter evidence, this is closely in line with economic intuition, since a lower bound for domestic inflation increases the likelihood of a monetary policy consistent with the anti-deflationary credibility constraint.

4.2.2 Hybrid Forward-looking Expectations. We now address the credibility estimates obtained assuming our alternative proxy for the real interest rate, where a backward-looking approach is combined with some forward-looking components relying entirely on market-based expectations. While corroborating some basic findings documented in Section 4.2.1, this further set of estimates discloses some new empirical insights, thus usefully complementing the econometric exercise carried out in the previous section.

Consider, first, long-run inflation target credibility.

Figure 6 reproduces the evolution of the posterior probability of a mean-reverting process for z_t, assuming hybrid forward-looking expectations. In line with the previous section, this posterior probability is tendentially increasing over time, thus confirming the existence of a rising degree of

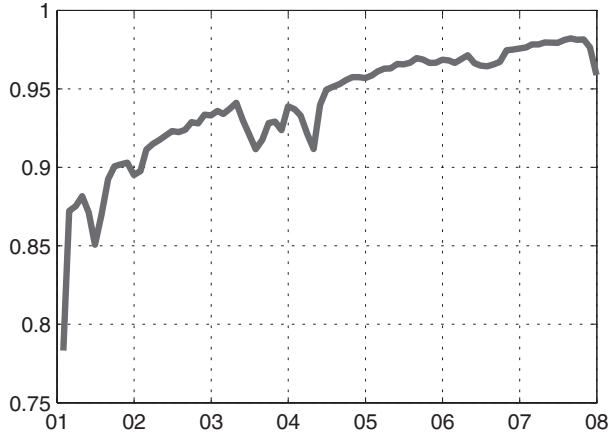

FIG. 6 Posterior probability of $\rho < 1$; hybrid forward-looking expectations

[16]Recall from Section 2.2 that the anti-deflationary credibility constraint is given by $z_1 \leq 0$. Under purely backward-looking expectations $r_t^e \equiv i_t - \pi_t$. Therefore, substituting this value in the definition of z_1, the above constraint may be expressed as $(i_t - \pi_t) - (i_t - \pi_{\min}) \leq 0$. The latter inequality, in turn, may be simplified to $\pi_t \geq \pi_{\min}$.

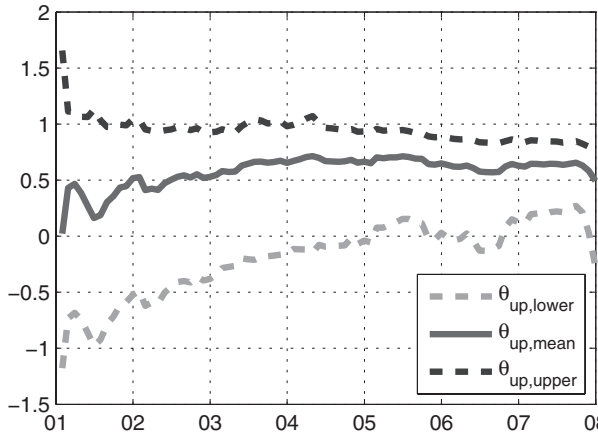

FIG. 7 Posterior mean and confidence interval for θ_u; hybrid forward-looking expectations

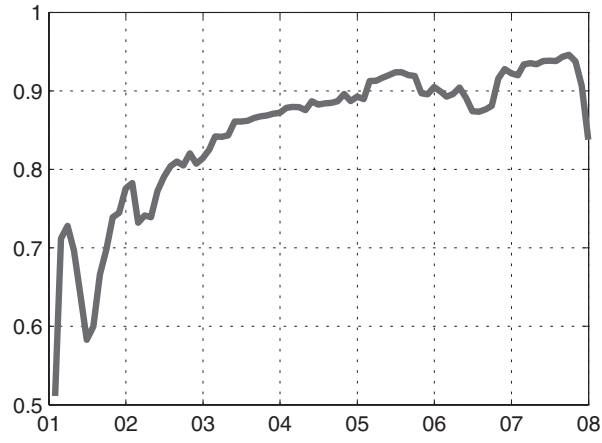

FIG. 8 Posterior probability of $\theta_u > 0$; hybrid forward-looking expectations

confidence of market agents towards the ECB commitment to its officially declared inflation targets. Differently from the previous evidence, however, we observe two main credibility reversals: the former between mid-2003 and mid-2004, and the latter towards the very end of the sample. As the following discussion will reveal, both these reversals may be easily ascribed to some specific results concerning the existence of, respectively, deflationary and inflationary risks during the above periods.

Figures 7 and 8 plot, respectively, the posterior mean and confidence interval for θ_u and the posterior probability of a positive value for this parameter, assuming that r_t^e reflects hybrid forward-looking expectations.

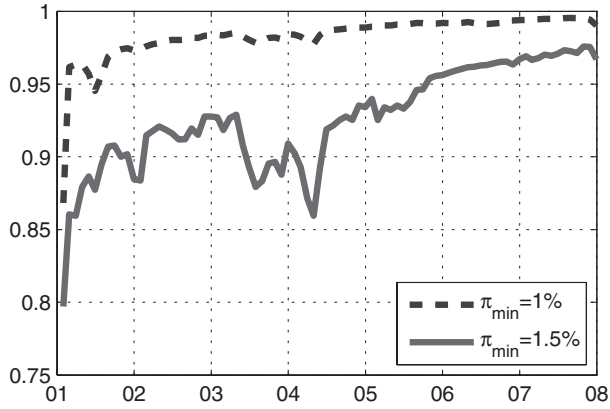

FIG. 9 Posterior probabilities of $\theta_l < 0$; hybrid forward-looking expectations, $\pi_{min} = 1$ per cent, $\pi_{min} = 1.5$ per cent

The posterior mean for θ_u is consistently positive across the whole sample, while displaying higher values than those recorded under the alternative expectations hypothesis. The anti-inflationary credibility constraint is therefore more strongly supported by data in the present set-up. This is clearly apparent from Fig. 8 where, most of the time, the degree of anti-inflationary credibility records higher values and a much smoother pattern than those obtained under backward-looking expectations. Notwithstanding this more favourable anti-inflationary scenario, Fig. 8 documents a larger credibility decrease during the last months of 2007. The latter result explains the significant drop in long-run inflation target credibility occurring at the end of the sample period (see Fig. 6).

Consider, finally, the results for anti-deflationary credibility. Figure 9 plots the posterior probability of θ_l being lower than zero assuming, respectively, a larger ($\pi_{min} = 1$ per cent) or a smaller ($\pi_{min} = 1.5$ per cent) inflation target band.

In line with economic intuition, assuming a larger band generates more favourable credibility results, since the credibility constraint is less seriously binding. However, since in Section 3 we argued that a higher inflation floor ($\pi_{min} = 1.5$ per cent) is more suitable to assess the ECB's anti-deflationary commitment, we focus our discussion on the empirical evidence associated with the lower graph in Fig. 9.

Inspection of this graph reveals that the introduction of forward-looking components in the measurement of the real interest rate generates rather different results in terms of anti-deflationary credibility. Actually, whereas in the previous section anti-deflationary credibility was monotonically increasing over time (see Fig. 5), our new empirical estimates point out significant credibility reversals between mid-2003 and mid-2004.

The credibility reversals occurring during this period explain the concomitant decrease in long-run inflation target credibility which we have mentioned before (see Fig. 6). Quite interestingly, moreover, these credibility reversals display a remarkable correspondence with the evolution of the overall macroeconomic outlook in the euro area.

Economic activity in Euroland remained highly subdued in 2003, reflecting a weak domestic demand and the negative impact of the Iraq crisis on the global economy. The Eurosystem staff macroeconomic projections continued to underline the existence of downside risks to economic growth, while the combination of ample liquidity and monetary easing had driven interest rates to historically low levels in main industrial countries.

In this context, the concerns for strong deflationary pressures became very widespread, and the uncertain evolution of our anti-deflationary credibility indicator in 2003–4 captures quite accurately the above risks. These relevant deflationary risks were repeatedly emphasized in many official documents released during this period (see the Appendix, quotations [E] and [F]), and led the ECB to a major change in its monetary policy strategy which introduced a new definition of price stability in the euro area (see the discussion on this issue in Section 3).

4.3 Alternative Priors Assumptions

In line with the previous analysis, the priors for the means are centred, respectively, on zero (θ) and on 0.95 (ρ), while the prior variances are increased in order to model a higher degree of parameter uncertainty. More specifically, we analyse an 'intermediate case' in which both prior variances are set to 10, and a 'worst uncertainty case' in which these variances are set to 100.

Throughout this section, we focus on the implications of alternative prior assumptions on the degree of anti-inflationary and anti-deflationary credibility.[17] As regards the latter indicator, we refer to the case where π_{min} = 1.5 per cent since, as motivated in Section 3, this less conservative minimum inflation threshold is more consistent with ECB's monetary policy strategy.[18]

Figures 10–13 summarize our empirical evidence.

The former two figures (Figs 10 and 11) show the results from Monte Carlo simulations obtained using backward-looking expectations and refer, respectively, to the posterior probability of $\theta_u > 0$ (anti-inflationary credibility) and to the posterior probability of $\theta_l < 0$ (anti-deflationary credibility).

[17]All additional information about the simulations performed in this section (posterior means and posterior confidence intervals of parameters) is available from the authors upon request. We omit to present empirical estimates concerning long-run inflation target credibility, since these results are qualitatively and quantitatively similar to those obtained for other credibility indicators.

[18]Note, however, that, assuming a larger inflation band (i.e. setting π_{min} = 1.0 per cent), the empirical evidence is broadly unaffected with respect to that presented in this section.

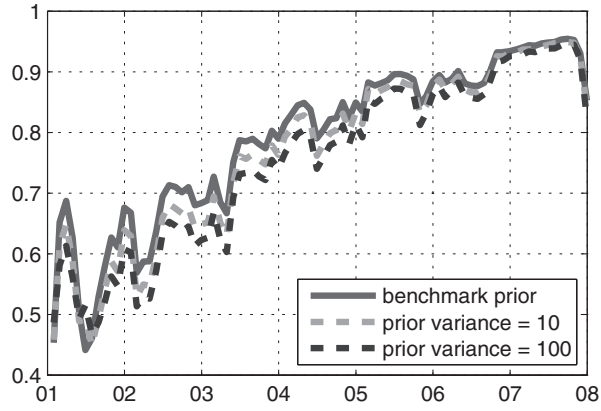

FIG. 10 Posterior probabilities of $\theta_u > 0$; backward-looking expectations, alternative priors

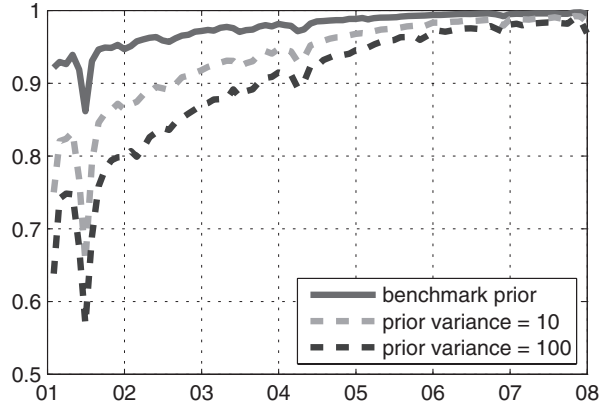

FIG. 11 Posterior probability of $\theta_l < 0$; backward-looking expectations, alternative priors

The latter figures (Figs 12 and 13) provide the same information under the alternative assumption to model the real interest rate. Each figure contains three plots, comparing the empirical evidence obtained in Section 4.2 with the effects induced by an intermediate degree of parameter uncertainty ('intermediate case') or by a very high degree of parameter uncertainty ('worst uncertainty case').

The joint inspection of these figures points out two relevant empirical regularities.

1. The overall pattern of credibility indicators mimics that characterizing the benchmark scenario. However, in all circumstances, credibility estimates are lower the higher are the prior variances assigned to the model's parameters.

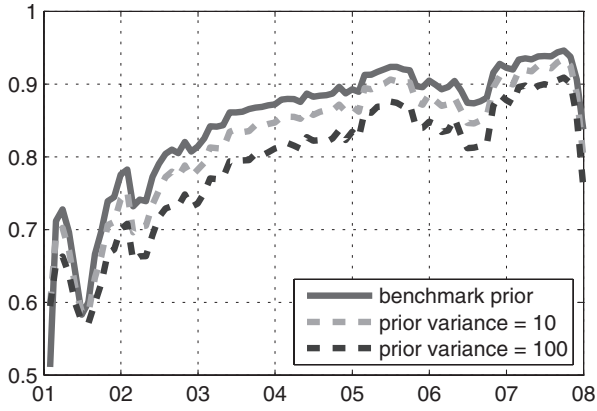

FIG. 12 Posterior probability of $\theta_u > 0$; hybrid forward-looking expectations, alternative priors

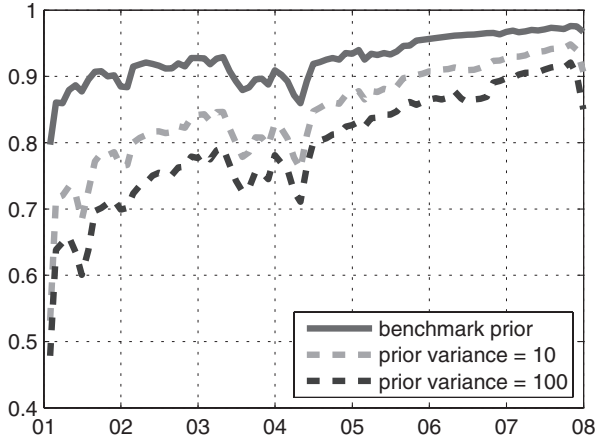

FIG. 13 Posterior probability of $\theta_l < 0$; hybrid forward-looking expectations, alternative priors

2. The gap between credibility estimates under the benchmark scenario and alternative prior assumptions tends to decrease as new sample information is used to generate posterior probabilities.

Focusing on the former evidence, we observe that progressively increasing prior variances leaves the overall credibility patterns broadly unaffected, although the introduction of higher uncertainty generates significant scale effects. Posterior probabilities associated with the benchmark scenario are consistently higher than those obtained in the 'intermediate case' which, in turn, exceed estimates recorded under the 'worst uncertainty case'.

During the initial part of the period, sample information is relatively limited, while prior information plays a prominent role in estimating the

above densities. Thus, imposing higher uncertainty generates lower credibility estimates, since sample information is combined with much dispersed priors about the true value of the model's parameters. The economic intuition is that higher uncertainty about the consistency of the ECB's strategy with official inflation targets reduces the degree of monetary policy credibility.

As regards the latter empirical regularity, i.e. the tendential elimination of the gaps observed under alternative prior assumptions, this result is strictly related to the above discussion. As time goes by, alternative prior assumptions exert a reduced influence in the estimate of posterior densities, thus dampening the negative effects associated with higher uncertainty. The economic intuition is that subjective estimates about monetary policy credibility are progressively sharpened over time, dissipating the initial effects induced by higher uncertainty, as agents observe the implementation of the ECB's strategy and evaluate its consistency with official inflation targets.

5 Concluding Remarks

In this paper we extend Svensson's (1994a) 'simplest test' of inflation target credibility inside a Bayesian econometric framework. Our contribution fills one relevant gap in the applied literature, providing some time-varying estimates about the degree of anti-inflationary and anti-deflationary credibility, and yielding a quantitative assessment about the long-run consistency of monetary policy with official inflation targets.

Using two alternative proxies for the expected real interest rate, we apply the above framework to estimate the degree of monetary policy credibility during the first years of the Eurosystem. Overall, our empirical evidence suggests that the ECB's monetary policy strategy was highly successful in this regard. According to our estimates, long-run inflation target credibility exhibits a steadily increasing trend, only occasionally interrupted by a few temporary declines. This result points out that the ECB strategy was able to establish a satisfactory degree of confidence about the long-run consistency of monetary policy with the primary objective of price stability.

Turning to the empirical findings concerning other credibility indicators, our results are broadly in line with the existing literature, albeit with some important qualifications. Analysing the ECB track record during the first four years, Lugaresi and Rotondi (2003) conclude that monetary policy credibility was perfect. While sharing this positive judgement, our paper challenges the presumed existence of full monetary policy credibility. As discussed in Section 4, although documenting an increasing trend, our investigation detects some significant credibility reversals.

As regards the ECB's anti-inflationary reputation, our analysis reveals a highly unstable pattern in 2001–2; during this period Euroland was suffering from some negative supply shocks, while inflationary expectations were further being fuelled by a consistent depreciation of the euro/US dollar

nominal exchange rate. Moreover, the ECB's anti-inflationary credibility discloses a less favourable pattern towards the end of the sample, when increases in oil and food prices produced significant upside risks for price stability in the euro area.

Turning to the ECB's anti-deflationary reputation, our estimates assuming a lower inflation target of 1.5 per cent and hybrid forward-looking expectations point out some major decreases in 2003–4. Quite interestingly, these credibility reversals are concomitant with a significant change in the macroeconomic outlook of the euro area (as witnessed by increasing fears of deflationary pressures and by the ECB revision of its monetary policy strategy at mid-2003).

This empirical evidence is robust to alternative prior assumptions, as shown by additional simulations imposing a higher degree of uncertainty about the model's parameters. Overall, these results have a good economic intuition, implying that the adverse effects on credibility induced by higher uncertainty die out over time, as agents observe the effective implementation of the ECB's monetary policy strategy and evaluate its consistency with official inflation targets.

Although our methodological framework generates sensible empirical findings, the symmetrical behaviour of shifts in the market assessment of the ECB's credibility may be open to criticism. In other words, it might be more reasonable to assume that the market 'downgrades' the ECB in terms of credibility when it fails to reach the inflation target more than proportionally in comparison with periods during which the central bank meets the target. Accounting for this feature seems a promising area for future research, although this would probably complicate the analysis, possibly introducing some kind of non-linearity and state dependence in the underlying theoretical model.

Appendix

Quotations from Official Economic Documents

[A]

The current level of HICP inflation, 3.4% in May 2001, mainly reflects the direct effects of the recent increases in food and energy prices and the indirect effects of the pass-through from past developments in import prices. Given the nature of these shocks, and taking into account the current monetary policy stance, it is expected that they will have only a temporary effect on inflation rates. (. . .) Overall, on the basis of the analysis under both pillars, the current stance of the monetary policy of the ECB should ensure price stability over the medium term. (ECB, 2001, pp. 5–6)

[B]

The recent rise in inflation should not have medium-term consequences, as it was largely due to exceptional and short-lived factors, such as particularly adverse weather conditions in some parts of the euro area, which led to strong increases in unprocessed food prices. (. . .) Overall, the current expectation is that, in the course of 2002, HICP

inflation will stabilize at levels safely below 2% in line with the ECB's definition of price stability. (ECB, 2002, p. 5)

[C]

Recent increases mainly in oil prices have pushed headline inflation rates to levels significantly in excess of 2% (. . .) and it is likely that inflation will remain elevated in the short term. (. . .) Strong vigilance with regard to upside risks to price stability is warranted. It is essential that the increase in the current inflation rate does not translate into higher underlying inflationary pressures in the euro area. (ECB, 2005, p. 5)

[D]

Oil prices have risen strongly in recent months, and food prices have increased substantially, reflecting higher global demand. (. . .) Looking ahead, the HICP inflation rate is expected to remain significantly above 2% in the coming months. (. . .) In the Governing Council's view, risks to this medium-term outlook for price developments are fully confirmed to lie on the upside. (. . .) The monetary analysis confirms the prevailing risks to price stability at medium to longer-term horizons. (ECB, 2007, p. 6)

[E]

Global inflation remains very low, with consumer prices expected to increase by less than 2% in 2003 in advanced countries (. . .). Given the expectation that output gaps in the United States and the euro area will widen further in the short term (. . .) a number of observers have expressed concerns that outright deflation could become a more widespread problem. (. . .) Since deflation has large potential costs, these concerns reinforce arguments for erring on the side of monetary accommodation at the present juncture, and underscore the importance of central banks' making clear that they will act aggressively and preemptively to forestall deflation if the need arises. (IMF, 2003a, p. 10)

[F]

Inflationary pressures remain very low. (. . .) Against this background, and given the weakness of the global recovery, the possibility of deflation has attracted increased attention. (. . .) In an environment of low inflation, the possibility of a temporary period of price declines in the event of an adverse shock remains significant in a number of countries, most importantly Germany, adding to arguments for maintaining a relatively accommodative monetary stance. (IMF, 2003b, pp. 7–9)

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